An exploratory analysis of the societal impacts of demand congestion

A case study of Amsterdam following a mixed-methods approach

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Gemeente Amsterdam

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by

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Preface

I am very grateful to have reached this point in my academic journey and completed this report, which marks the end of both my thesis research and my studies. It has been an incredibly exciting and insightful period of my life, and I feel fortunate to have been surrounded by such a motivated group of students and staff at the faculty of Technology, Policy and Management. While most of our interactions during the master program were conducted online, I am grateful to everyone who contributed to my academic and personal development during my time here. In particular, I would like to express my sincere appreciation to my thesis supervisors, Stefan Pfenninger and Trivik Verma, whose invaluable support has led to the successful completion of this research. Your ability to put things into context and simplify complex matters have been immensely valuable.

The past few months, during which I conducted this thesis research, have provided me with a unique and enriching experience. Not only did I gain knowledge in academic research, but I had the opportunity to work on this project as part of my graduation internship at the municipality of Amsterdam. Completing my bachelor's and master's degrees at the TPM faculty, this was the perfect way to conclude my learning journey. I am grateful to the EVA team, particularly Ruben Voerman and Naut Loots, for involving me in their team and providing guidance throughout my project. Your support has made my graduation experience a lot easier and fun!

I would like to give my heartfelt thanks to my family, friends, and loved ones for their unconditional support and motivation throughout my thesis research project and my entire studies. At times it was an incredible challenge, and I am not sure I would have made it without you. Graduating alongside new friends from Delft and old friends from school has been incredibly motivating. I am very excited to start the next chapter of our lives together!

Julie H.M. van den Brink
Amsterdam, June 2023

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Abstract

The electricity infrastructure plays a vital role in addressing climate change. However, the integration of variable renewable sources and electrification is straining existing grids, leading to congestion events worldwide. To maintain reliability and safety, system operators resort to curtailment of supply and demand, imposing restrictions on their customers. This research objective is to understand the consequences of unmet electricity demand and to contribute to the existing literature on electricity grid congestion. By doing so, it aims to support municipalities with informed decision-making to manage demand congestion. The research question is as follows: *"What are the societal impacts of demand congestion in the electricity system of highly populated urban areas in developed societies?"*

Using a mixed methods approach, including desk research, semi-structured interviews, and geospatial analysis techniques, the study focuses on the medium voltage distribution network in Amsterdam. The study explores the implications of demand congestion for different customer segments, and the impacts thereof. A holistic impact assessment framework is developed, that systematically evaluates spatio-temporal societal impacts, taking into consideration the multidimensional approach of sustainable development: environmental, social, and economic.

The research finds that demand congestion leads to a lack of universal access to electricity, that depends on timing, region, and the type of connection requested. Large-scale customers are affected, while small-scale customers are not. Segmenting the affected customers into industry, commercial business, public services, and urban development, each segment responds differently to transport restrictions. Commercial businesses are more flexible, as they can explore alternatives and optimize existing contracts, while industry and urban development face structural electricity shortages and significant unmet demand. Public services find temporary solutions due to stakeholder goodwill, but as congestion persists, this will be complicated.

The consequences of demand congestion have broad societal impacts that hinder sustainable development across all three dimensions, emphasizing the need for effective congestion management. CO_2 emissions, housing, and employment are identified as particular important societal impacts in Amsterdam to assess and mitigate. The severity of societal impacts will vary across segments. Demand congestion in the industry segment will lead to significant increased CO_2 emissions and job losses, whereas in the urban development segment, it could lead to significant delays of housing construction.

To mitigate these impacts and provide congestion relief, local governments should prioritize collaboration among operators, regulators, and other relevant stakeholders. Furthermore, municipalities should proactively promote and support sustainable energy production alternatives, as well as encourage the optimization of efficiency. A congestion management approach that includes area-targeted and segment-specific investments is recommended, ensuring a balanced distribution of impacts. This is crucial for Amsterdam, as the analysis shows that 80% of the city is expected to experience demand congestion any time between 2023 and 2030, with an unequal spatial distribution to the west. Decision makers should continuously assess these impacts to evaluate the effectiveness of congestion management, for which the holistic assessment framework can be used.

This exploratory study establishes a foundation for further research in the field of demand congestion, contributing to the ongoing discourse on sustainable energy infrastructure. Future studies can expand upon these findings by implementing the assessment framework across all segments and indicators, using different case studies or enriching the indicator selection. Further research to clarify roles, responsibilities and resources within the multi-actor network would enhance the management effectiveness of this complex urban challenge.

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Nomenclature

Abbreviations

Abbreviation	Definition
ACM	Authority for Consumers & Markets
CB	Commercial Business
DER	Distributed Energy Resource
DSM	Demand Side Management
DSO	Distribution System Operator
DSR	Demand Side Response
EVA	Elektriciteit Voorziening Amsterdam
EV	Electrical Vehicle
ESS	Energy Storage System
GDP	Gross Domestic Product
GIS	Geo Information System
HDI	Human Development Index
LC	Large-scale Customer
LV	Low-Voltage
MW	Mega Watt
MV	Medium-Voltage
PS	Public Services
PV	Photovoltaic
SBI	Standaard Bedrijfsindeling
SC	Small-scale Customer
SDG	Sustainable Development Goals
SIA	Sustainable Impact Assessment
SME	Small and Medium-sized Enterprise
TCT	Time-limited Capacity during Transport restrictions
TS	Transmission System Operator
UD	Urban Development
UPG	Urban Power Grid
VRES	Variable Renewable Energy Source

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1
Introduction

1.1. Motivation

The effects of climate change on humanity and nature are worse than previously anticipated, and will be magnified in cities (IPCC, 2022). This is extremely problematic, since half of the world's population live in urban areas, whilst population- and urbanization rates are growing. One of the biggest contributors to climate change and the earth's temperature rise is the unparalleled emission of greenhouse gases worldwide. To this day, nearly 81 percent of our energy comes from fossil fuels (IEA, 2020). To ensure a safe and sustainable future, there is an urgent need to change our energy consumption and production; Policy makers play a vital role in this energy transition (IPCC, 2022). The resulting increased demand for renewable energy sources such as wind and solar power, as well as the electrification of various sectors such as transportation and heating, has led to an explosive growth of usage of the electricity system. The electricity infrastructure has to be able to carry this growth, therefore it can be seen as the backbone of the energy transition (Brown & Cutler, 2022; NOS, 2021; PBL, 2022).

In some regions, electrical networks are not receiving the essential recognition that they need. Grid infrastructure expansion and enhanced grid flexibility are not keeping up with the increased impact, resulting in a rise in frequency and magnitude of congestion events worldwide (Haque, Vo, et al., 2017; Loschan et al., 2023; Merino et al., 2021; Spiliotis et al., 2016). Vietnam had to stop connecting new solar and wind projects for the remainder of the year starting early 2022 as a cause of frequent grid overloads and high curtailment rates. Similarly, long grid planning and permitting times in Germany have resulted in insufficient transmission capacity to link the north and south, leading to even higher curtailment rates (Babrowski et al., 2016). Meanwhile, the Netherlands is struggling with the repercussions of a swift rise in electrification without sufficient smart grid infrastructure, which has caused limitations for some non-residential electricity consumers (IEA, 2022b). The same is occurring in regions of Sweden, where the lack of capacity in the electricity networks has led to restrictions of new connections, and existing grid customers not being able to receive a capacity upgrade (Palm, 2021).

The electricity system is a complex socio-technical system, thus disruptions can have far-reaching implications for both the technical and social layers. The modern society is highly reliant on the electricity infrastructure, as it plays a vital role in powering daily life: "An adequate energy supply has been identified as a key prerequisite for economic, cultural and social development in complex societies" (Arto et al., 2016). The European energy crisis of 2021 has painfully pointed out the reliance of Europe on energy and their vulnerability to energy availability. The limited capacity of the transmission and distribution grids accentuates this, as it causes electricity shortages (SIEMENS, 2022). Policy makers should be taking action on the power systems under strain, amongst others by focusing on the expansion of robust and smart electricity grids (IEA, 2022a).

1.2. Research problem

Given the urgent need for a proper functioning electricity system, it is crucial to understand the underlying causes of congestion and the consequences of a constrained grid. The electricity infrastructure is designed to cater to the maximum impact on the system during peak hours, known as peak-load. Congestion is the result of a mismatch between that peak-load and the capacity limits of the grid (see the black box in Figure 1.1). Besides network expansion, congestion can be prevented by actively managing the balance of supply and demand in the system, such as by curtailing the production or consumption of electricity. The frequency and magnitude of curtailment varies depending on the capacity and flexibility of the grid, the characteristics of demand and supply in the region, and the management style of the system operators. Electricity network planning and management is very different per country, due to policies, regulations, financial factors, the ownership structure and geographical constraints (Abeysinghe et al., 2021).

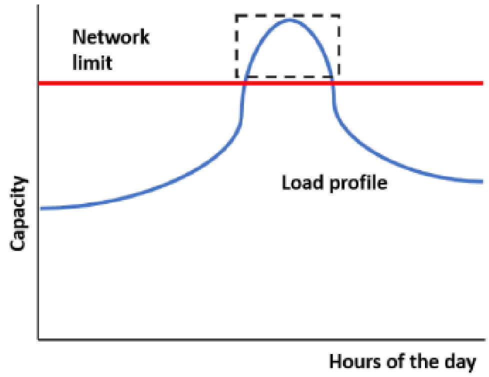
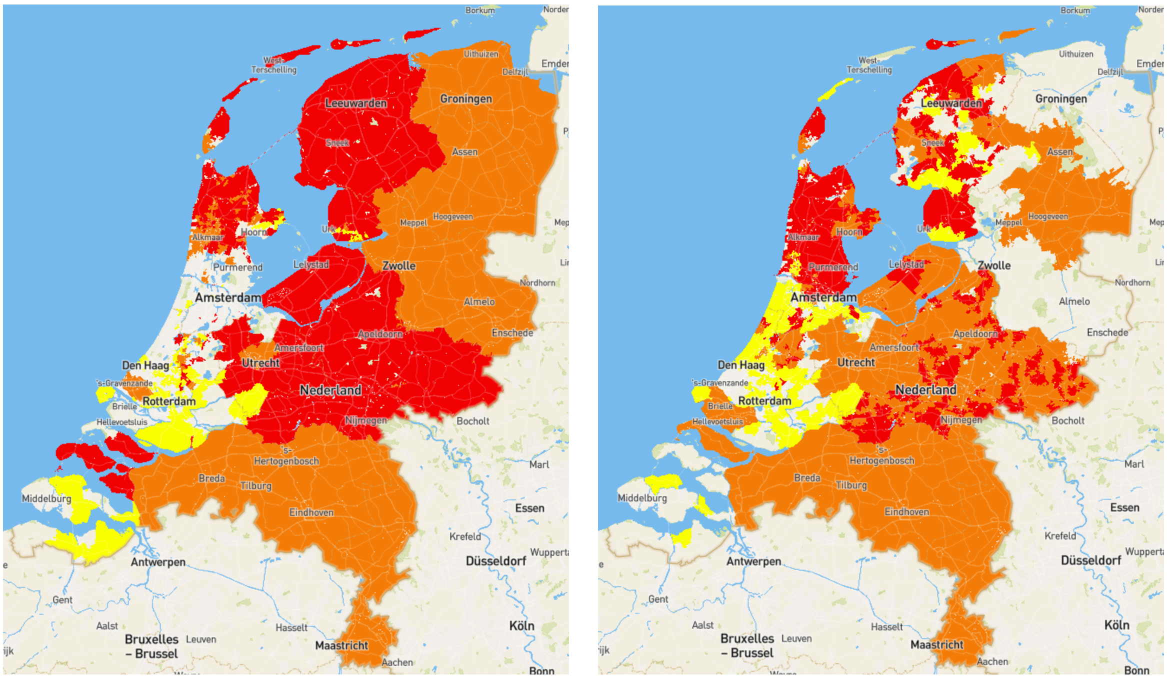


Figure 1.1: A visualisation of the total impact on a electricity network with insufficient capacity (Roques et al., 2021)

In countries with near-perfect stability and reliability of electricity distribution such as the Netherlands, grid operators want to prevent the occurrence of congestion as much as possible. As a result, Dutch operators allocate electricity contracts based on whether an asset in the system is reaching its capacity limit during peak-load (Enexis, 2019). When assets are at risk of congestion, operators announce *transport scarcity*: they put a halt to complying to client requests for new large-scale connection contracts or expansions thereof, resulting in curtailment (Liander, 2023). Many regions of the Netherlands are currently experiencing transport scarcity for either the supply or demand of electricity, or both (Figure 1.2). The terms congestion, network constraints and transport scarcity are often used interchangeably and refer to the situation of the electricity transportation system being at its limits.

After conducting an extensive literature review, reported in chapter 2, I found that congestion has mostly been researched in relation to the curtailment of renewable energy production. These studies focus on the integration of distributed generating units with either the low-voltage or the high-voltage network. There is a gap in literature on congestion caused by demand, and the consequences of that demand being left unmet in developed societies. Unlike temporal electricity shortages caused by power outages commonly studied in European countries, this unmet electricity demand is caused by structural insufficient grid capacity. Demand congestion is most likely to occur in the medium-voltage network in highly populated urban areas (Haque, Nguyen, et al., 2017; Hermans et al., 2022). This upcoming problem is relevant to European countries where the explosive electricity demand and supply following the energy transition could rapidly outgrow the capacity of the current electricity system.

Large amounts of unmet electricity demand in developed societies are likely to result in significant societal costs, including reduced potential for CO_2 reduction, deceleration of electrification for the energy transition, and stunted growth of businesses. The effectiveness of a nation's power system plays a critical role in its socio-economic development and Gross Domestic Product (Adefarati & Bansal, 2019). To substantiate and validate decision-making on additional policy measures to solve congestion, governments need to determine whether the added value of innovative solutions outweigh the costs (CE Delft, 2022a).



(a) Congestion for supply of electricity. Yellow: limited capacity, orange: under investigation, red: transport scarcity

(b) Congestion for consumption of electricity. Yellow: limited capacity, orange: under investigation, red: transport scarcity

Figure 1.2: Transport scarcity in the electricity system of the Netherlands, maps from (Netbeheer Nederland, 2023)

1.3. Research questions

This thesis is exploratory and aims to describe and understand the emerging phenomenon of demand congestion in the electricity system, specifically in highly populated urban areas. The main goal is to support Dutch local governments with substantiated and robust decision making on the topic. Contributing to the gaps found in literature as described in section 2.1, with this thesis I aim to answer the following research question:

"What are the societal impacts of demand congestion in the electricity system of highly populated urban areas in developed societies?"

To help answer the main research question, it is divided into sub questions of different nature, following a mixed methods approach. The questions are of qualitative or quantitative nature, and serve different goals, such as to describe, explore, explain and evaluate. I explore these questions via an Amsterdam case study.

1. How does congestion impact the functioning of the electricity system?
2. What are the consequences of demand congestion and how do these vary per affected customer segment?
3. What are the potential societal impacts of demand congestion in developed societies?
4. Which areas in Amsterdam are predicted to experience congestion until 2030?
5. What are the societal impacts of demand congestion by location, customer segment, and year in Amsterdam?

1.4. Research relevance

Societal relevance Providing adequate electricity facilities is a common challenge in many parts of the world. The specific circumstances and challenges vary widely depending on the location and regulatory environment. This work explores and explains how society is affected by the phenomenon of demand congestion. The work can function as a knowledge base for decision makers, and the insights should support local governments with policy making to address this grand urban challenge. This is desirable for the following two main reasons:

- Electricity transport scarcity caused by demand congestion is resulting in large amounts of unmet electricity demand. For complex societies to function and grow, there must be a steady energy supply. One of the main sources of services and product production that support economic, social, and cultural development, is electricity (Arto et al., 2016).
- The electricity infrastructure is the backbone for transitioning to cleaner energy sources. Because of congestion for supply and demand, electrification plans are being put on hold and new variable renewable energy resources cannot be operated.

Scientific relevance This research will add to the state-of-the-art of complex socio-technical systems with a multi-actor network, and in specific to the energy systems- and policy literature. More specifically, it adds to the already existing body of literature on electricity congestion. This work lays a basic foundation for researching demand congestion in the medium voltage grid in the urban area, as it has been fairly absent in literature. Adding to that, it contributes because it includes a unique city-wide case study. Highly energy-consuming and densely populated cities experiencing rapid growth are likely to be faced with this problem, thus can learn from this example. Furthermore, taking a holistic approach is rather unique in congestion research, which mainly has been focusing on techno-economical implications.

Academic relevance The electricity system is a complex socio-technical system that encompasses a variety of interconnected and interdependent elements. Technically, the system involves a broad range of technologies, including power plants, transmission lines, transformers, and substations. Socially, the system involves a multitude of stakeholders, including producers, regulators, policymakers, and consumers, whom have differing interests, goals, and preferences, that can impact how the electricity system operates. The complexity of the research problem aligns perfectly with the master's program Engineering and Policy Analysis of the faculty of Technology, Policy, and Management at Delft University of Technology. The program is focused on generating knowledge on the behavior of large-scale, socio-technical, and complex systems, using modeling, structuring and analyzing techniques. The aim is to support, improve or contribute to policy making with wicked problems in multi-actor arenas, using data-driven approaches.

1.5. Report structure

Chapter 2 provides the theoretical background, presenting the current state-of-the-art research, along with an overview of the electricity system and a detailed description of the case-context. Chapter 3 describes the chosen case-study mixed methods approach and the specific data collection and analysis methods employed, for each research question in detail. Chapter 4 presents the findings obtained from the research, which are further discussed and analyzed in Chapter 5.

2
Theoretical background

This chapter aims to enhance the reader's comprehension of the complex subject by presenting the theoretical background. This chapter consists of three main parts: a literature review of the state-of-the-art of the research problem, an overview of the electricity system in the Netherlands and a case description.

2.1. State-of-the-art

The objective of this section is to offer a comprehensive summary of the existing literature and identify the research gaps that are addressed in this thesis. I do so by firstly presenting the existing literature on electricity grid congestion, and secondly on how impact assessments have been conducted on electricity availability in both developing and developed countries. Following up, the knowledge gaps that will be addressed in this thesis are discussed. This should provide a scientific foundation for the project and situates the contribution of this research within existing literature.

2.1.1. Congestion on the electricity grid

Transport capacity limitations

The trends of electrification and the shift to renewable resources have brought forth a newly emerged problem in the energy system: thermal overloading and voltage limit violations on the electricity grid. Both problems cause damages, disturbances and outages in the system. Thermal overloading, more commonly known as congestion, occurs when the limits of the physical network do not suffice to meet supply or demand. The transportation capacity is constrained when a specific line or element reaches its maximum capacity and cannot handle any additional electricity than it currently carries. As a result, the electrical components generate more heat than they are designed to handle due to excessive electricity flow (Merino et al., 2021). Sporadic short overflow does not immediately result in power failure (it does lead to parts wearing out faster), but structural overflow does. Research by Hermans et al., 2022 shows that networks in rural areas are more likely to incur voltage violations, whereas the power grids in the urban area experience mostly congestion. Haque, Nguyen, et al., 2017 affirm this, stating that "densely clustered urban distribution networks are becoming more prone to network congestion in the upcoming years" and that they are "likely at the area level of the distribution transformer or main outgoing feeders". The latter are part of the medium voltage distribution grid.

Ensuring the safe and reliable operation of electricity transportation networks is the responsibility of network operators. This involves planning, developing, and investing in the required infrastructure and assets over the long term. In the short term, it entails ensuring that the network is operational. Grid operators do not yet have real-time insights into the state of the entire system, nor can they influence the impact on the system due to technical and regulatory reasons (Ghazvini et al., 2019). Since operators cannot influence the impact on the system to stop thermal overloading, they have to take preventive measures to safeguard the physical state of the assets. Components are thus designed with thermal limits and the system is operated with transport restrictions when necessary (Decker, 2021). The way in which the network is operated and maintained is a significant contributing factor to whether congestion is mitigated, which is very different per country or even per system operator. For instance, the Dutch electricity system is one of the worlds most reliable, being operational for 99.9997% of the time in 2021 (Netbeheer Nederland, 2022). Whereas in African countries, load shedding, power outages and disturbances are business as usual.

The changing nature of the electricity network - which now comprises more distributed generating units powered by volatile renewable energy sources - has required the role of operators to evolve from passive to active (Hadush & Meeus, 2018; Haque, Vo, et al., 2017). If the system operator foresees a discrepancy between the injections of electric power into and withdrawals from the transportation system, the operator will have to take action to "balance" the system. This can involve either dispatching generation or curtailing demand (Decker, 2021). The capacity of the electricity grid is thus becoming a bottleneck in the facilitation of electricity flows. If this is structural, we speak of transport scarcity. It should be noted that currently, transport scarcity is declared based on forecasts of congestion, not on real-time insights. As a consequence, theoretically congested assets in the grid are rarely loaded to their limits in reality (TKI Urban Energy, 2022).

Many countries, like Germany, struggle especially with the integration of variable renewable energy sources (VRES) into the electricity system, particularly in the low and medium voltage networks. These networks were originally not intended to accommodate extensive decentralized electricity generation (Henni et al., 2021). Adding to that, renewables are dependent on weather conditions, resulting in non-constant and volatile production levels throughout the day and year (Haque, Nguyen, et al., 2017). They produce big peaks of supply during sunny or windy hours (Netbeheer Nederland, 2019). This volatility is difficult to predict: the amount of power generated can fluctuate rapidly and unexpectedly. Due to this inherent volatility, it has become more challenging to meet demand based on traditional generation methods, that could easily correct for day-ahead demand predictions. As such, literature on supply congestion is mostly focused on finding solutions to cater for the increased volatile supply, to ensure the integration of renewable energy sources (Badanjak & Pandžić, 2021; Fattaheian-Dehkordi et al., 2022; Göke et al., 2022; Huang et al., 2015; Schermeyer et al., 2018).

In Europe, distribution networks are typically managed using a fit-and-forget approach, which has been effective due to the manageable scale and simultaneity of conventional residential demand. However, with the widespread integration of distributed generation and the adoption of electric heating and vehicles, the demand, simultaneity, and congestion risks in distribution networks have increased significantly (Vanin et al., 2022). Despite the significance of these emerging risks, congestion in the electricity system caused by demand is yet severely underrepresented in literature. Although several studies have been conducted on demand response solutions to mitigate congestion, these studies have mainly focused on future prospects of increased demand impact, but not on actual demand congestion examples. These studies focus on flexible demand from electric vehicle charging, energy systems and heat pumps, particularly on the low voltage distribution grid (Haque, Nguyen, et al., 2017; Haque, Vo, et al., 2017; Khomami et al., 2020; Schultis, 2021; Spiliotis et al., 2016; Vo et al., 2017). They research the potential of demand congestion mitigation, but do not address the impact of unmet electricity demand.

Solutions for grid congestion

Network capacity challenges have historically been solved by reinforcing and expanding the electricity infrastructure. Expanding the medium voltage distribution grid in urban areas is a complex, and both time- and money expensive solution. The planning and development of a new substation comprises 5 to 8 years, which is a huge bottleneck for solving congestion problems on the short-term (Liander, 2023). It involves laying cables and building new transformers and feeders of significant size in an already dense public space. It requires significant investments, expertise of scarce technical staff and proper coordination between various stakeholders (Ministry of Economic Affairs and Climate Policy, 2022).

Since the capacity limitations only occur several hours per year during peak-load periods, network expansion is not the most efficient solution (Haque, Nguyen, et al., 2017). A short-term solution is congestion management: daily redistribution of capacity using pricing- and market mechanisms (Ghazvini et al., 2019; TenneT, n.d.). Operators in the Netherlands apply congestion management where possible by asking consumers with contracts of 1 MW or more a day ahead to temporarily give back capacity for monetary compensation (Liander, n.d.). This approach, known as re-dispatching, tends to adjust the flows of electricity to prevent or alleviate congestion (Loschan et al., 2023). The implementation is quick and made-to-measure, but it is expensive, cooperation is not guaranteed and it is not a sustainable solution to structural capacity scarcity.

Most research conducted on congestion has a focus on finding technical solutions, mostly referred to simply as 'congestion management'. These studies often research the electricity grids in west European countries, and they assess the solutions with a technical, economic or techno-economic analysis (Cai & Li, 2021; Göke et al., 2022; Haque, Nguyen, et al., 2017; Hartvigsson et al., 2023; Liu & Zhong, 2019; Loschan et al., 2023; Roques et al., 2021; Schultis, 2021; Spiliotis et al., 2016; Vo et al., 2017). Adding to that, some of the congestion management literature is conducted on using market-mechanisms as congestion relief (Badanjak & Pandžić, 2021; Huang et al., 2015; Khomami et al., 2020). It is worth noting that these studies only highlight the relevance of their research briefly; None have conducted a thorough analysis on the consequences of congestion other than the technical implications for the system.

Roques et al., 2021 emphasize the need for a holistic analysis on extending and improving congestion management, as well as exploring policy tools such as revising electricity contract allocation. The latter is known as administrative congestion management mechanisms (Palovic, 2022). To solve congestion, active collaboration is needed between stakeholders such as the government, industries, companies, households and the regulator & operators of the system. The focus should be on faster realization of expansion, more efficient use of the current grid and smart solutions that increase flexibility (Ministry of Economic Affairs and Climate Policy, 2022). The complex multi-actor network can easily hamper decision-making and change, but if managed well, it provides opportunities such as content enrichment and innovation (De Bruijn & Heuvelhof, 2018). While a technical or engineering solution can often solve a complex technical problem, the involvement of multiple players with different perspectives and conflicting interests means that solutions may need to be negotiated or imposed by a party with sufficient power (Bots et al., 2022).

Flexibility as congestion relief

Power system flexibility is a critical aspect of a reliable and cost-effective electricity system. It refers to the ability of the power system to manage the variability and uncertainty of demand and supply across all relevant timescales (Badanjak & Pandžić, 2021). According to Yamujala et al., 2022, flexibility must be integrated into all parts of the electricity system. This can be achieved through various means, such as upgrading the grid to be smarter, improving current operations to be more efficient within current limits, using industrial heating loads, demand flexibility, energy storage, and fast response resources (Sreekumar et al., 2022; Yamujala et al., 2022). Flexibility-related solutions provide system operators with an economical, efficient, and effective alternative for system management (Bouloumpasis et al., 2019; Enexis, 2019). Proper collaboration and coordination between system operators is required to ensure reliable and efficient use of flexibility solutions (Gerard et al., 2018; Hadush & Meeus, 2018). However, regulations, the market and the products are also of great influence on the success.

Flexibility has the potential to make more efficient use of the existing capacity in the power system. By shifting and shaving the peaks, additional capacity is unlocked that could provide congestion relief (CE Delft and ECN.TNO and SMV, 2019). The time it takes for flexibility services to activate can range from seconds to several hours, making it a time-efficient solution. Moreover, grid flexibility is essential for the continuous integration of variable renewable energy sources (Fattaheian-Dehkordi et al., 2022). Efficient management of the intermittency of VRES is crucial to ensure the reliability of the system. This can be done by ramping up or down capacity by deploying system flexibility, in order to secure power balance. (Yamujala et al., 2022).

Demand side flexibility solutions are focused on changing the amount of demand and shift the spatial and/or temporal pattern of it (Piano & Smith, 2022). A dichotomy of demand flexibility mechanisms is made by Demand Side Management (DSM) and Demand Side Response (DSR), the primary being provided by technologies steered directly like active power curtailment, the latter being provided by demand-side actors steered indirectly with market methods. These approaches can be implemented either central or decentral; Decentral approaches are generally less complex, as they manage only local objectives and stakeholders, whereas the central approach requires a central coordinator (Haque, Vo, et al., 2017). Demand flexibility mechanisms can focus either on mitigating network peak demands or on solving congestion as it occurs, but the latter requires real-time data. Supply flexibility can be done by altering electricity production at the central source, curtailing VRES production and increasing reserve margins to secure system stability. Operating the system can be done more efficiently if flexible ramping up or down of capacity is possible for all electricity generators in the system (Sreekumar et al., 2022).

Grid infrastructure can facilitate flexibility by optimal network reconfiguration, smart grid technologies, line rating altering and the use of Energy Storage Systems (ESS) (Gough et al., 2020). The latter is seen as one of the key technologies for accelerating the energy transition, because of its capability to decouple temporality and spatiality from electricity demand and supply (Cai & Li, 2021). At present day, energy storage is often not yet taken into account in grid planning as a substitute for expansion, even though research shows that long-term storage for congestion management can greatly decrease overall system costs (Göke et al., 2022). Nonetheless, due to the current regulatory framework prohibiting system operators to intervene in storage operation, subsidies stimulating private investment in storage capacity has limited impact on network congestion. It cannot be guaranteed that private storage will be operated to facilitate relief during critical peak-hours, as they can also be used for commercial exploitation (Grimm et al., 2020; Vo et al., 2017).

2.1.2. The impact of electricity on society

The concept of sustainable development has gained widespread acceptance as a fundamental goal for public policy and decision making in various types of economies, developed & developing, and at different levels of intervention (Bond et al., 2001; Nautiyal & Goel, 2021). It is a widely discussed topic in many communities, including governments, non-governmental organizations, and academic circles. It goes beyond mere economic growth: it strives to achieve a form of development that is not only economically feasible but also socially desirable and environmentally sustainable (Bond et al., 2001). It calls for equitable, environment-friendly, and balanced growth, departing from the traditional focus on income or wealth as the sole measure of development (Bhattacharyya, 2012). Essentially, sustainable development means satisfying current needs without putting the ability of future generations to meet their own needs in peril. The ultimate goal is thus to strike a balance between social and economic activities and the environment (Nautiyal & Goel, 2021; Wang et al., 2009).

The increased recognition of sustainable development as a comprehensive policy objective has sparked interest in evaluating the influence of specific interventions. Reliable evaluation criteria and methods are essential to select the most suitable option, inform policymakers about the integrated performance of alternatives, and monitor impacts on development. In this fast-growing field, a variety of criteria and measurement tools are developed, underscoring the significance of conceptual and methodological work in this area (Bond et al., 2001; Wang et al., 2009). The global community has agreed on 17 Sustainable Development Goals (SDGs) to address various global development challenges and inequalities. The SDGs provide a framework to include social, economic and environmental sustainability in development processes. They can be used as reference point to identify key areas of interest for development projects or to measure progress. The United Nations has organized its indicators for sustainable development around four main dimensions - social, economic, environmental, and institutional - with equal emphasis given to each dimension (United Nations, 2001).

The societal impact of electricity in developing countries

Previous studies have extensively investigated the effects of *electricity generation* on the environment and the economy. The majority of these studies have focused on quantifying emissions, energy payback periods, and costs. Evans et al., 2009 say that additional to the conventional environmental factors, the social and economic impacts on human communities are of significant importance and should not be overlooked when choosing a method of production. Ali et al., 2023 agree, stating that a comprehensive sustainability assessment of power generation requires the integration of impacts on the environment, economy, and society from multiple disciplines. Wicaksono et al., 2020 followed the same three dimensions when categorizing indicators for the assessment of the sustainability of electric power generation in Indonesia. Wang et al., 2009 found that criteria used in literature to assess energy supply systems for sustainable energy decision making are mainly categorized by four dimensions: social, environmental, technical, and economic criteria.

The impact of the access to electricity on society is one of the major impediments to economic development and the provision of public services in rural areas of developing countries (Wassie & Adaramola, 2021). The issue of *access to energy* has a distinct regional dimension, with Sub-Saharan Africa and Developing Asia being the regions where the problem is most acute, and is primarily faced by rural communities. Therefore, almost all research conducted on the impact of electricity availability on society has been conducted in these regions (Bhattacharyya, 2012). Kumari et al., 2021 examined the impact of rural electrification on the socio-economic development of households in Asia focusing solely on the social and economic dimension, Lenz et al., 2017 did the same for Rwanda. Bezerra et al., 2017 (in Brazil) and Wassie and Adaramola, 2021 (in Ethiopia) researched the implications of rural electrification on economic development, social welfare and environmental sustainability. Bhattacharyya, 2012 and Ilskog, 2008 conduct the most holistic critical analysis of having access to energy on sustainable development, following five dimensions: technical, economic, social/ ethical, environmental and institutional.

The societal impact of electricity in developed countries

Studies on the impact of electricity availability in developed societies mainly focus on the *reliability*: providing a secure supply of electrical energy at any time. Interruptions in the system reduce reliability, as they cause electricity shortages for several hours or days. Such power outages are occasional occurrences for western societies (Baarsma & Hop, 2009). They can result in substantial financial losses, such as decreased production, as well as non-financial losses, like reduced health and safety concerns. Estimating the costs of power outages is thus a heavily researched area; They serve the purpose of substantiating decision making on infrastructural investments, by laying bear the reliability benefits over the cost of not served electricity. Sun et al., 2009 prove, using a quantified financial model, that the costs of maintaining a stable power supply in a city are significantly lower than the costs incurred from power disruptions. In the Netherlands, the social cost of reliability - under the present Dutch level of one outage of two hours every four years - is €2.80 on average per household and €33.10 for each SME firm (because of higher opportunity cost). The total cost to Dutch society is almost €50 million (Baarsma & Hop, 2009).

In contrast to temporal power outages, structural electricity shortage refers to a situation where the demand for electricity consistently exceeds supply over a longer period of time, typically months or even years. Electricity shortage caused by distribution capacity limitations can happen in any region where the demand for electricity is growing rapidly and the infrastructure is unable to keep up. This can be particularly common in urban areas with high population growth and urbanization rates, and limited space for infrastructure expansion. Pakistan experienced a severe electricity crisis due to such a widening gap between demand and available system capacity, characterized by an overloaded infrastructure, significant capacity shortfall, and high transmission and distribution losses. These shortages have had a substantial impact on Pakistan's economy, with negative effects on employment, international competitiveness, exports, poverty alleviation, and GDP (Kessides, 2013). A similar study has not been conducted in a European country.

Though studies on the energy-growth relationship have been pursued extensively, no effective consensus has been reached for developed countries. The majority of research indicates a strong correlation between energy consumption and standards of living in developing countries. Conversely, in developed countries, there is typically a decoupling of the relationship between energy consumption and Human Development Index (HDI). In addition, countries have exhibited an improvement in their capability to achieve higher levels of development with a constant amount of energy demand. Likewise, there is a positive correlation between HDI and GDP until a certain threshold is reached, beyond which HDI becomes unresponsive to changes in GDP (Arto et al., 2016). Best and Burke, 2018 agree, saying that there is no significant difference in subsequent economic growth performance across countries with varying levels of initial electricity availability. Rather than being a binding constraint on economic growth, electricity availability can be scaled up as economies grow. Controversially, a study on the causal relationship between sustainable economic welfare growth and energy consumption for G7 countries found that energy consumption is indeed necessary for growth (Menegaki & Tugcu, 2017). Best and Burke, 2018 also suggest that while electrification programs may not have direct benefits for economic growth, there are social, health, and environmental benefits that could justify expanding electricity availability.

2.1.3. Knowledge gaps addressed

Most congestion literature focuses on the low voltage distribution grid or on the national high voltage transmission grid (Göke et al., 2022; Loschan et al., 2023). Congestion in the assets of the medium voltage grid is underrepresented in literature, though they are a crucial part of the electricity system feeding our cities. The problem of demand congestion is amplified in metropolitan areas, since they have a high population density and accommodate many commercial and industrial activities (Vo et al., 2017). The urban electricity system should thus be a high priority of energy policy makers (IEA, 2021). Since congestion literature mainly focuses on the integration of VRES to mitigate curtailment of renewable energy production, with this work I focus on the increased grid impact caused by demand and the mitigation of demand curtailment. In conclusion, my focus is on demand congestion in the medium voltage distribution network feeding highly populated urban areas.

To the best of my knowledge, demand curtailment due to grid capacity constraints and the effects of the following structural electricity shortages has been absent in literature. The nexus between transport scarcity, electricity consumption and sustainable development in developed societies has not yet been researched. As the implications of demand congestion are not yet known, it is difficult for local governments and other important decision makers in the multi-actor system to manage this novel complex urban challenge. In order for decision makers to prioritize their resources, they need to know when and where to invest (Municipality of Amsterdam & Liander, 2021). System operators know how to predict and quantify congestion in technical terms expressed in unmet energy demand, but there is a gap in literature on the societal impact of unmet electricity demand in developed societies (CE Delft, 2022a). Validation and effectiveness of decision-making for the deployment of additional short-term solutions for congestion management crucially rely on the latter.

Most literature found on congestion management is focused on assessing solutions using techno-economic dimensions. Since decision making on innovation and technologies for sustainable development requires a holistic approach, I will focus on the environmental, economic and social dimensions. This is in line with the knowledge gap identified by Best and Burke, 2018, saying that the social, health and environmental benefits of electricity availability should be explored additional to economic growth. In order to enable proper urban energy planning, it is crucial to perform the impact analysis on a higher aggregation level that encompasses entire neighborhoods or conduct city-scale research, rather than focusing on specific cases or projects (Municipality of Amsterdam, 2021).

2.2. A quick recap of the electricity system of the Netherlands

Electricity is transmitted at different voltage levels from the source to the end-user. The national high voltage transmission grid carries electricity at a voltage between 50 and 400 kV to minimize energy losses over long distances and maximize transport capacity. It connects regional grids to major power stations and it links to neighboring countries. Electricity is then transformed to medium voltage levels (10-50 kV) flowing onto the regional distribution grid. Lastly, the voltage is transformed to low voltage levels (230-400 V), which is the appropriate voltage level for consumption (see Figure 2.1). The Dutch electricity system is one of the worlds most reliable, with customers experiencing an average of 30 minutes of electricity loss per year (Baarsma & Hop, 2009). In 2021, the Dutch national grid was operational for 99.9997% of the time (Netbeheer Nederland, 2022). Electricity is a vital resource for a wide range of purposes, including lighting, heating, cooling, cooking, transportation, and communication. The residential (22%), commercial (31%), and industrial (33%) sectors are the main consumers of electricity in the Netherlands, with a total consumption of 121 billion kWh in 2021 (CBS, 2022a, 2022b). See section A.1 for an extensive overview of the Dutch electricity system.

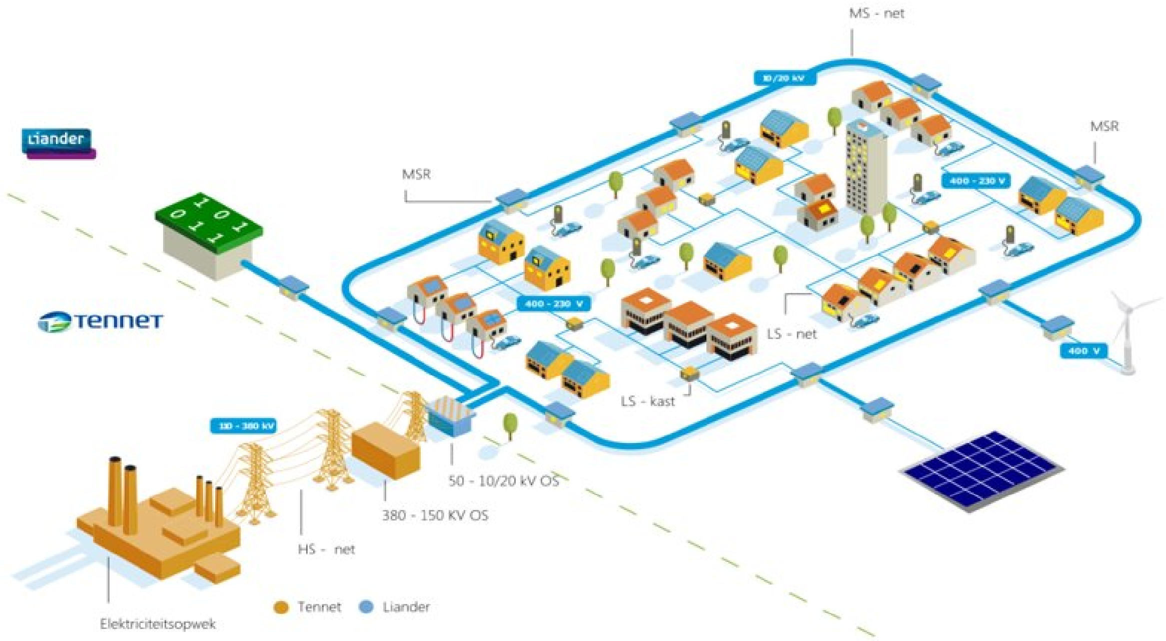


Figure 2.1: Overview of the electricity infrastructure in the urban area (Municipality of Amsterdam & Liander, 2021)

The electricity market is a delicate balance between the supply and demand of energy, which must be maintained at all times to ensure a stable and cost-effective system: the differences in timing and location have to be actively managed by network operators to continuously complement each other. In the past, electricity production levels were altered to match the predicted demand. The production of electricity occurred in centrally managed conventional power plants that were reliant on fossil fuels, thus could be easily adjusted. With the growing use of distributed variable renewable energy sources, the market is shifting from being demand-driven to supply-driven. This has resulted in the need for new market mechanisms and innovative solutions to provide flexibility in supply and demand, as well as for all stakeholders to adapt and embrace a more flexible and dynamic electricity market (Ministry of Economic Affairs and Climate Policy, 2022). See section A.3 for a more elaborate explanation of supply and demand.

Since the liberalization of the electricity sector in 1989, the multi-actor network consists of six independent roles: generation, transmission, distribution, supply, metering, and trading (Verbong & Geels, 2007). The system is regulated by the Authority for Consumers & Markets (ACM). There are six Distribution System Operators (DSOs), with three of them - Liander, Enexis, and Stedin - holding almost 95% of all connections (see Figure 2.2, with Liander in light blue). Every DSO is appointed a region to operate in to avoid competition because of the high investment costs. As per the law, the primary responsibilities of DSOs are to manage and maintain the medium- and low-voltage network infrastructure and efficiently invest in infrastructure expansion. They are legally obligated to always provide a client request with a physical connection to the grid in a non-discriminatory manner and to always deliver electricity as the agreed-upon capacity (Netbeheer Nederland, 2019). Since the governments (national, regional and local) are their shareholders, their focus is not on generating profits. Instead, their primary goals are to keep overall costs low, minimize power losses, and maintain the highest level of reliability and stability in electricity supply (Liander, 2023).

TenneT, the Transmission System Operator (TSO), is responsible for the management, maintenance, and development of the high-voltage transmission network, with the main goal to provide safe, secure and reliable transmission. In order to maintain the stability and quality, they have to balance supply and demand in real-time; They do so by precisely controlling the electrical power injection into and withdrawal from the grid, including the exchanges with other countries. The ACM monitors the market to ensure functionality and protect consumer interests. They do so by setting a maximum to tariffs

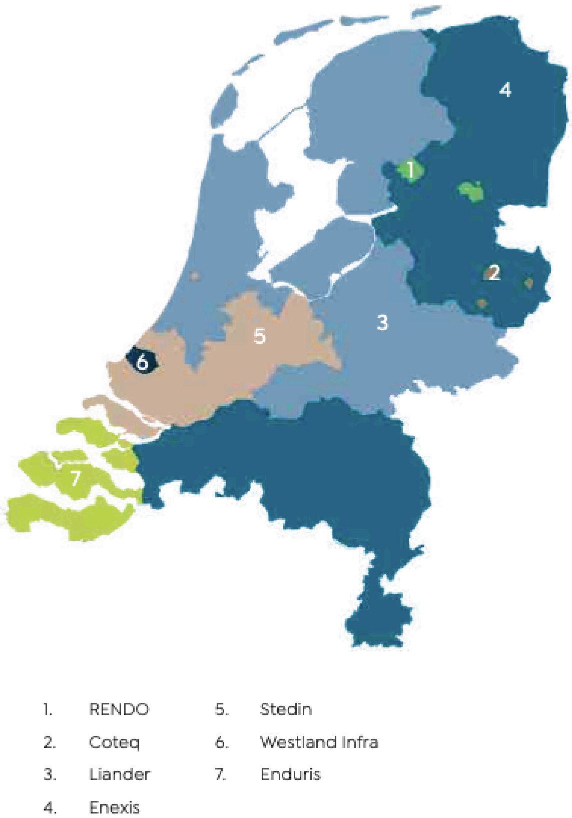


Figure 2.2: Overview of Distribution System Operator regions in the Netherlands (Netbeheer Nederland, 2019)

that operators can use to charge their customers for selling or transporting energy. As a consequence, the decisions made by the ACM affect investments that can be made in the grid. The ACM holds the position that investments are only efficient and effective if its use of capacity can be substantiated. This has caused a rather reactive than proactive expansion of the grid in the past years in the Netherlands (Netbeheer Nederland, 2019).

After the liberalization of the electricity market, the role of the Dutch government in the electricity sector has changed significantly (Verbong & Geels, 2007). While the government still has the responsibility of setting the overall framework for the electricity market, it no longer has a monopoly on the generation and supply of electricity. The national government plays a rather guiding role, providing support in the form of subsidies, in combination with regulation and enforcement. The regional governments are responsible for developing and implementing energy strategies that are in line with the national energy goals. They work closely with the TSO and DSOs to ensure that the regional electricity grids can accommodate the growing electricity demand and number of renewable energy sources.

The local governments are responsible for promoting sustainable energy initiatives within their communities, such as energy cooperatives and community-based renewable energy projects. Though the governments are stakeholders of the DSO - Liander is owned for 45% by the province of Gelderland, 13% by Friesland and 9% by Amsterdam - they do not have the responsibility of maintaining, managing and planning the electricity system. Nevertheless, they are involved in the permitting process for new infrastructure and energy projects, such as wind turbines parks. With these permits, they have a role in spatial planning and can influence the location of new energy infrastructure. By working together with other stakeholders, such as energy companies, residents, and businesses, the regional and local governments have a crucial role as facilitator, enabler of societal engagement and promoter in addition to that of policymaker (Borrás & Edler, 2020). See section A.2 for an extensive overview of the multi-actor system.

2.3. Case description: Amsterdam

2.3.1. Why the city of Amsterdam?

The impact on the electricity grid of Amsterdam is expected to experience an immense rapid growth: the current maximum peak-load of ±1.000 MW will grow with a factor of 2,5 to 3 by 2030 and 3 to 4,5 by 2050. If no action were to be taken, approximately 80% of the substations would be congested by 2030 (Municipality of Amsterdam & Liander, 2021). Due to tight regulations, high financial costs and lengthy time frames of planning and construction, grid expansion has already not been keeping up with the explosive growth of usage of the electricity infrastructure (NOS, 2022). As a result, Amsterdam was the pioneering city of the Netherlands facing structural electricity shortage caused by demand congestion in the urban electricity system. The first announcement of a congested asset was done in September 2021 (Liander, 2021a), which grew to nine by the end of 2022. The number of congested substations will most definitely continue to grow (Municipality of Amsterdam & Liander, 2021), and it is very plausible that congestion will occur on the low voltage grid as well (P. Begemann, 2023).

Amsterdam is an interesting city to research demand congestion due to its rapidly growing population and expansion to becoming a metropolis; The city has 918 thousand inhabitants (Municipality of Amsterdam, 2023) and is growing with 10 thousand inhabitants per year (Municipality of Amsterdam & Liander, 2021). This is accompanied by the expansion of housing construction and economic activities, which both necessitate an uninterrupted and stable supply of electricity. To address the shortage of available housing in Amsterdam, the municipality plans to construct an additional 7.500 dwellings every year (Municipality of Amsterdam, 2022c). For context, as of January 1, 2022, Amsterdam had a total of 456.000 houses available (Municipality of Amsterdam, 2023). It has proven to be a tremendous puzzle to make space to grow towards a sustainable future in an extremely densely populated urban area, while maintaining the historic character set in 750 years of Amsterdam (Municipality of Amsterdam, 2021). The issue of congestion is already prevalent and is likely to become more problematic as demand growth is explosive and infrastructure expansion difficult.

The effects of electricity shortage on a city's businesses and their operations are important to consider, as it will have far-reaching impacts on the local economy. The economy of Amsterdam is both diverse and dynamic, with a thriving tech industry, financial sector, and creative industry. Currently, the city is home to around 590.000 jobs (12% in health, 18% in 'advice and research', 8% in finance and 8% in IT) (Municipality of Amsterdam, 2023). However, the COVID-19 pandemic has had a significant impact on the city's economy, with Amsterdam experiencing a faster decline in deployment rates than the national average, dropping by 3% compared to 1,2% nationally (van Zoelen, 2021). Despite these challenges, Amsterdam remains an international hub, with several thousands of international corporations and numerous headquarters of large multinationals. The city's stable business climate, diverse talent pool, and entrepreneurial mindset make it an attractive location for businesses looking to invest.

To further strengthen its competitiveness and ensure sustainable development and innovation, Amsterdam aims to attract even more (international) knowledge and investments. This strategy will provide a solid foundation for future prosperity and help the city become less vulnerable to economic crises such as the one caused by the pandemic. To achieve these goals, the city is committed to creating an attractive business climate that supports cutting-edge startups and social entrepreneurs. The effects of demand congestion are likely to have a significant impact on achieving these objectives, making it an interesting case to study the phenomenon.

Furthermore, Amsterdam has set ambitious goals for the use of renewable energy and sustainable urban development. The city of Amsterdam aims to be climate neutral by 2050, free of natural gas by 2040, have only emission-free mobility by 2030 and contribute to the Regional Energy Strategy (RES) with 127 MW sourced from wind and 400 MW by solar PV (the Municipality of Amsterdam, 2020). The municipality of Amsterdam aims to reduce CO_2 emissions on its territory by 55% in 2030 and by 95% in 2050, compared to the baseline year of 1990 (the Municipality of Amsterdam, 2020). To achieve the 2030 goal, the pace at which the reduction in emissions takes place in Amsterdam must accelerate by about 2,5 times. Research conducted by CE Delft, 2022b indicates that the achievement of the 55% goal is contingent upon the successful implementation of all intended policies and their effective execution. Demand congestion is expected to have a significant impact on Amsterdam's ability to achieve its sustainability goals, making it an interesting case study for the phenomenon.

The rapid growth of sustainable developments such as heat pumps, electric vehicles, and other electrification goals will significantly add to the explosive electricity demand in the city. In 2020, the city consumed a total of 52.296 TJ of energy, with 30% in the form of electricity, 49% as heat, and 21% as vehicle fuels like gasoline, diesel, and LPG (Government of the Netherlands, 2023). CO_2 emissions in the same year were 3.330 kton, with 38% from electricity, 38% from natural gas, and 24% from vehicle fuels (Goverment of the Netherlands, 2023). These percentages are due to the varying CO_2 emission factors of different energy carriers, which depend on the mix of primary energy sources used. In 2020, the emission factors were 0.292 kg/kWh for electricity, 1.785 kg/m3 for natural gas, and 25.350 kg/GJ for heating. To make it comparable: 81.111 kg/TJ for electricity, 56.398 kg/TJ for natural gas, and 25.350 kg/TJ for heating (Goverment of the Netherlands, 2023). However, with the integration of renewable energy sources, the emission factor for electricity is expected to drop to 0.21 kg/kWh in 2025 and 0.09 kg/kWh in 2030.

2.3.2. The urban electricity infrastructure of Amsterdam

The medium-voltage electricity grid in Amsterdam is owned and operated by Liander. In 2021, they had 494 thousand clients with a connection to the grid (Liander, 2022a), of which 478.325 small-scale connections. The medium-voltage network is made up of twenty-two substations, 2.300 transformer houses and approximately 3.500 kilometers of cables below the ground (Municipality of Amsterdam & Liander, 2021). Substations ('OS' in Figure 2.1) are crucial assets in the urban electricity system, as they perform medium-voltage transformations and electricity distribution. They are equipped with various assets, including transformers, switchgear, and protection devices, which define their capacity. The most common types of transformations conducted are 150/50 kV, 50/20 kV, and 20/10 kV.

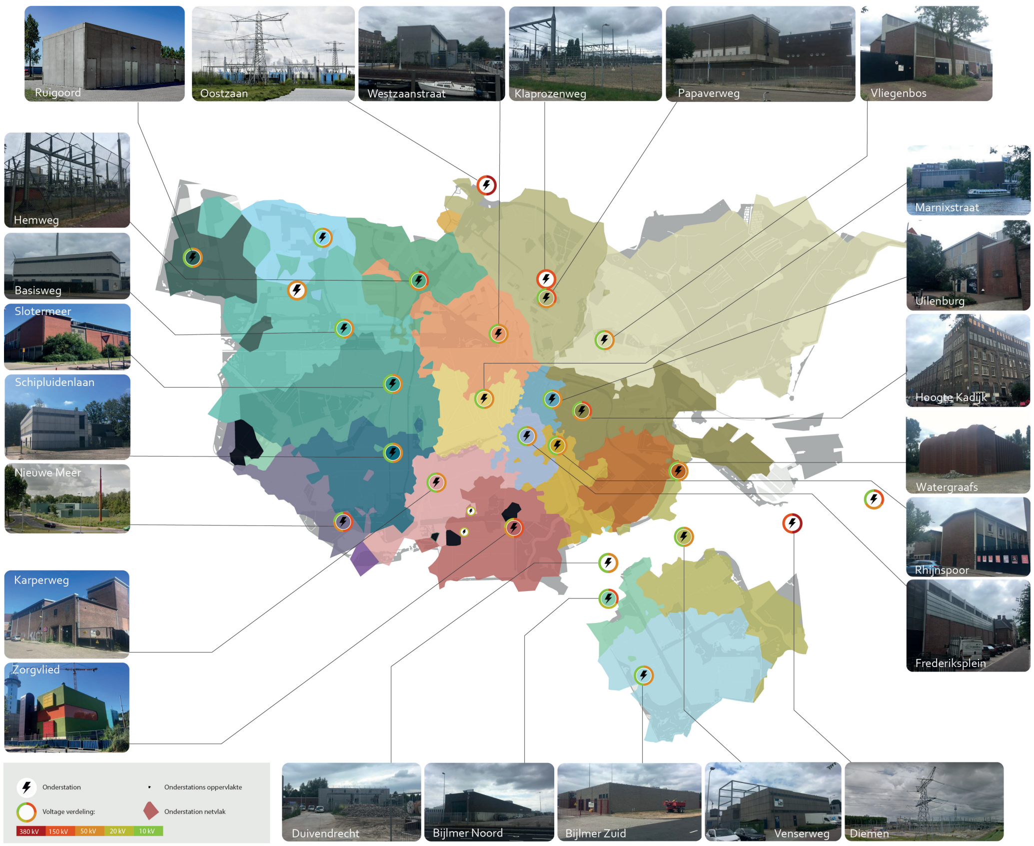


Figure 2.3: Map of all substations in Amsterdam, from (Municipality of Amsterdam & Liander, 2021)

As can be seen from Figure 2.3, a substation feeds a fairly large area, which explains the large impact of congestion as compared to a congested cable in the low voltage grid (P. Begemann, 2023). A substation has an average surface of 3 km^2, with a range from 1 to even 5 km^2, and it occupies space above and below surface level. It is preferably located as close as possible to the consumer to improve efficiency and thus decrease electricity cost. These primary assets of the urban power grid are expected to last, with proper maintenance, several decades.

The city has nine substations that convert the electricity supplied by TenneT from 150kV to lower levels: Zorgvlied, Watergraafsmeer, Venserweg, Noord Papaverweg, Nieuwe Meer, Hoogte Kadijk, Hemweg, Bijlmer Zuid, Bijlmer Noord. The remaining thirtheen substations can maximally convert levels of 50kV: Basisweg, Frederiksplein, IJpolder, Karperweg, Marnixstraat, Rhijnspoor, Ruigoord, Schipluidenlaan, Slotermeer, Uilenburg, Vliegenbos, Westhaven, Westzaanstraat. The capacities of these stations are very different, ranging from 20MVA (IJpolder) to 600MVA (Hemweg). The list of twenty-two substations I mention here is not entirely congruent with the substations referenced in Figure 2.3: IJpolder and Westhaven are not labelled but their feeding areas are depicted in the upper left corner in light blue and green, Klaprozenweg is a TenneT station and a few stations mentioned in Figure 2.3 are not located on municipal grounds: Oostzaan, Diemen, Duivendrecht, Bijlmer Noord and Venserweg. Only the latter two have their own feeding area in the city, depicted in the lower right corner in yellow and green. The currently congested stations are: Basisweg, Hemweg, IJpolder, Ruigoord, Slotermeer, Westhaven, Westzaanstraat, Noord Papaverweg and Vliegenbos (Liander, 2022b).

2.3.3. Efforts of congestion relief in Amsterdam

Collaboration within the multi-actor system

Upon the first announcement of congestion, the stakeholders in the multi-actor network saw the need to closely collaborate to effectuate a future-proof electricity grid. A task force was set up consisting out of the municipality of Amsterdam, the TSO, the DSO, and the Port of Amsterdam. The latter was included as a significant amount of the future gird impact comes from the parties located in the harbor area. The task force collaborates on the planning of the electricity infrastructure, taking a strategic and integral view. They extensively research the future impact on the grid, which has been reported in two theme studies, with a third in progress (Municipality of Amsterdam & Liander, 2021).

Collaborating and making decisions in a multi-actor network can be challenging due to the varying perspectives, objectives, and resources of each stakeholder (De Bruijn & Heuvelhof, 2018). None of the stakeholders in this system hold all the necessary power and resources to address the congestion issues independently. A task force is a promising approach to address the complexities of congestion in a team effort. The task force aims to jointly coordinate and accelerate the expansion of infrastructure, find ways to distribute the scarce space on the network in a socially responsible way, and develop effective short-term solutions to alleviate congestion problems (Port of Amsterdam, 2021). By collaborating more closely, a task force can help to speed up the decision-making process and overcome challenges associated with solving complex problems in a multi-actor network.

Planned expansion of the infrastructure

In response to the increasing demand for electricity capacity in Amsterdam, the city's electricity network is set to undergo significant upgrades over the coming decades. The "Ontwikkelingskader Elektriciteitsvoorziening Amsterdam 2035" outlines the need for major modifications, including the construction of 29 new substations at 23 new locations and the expansion of 12 out of 22 existing ones. A draft of the future network topology of the medium voltage grid in 2035 is provided in Figure 2.4. The expansion of the electricity network will primarily focus on the substations, as they are the main bottleneck. They serve as the crucial link between TenneT's national transport network and Liander's distribution network. In addition, there will be a need for approximately 2.600 new transformer houses and hundreds of kilometers of extra cables have to be installed underground (The Municipality of Amsterdam et al., 2022).

The expansion of the electricity network in Amsterdam will require substantial investments and construction efforts from both TenneT and Liander, with a total cost estimated at €750 million for Liander and €650 million for TenneT. The implementation of this task is expected to take place mainly between

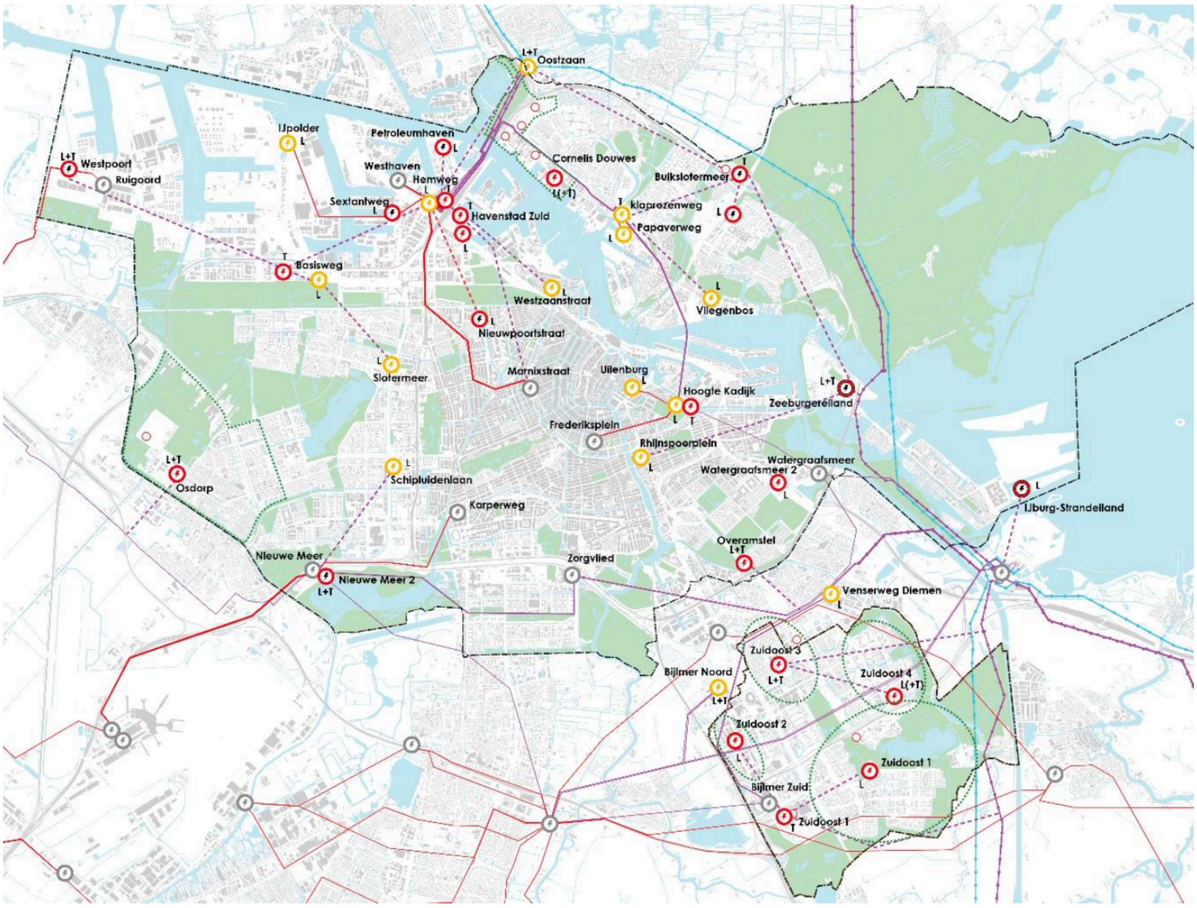


Figure 2.4: Planned expansion and construction of substations owned by Liander and TenneT in Amsterdam by 2035 (The Municipality of Amsterdam et al., 2022).

2023 and 2028. This timeline is due to the careful procedures that must be followed for spatial and legal considerations in the decision-making process. As said before, constructing the medium voltage network in dense urban areas is very complex. Moreover, the national shortage of technical personnel and scarcity of materials poses a significant challenge (Liander, 2023). This scarcity will lead to longer lead times for the delivery of equipment and result in project delays (The Municipality of Amsterdam et al., 2022). As a result, demand congestion will not be solved in Amsterdam on the short term and is expected to have significant impact until all necessary expansions are successfully completed.

Alternative approaches for congestion relief

Whilst grid expansion is a critical solution for solving congestion problems on the long-term, there are several other approaches available to provide relief to transport scarcity. Part of the alternatives can be applied in the short term and therefore provide an interim solution until the grid is expanded, others are a permanent solutions. Whether a solution is applicable depends highly on the use-case, most importantly whether the problem of the client lays with demand or supply. Liander defines four behind-the-meters solutions directly within reach of the client to provide transport scarcity relief: smart charging, own off-grid production and consumption, cable pooling and energy storage (Liander, 2023). Regulations imposed by the ACM and the law restrict the solution space DSOs have at hand for congestion relief approaches and withhold them from giving advice to denied customers.

Three other smart solutions that require changes in current regulation are in the pipeline and still under discussion with all stakeholders: (1) flexible contracts with periodic capacity supply, (2) energy storage systems and (3) group connections for energy hubs (Ministry of Economic Affairs and Climate Policy, 2022). The primary is being experimented by Liander in Amsterdam with "Time-limited Capacity during Transport Restrictions" contracts (TCT). By means of TCT, customers can transport more electricity over the grid than is determined in their contracted transport capacity during specific time windows determined by Liander. The customer retains their transport restriction, but exceedances of their contract are tolerated during the agreed-upon times. The responsibility for not exceeding the agreed-upon power limits lies with the customers, and there are no technical limitations to prevent them from doing so (Liander, 2023). This poses a risk for the DSO, as frequent breaches of the limits by TCT customers can result in quicker deterioration of the system.

On March 2, 2023, the ACM announced that it will allow grid operators to give priority to projects on the waiting list for electricity capacity that reduce or solve congestion when connecting to the power grid. The ACM also wants to make this priority rule possible for projects with a societal function, such as security services, healthcare, or schools. This means that grid operators in congested areas can deviate from the rule that the first applicant for electricity is the first to gain access to the grid. Assessing the degree of priority will be based on objective and transparent criteria, which should reflect the client's contribution to achieving a set of societal goals. For this purpose, the ACM will start a code amendment process in the short term. They aim to publish the draft code decision in Q3 2023 (ACM, 2023).

Research by the task force reveals the promising potential of flexibility, showing that it could minimize peak-load by 10-20% in substation assets, currently the main bottleneck of congestion in Amsterdam (Municipality of Amsterdam & Liander, 2021). However, this flexibility analysis was done with rather high-over assumptions, as it does not elaborate on specific scenarios or techniques. Since the results of the TSA can and have been used to substantiate policy decisions such as the 2035 implementation agenda (the Municipality of Amsterdam et al., 2022), further detailed research into the potential of flexibility is desirable.

2.3.4. Internship at the municipality of Amsterdam

As part of a graduation internship, this study is conducted under guidance of the municipality of Amsterdam. I have given special attention to remain as independent as possible from third party interests, as this is crucial to safeguard the objectiveness of scientific research. The results are not influenced in favor of any party, and since the problem remains a joint task, the results are expected to be beneficial for all stakeholders. The graduation internship is executed at the municipality of Amsterdam within the team 'Elektriciteit Voorziening Amsterdam' (EVA). This team is part of the section *Ruimte en Economie*, and more specifically within the division *Ruimte en Duurzaamheid*. Team EVA focuses on ensuring the facilitation of the electricity system for the city of Amsterdam. They do so by focusing on the following three pillars (Municipality of Amsterdam & Liander, 2021; the Municipality of Amsterdam, 2020):

1. Expansion of grid capacity by building new or improving existing infrastructure
2. Smarter use of the current grid capacity by adopting innovative and flex solutions
3. Strategic and integral planning of electricity system facilities in combination with other urban challenges, such as solar PV plans or electric mobility

During my research internship at the municipality, I had the privilege of working closely with the EVA team on a daily basis. This collaboration provided me with invaluable opportunities to learn, observe, and actively participate in addressing congestion challenges in Amsterdam. As part of our collaboration, the EVA team and I also had the opportunity to spend one day per week at the Liander office. This experience allowed me to gain firsthand exposure to the operations and processes of a key stakeholder involved in managing the electricity grid. Working alongside the EVA team at Liander provided me with a deeper understanding of their roles and responsibilities, as well as the challenges they face in ensuring reliable and efficient electricity supply.

Throughout my time with the EVA team and at the Liander office, I actively participated in topical meetings and discussions, and witnessed the decision-making processes related to congestion management. By working with the EVA team every day, I was able to collect valuable data and observations that significantly enriched my research. This hands-on experience can be seen as a "data collection method" as it provided me with real-world insights, practical knowledge, and a deeper understanding of the complexities and dynamics of congestion management in Amsterdam.

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3 Methods

Research methods are tools and techniques for scientific research. They can be of quantitative or qualitative nature, and are ways of collecting, structuring and analysing data to create new information. Choosing the right methodology to answer the research questions and clearly describing the steps to be taken makes a research reproducible, which gives the results validity (Walliman, 2021). First, the choice for using a case study-mixed methods approach is explained. Second, the choice of methods for data collection is substantiated. Third, the specific research steps are described per sub question, explaining how the collected data is analyzed.

3.1. Research approach: case study-mixed methods

This thesis aims to answer the following question: *"What are the societal impacts of demand congestion in the electricity system of highly populated urban areas in developed societies?"*. The nature of the main question is complex and diverse. Explaining the real world situation with data and numbers is labeled as the 'effects-of-causes' approach (Mahoney & Goertz, 2006). This suits a quantitative strategy. Exploring an individual situation in-depth is labeled as the 'causes-of-effects' approach (Mahoney & Goertz, 2006). This approach requires qualitative data. Since one research approach is deemed inadequate, a mixed-methods approach is applied. The mixed-methods approach allows for using both inductive and deductive methods for empirical data gathering. Combining the methodologies of methods is called 'triangulation', which is the concept of using multiple reference points to improve accuracy (Jick, 1979).

Qualitative research tries to explore, describe, discover, and understand, with the researcher interpreting the meaning of data. Quantitative research tries to explain, predict, test, and examine, with data being analyzed using statistical rules. The former strategy is inductive, the latter is deductive. Combining the two using concurrent mixed methods will strengthen the research, as a more comprehensive analysis is conducted (Creswell, 2009). The limitation of a qualitative approach is that it is less generalizable, but its strengths are that it provides in-depth descriptions and requires a small sample. The limitation of a quantitative approach is that it requires large samples, but in return, it is easily generalizable, and the results are in-breadth and include numerical overviews that allow for easy comparison. Mixing the two takes away their main limitations and complements their strengths (Jick, 1979).

A case study integrates well with the mixed-methods approach, therefore this research is designed following the *case study-mixed methods approach* (Guetterman & Fetters, 2018). This means that qualitative and quantitative data is collected within the case-specific context, which should result in detailed information. Yin, 2009 affirms the usefulness of combining a mixed-methods approach with a case study approach, which aims to explore, explain and describe. When employing a case study approach, researchers are able to closely analyze data within a specific context, resulting in a comprehensive depiction of a particular phenomenon. This research method is well suited to address the knowledge gap, as this research aims to explore a new phenomenon in-depth.

Criticisms of case study research highlight the potential for insufficient depth, inconsistent adherence to systematic procedures, and biased views that may influence the direction of findings and conclusions (Yin, 2009). These limitations are mitigated with a structured research plan and the triangulation of methods. Furthermore, the method's limitations confine the general interpretation of the findings solely to highly populated urban areas with similar multi-actor systems and electricity system management. However, the research approach provides an intriguing example for other cities that are not similar, which may ignite interest in conducting adapted research.

Case selection

The specific context I choose to analyze the phenomenon of demand congestion in, is the city of Amsterdam in the Netherlands. The city of Amsterdam has been dealing with demand congestion since September 2021 due to an explosive growth of electricity demand (Liander, 2021a). This growth is attributed to growing urbanisation rates, the ambitious sustainability goals of the municipality and the autonomous growth of the economy (Municipality of Amsterdam & Liander, 2021). It is one of the pioneering cities in the Netherlands dealing with structural electricity shortage due to demand congestion. See section 2.3 for an elaborate substantiation of why Amsterdam is an interesting case to explore.

Research scope

The geographical scope I take are the municipal boundaries of Amsterdam of 2021. In March 2022, the municipality of Weesp was incorporated to the municipality of Amsterdam. I exclude this area from my research, because I use a considerable amount of data from the TSA 2.0 study, which was conducted before the addition of Weesp (Municipality of Amsterdam & Liander, 2021). Furthermore, other open-source data on the city of Amsterdam that are used as inputarewere often not yet updated with Weesp data. The timeline is scoped to 2030. This is based on physical expansion plans already being in place to contribute to dissolving demand congestion in Amsterdam, and the explosive growth in demand is expected to stabilize on the long-term (Municipality of Amsterdam & Liander, 2021; The Municipality of Amsterdam et al., 2022).

3.2. Data collection

Following the mixed-methods approach, I collect both quantitative and qualitative data using both primary and secondary sources. Primary data refers to data that is collected firsthand by a researcher specifically for their research project. Secondary data refers to data that has been collected and analyzed by someone else or has already been published in some form, such as in books, articles, reports, or datasets. While primary data is unique and tailored to the research objectives, secondary data provides valuable context and background information. It's important to use a mix of methods to ensure that a range of perspectives and insights on the potential impacts of demand congestion in the case study is included. A conceptual overview of the methods is shown in Figure 3.1.

3.2.1. Desk research

Desk research is conducted to gather qualitative data. Document and literature research is used to explore existing knowledge on the matter in-depth, using a mix of grey and scientific literature complemented with policy documents. Grey literature are all documents that are not published in a scientific journal and peer-reviewed, such as reports by NGOs and knowledge institutes, government documents and working papers. Through my internship at the municipality of Amsterdam, I have access to a very extensive data bank of reports and researches conducted on this specific phenomenon. New insights are created by putting together different sources and materials, creating an aggregated and manageable overview which should be useful for decision making.

The advantages of this methodology is that it provides the researcher independence, since there is a huge information availability that is immediately accessible. This availability is magnified by the graduation internship at the municipality, which gave access to otherwise inaccessible information. The disadvantages are that it is difficult to make a selection of resources, reading all resources thoroughly is time-consuming, and information may prove to be contradictory (Johannesson & Perjons, 2014).

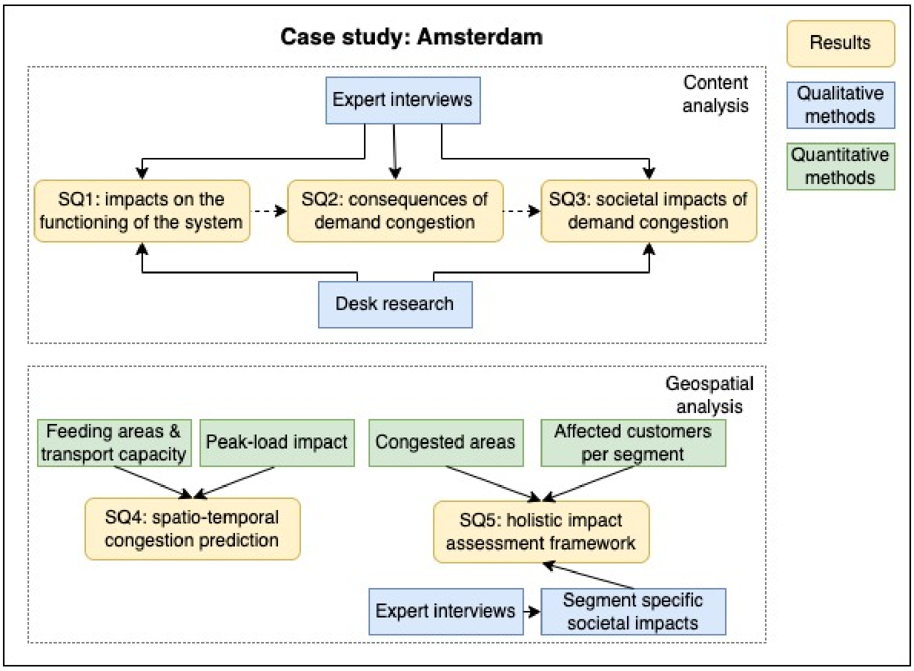


Figure 3.1: Conceptual diagram of the research approach and the research methods

3.2.2. Semi-structured interviews

To complement the qualitative data found with desk research, empirical data gathering is conducted by doing semi-structured interviews. People with expertise on the matter can confirm or invalidate information quickly and supply additional non-documented information. Interviews are a method that allows for complex and detailed data gathering, giving in-depth information on the topic. The interviews are of a semi-structured type (SSI), which is a practical method for in-depth conversations. This type allows the researcher to discuss various topics with multiple themes, but leaves flexibility for free responses.

A disadvantage of interviews is that it can be difficult to process interview data in a structured manner (Johannesson & Perjons, 2014). To address this limitation, a pre-determined duration of one hour is set for each interview and standardized questions are used, which are send to the interviewee beforehand. This approach facilitates easier and faster data analysis. During the interviews, permission is obtained to record them, and are then later transcribed using Dovetail. McLellan et al., 2003 suggest that the text selected for transcription should be based on the analytical contribution it will make to the study, with the research question driving what to include. Therefore, in this thesis, the interviews are transcribed globally, without including mispronunciations, slang, nonverbal sounds, grammatical errors, and background noises. Only sentences, paragraphs, passages, and stories relevant to the research question are included.

Other disadvantages are finding the right interviewees, scheduling the interviews, and a subjective and one-sided view. The participant selection in this research is limited to the network of the municipality of Amsterdam, which limits the variety of perspectives. This choice is made based on time constraints, since the internship facilitates establishing contacts with actors in the aforementioned network. The aim of this study is not breadth via a large sample, but rather to provide exploratory rich insights from a selected set of participants (Knott et al., 2022). Interviewees are sampled based on their expertise, with either the electricity system or the affected customers segments. The final sample is determined based on availability. To enhance availability and to ease scheduling, some interviews are held online. A list with of the interviewees and their expertise is provided in Table 3.1.

3.2.3. Geospatial data

Modeling for congestion management plays a crucial role in assisting system operators and energy policymakers when it comes to designing electricity systems (Hobbie et al., 2022). It is a method for

Expert	Function	Works on congestion	Expertise
1	Municipal official	Yes	Solving issues of demand congestion in Amsterdam, part of the task force
2	DSO area director	Yes	In contact with stakeholders in multi-actor network of electricity system in Amsterdam
3	Energy researcher	No	Energy systems researcher and senior consultant focussed on the energy transition and sustainability
4	Energy transition consultant	Yes	Assists parties struggling with congestion in Noord-Holland
5	Municipal official	No	Sustainability of the industry sector in Amsterdam
6	Municipal official	No	CO2 reduction, storage, and reuse of the industry sector in Amsterdam
7	Municipal official	No	Supports the business market with sustainability in Amsterdam
8	Municipal official	No	Supports the business market with sustainability in Amsterdam
9	Energy consultant	Yes	Consultant on energy- and utility services and urban planner in Amsterdam
10	Municipal official	No	Sustainability advisor for area development in Amsterdam
11	Municipal official	No	Area development (Sloterdijk 1 Zuid) in Amsterdam
12	Municipal official	Yes	Assists projects struggling with congestion in the public services segment

Table 3.1: Experimental interview set-up

drawing connections between factors using quantitative data. It does so by replicating the rules and relationships between different parts of a system, to describe the interactions (Herbst et al., 2012). It allows for processing big data sets at once, therefore it is possible to research a broad scope. Conclusions that can be drawn from this method are descriptive and explanatory, which is complementary to qualitative exploration (Epstein, 2008). A model is a simplified representation of reality that must be detailed enough to capture complex relationships, but simple enough to the point that there is nothing left to take out.

Precisely that simplicity is the biggest advantage of modeling, since it helps to understand a problem occurring in the complex world. As Box, 1976 said: *"all models are wrong, but some are useful"*. A model is as good as it's assumptions, thus heavily relies on the modelers' objectiveness and understanding of the system. The latter can be seen as a disadvantage, as modeling is often used for complex socio-technical systems. Another disadvantage of this method is that the quality of data input determines the quality of the information that can be drawn from it.

Geospatial data modeling is conducted using QGIS as geographical information system (GIS). It is a tool for combining spatial data, which allows for performing calculations and analyses. Results are visualized in geographical figures, which is a very useful format for decision making (Global Convenant of Mayors for Climate & Energy, 2021). Spatial analysis is often used in research related to renewable energy and sustainability in cities, because of its capability to combine different layers of geographical data (Choi et al., 2019). According to Hartvigsson et al., 2023, there have been recent advancements in electricity grid modelling using GIS tools for analyses, but they have been limited to technical factors. To bridge that gap, this research provides a holistic impact assessment using GIS.

The process of data collection and preparation is a crucial step for conducting spatial analysis. It is important to ensure that all input data is geospatial, which means that it should have a specific location on the Earth's surface. Having the most up-to-date data is desirable, as outdated data could result in inaccurate analysis. In addition, data sets should ideally be at the same aggregation level, for example, stored at the neighborhood level with consistent borders. Municipal borders often change, making it essential to ensure that all data is stored using the same boundaries to avoid inconsistencies. If data is not at the same aggregation level, data pre-processing is required, which could lead to loss of details or inaccuracies due to assumptions and generalizations. Similarly, if the boundaries of data sets differ, pre-processing is necessary to have consistent boundaries, which could also result in inaccuracies.

Peak-load impact data

The output data of the second "Themestudy Electricity Amsterdam" is used as input for the future peak-load impact expected in Amsterdam, since the results of the third update were not yet available at the time of this research. The theme study's output data is aggregated on a clustered district level as defined by Liander (Municipality of Amsterdam & Liander, 2021). Therefore, pre-processing is necessary to align this data set with the feeding areas' aggregation and borders, resulting in loss of accuracy and detail. The output dataset of the theme study contains the maximum and minimum peak-load measured in MW per region, per theme, and per year. The geographical scope taken by the theme study is the municipal border of Amsterdam, which in the time the study started excluded Weesp. The theme study was conducted before the start of the COVID-19 pandemic, therefore did not incorporate the effects of COVID-19 on electricity demand and supply. This means that trends of working from home or commuting after rush hour were not incorporate on demand profiles (Municipality of Amsterdam & Liander, 2021).

The data set includes only the demand and supply peak-load from within the Amsterdam area. However, there may be some minor impacts coming from outside of the municipal borders, which are also fed by the substations within Amsterdam. It should be noted that some substations could thus be congested earlier than modelled due to these external impacts. Whilst most LCs are connected through the feeding area, some require higher voltage levels and thus a connection directly to the substation. The data set used also excludes the impact from LCs directly connected to the substations under consideration. The peak-load impact of Amsterdam considered in this study is thus limited to that coming from the feeding areas of each substation. As a result, some areas may become congested earlier in reality than predicted by the analysis.

Segment establishment data

For sub question five, I utilize the BBGA dataset, an extensive public dataset provided by the municipality of Amsterdam. This dataset offers amongst others comprehensive information on the quantities of parties per SBI codes at various aggregation levels. Specifically, for this study, the dataset is employed to obtain the number of industry parties in sections B to E at the neighborhood aggregation level (Municipality of Amsterdam, n.d.-a). In this dataset, an establishment is a location of a business registered with the Chamber of Commerce where an economic activity is carried out by at least 1 employed person for a minimum of 12 hours per week. Values of 1, 2, 3, or 4 are rounded up to 5.

3.3. Data analysis

In this section I explain in detail which research steps are taken to answer each sub question in sequential order. In short, sub question one serves as a foundational exploration, initiating the research process by mapping the impacts on the electricity system. I utilize sub question 2 to gain an understanding of the affected segments and their responses to demand congestion. Sub question 3 is employed to explore the potential impacts of these responses and determine which impacts should be used as indicators in the assessment. The insights from these initial three questions are derived from data collected specific to the Amsterdam case-context, offering comprehensive and detailed insights into the phenomenon. However, they can be generalized to some extent to other densely populated urban areas with similar electricity system management. Sub questions 4 and 5 consolidate the gathered information to quantify the societal impacts of demand congestion, considering location, customer segment, and year specifically in Amsterdam.

3.3.1. Research steps for sub question one

"How does congestion impact the functioning of the electricity system?"

To research the impact of demand congestion on the functioning of the electricity system, I explore the phenomenon in Amsterdam on two aspects. First, I want to know what are the technical complications, namely how is the reliability of the system affected. And second, I want to know the operational complications, namely how the accessibility to the service is affected. To understand the operational consequences of demand congestion, it is necessary to explore how transport capacity is reserved and allocated. The data collection methods employed for answering sub question one are desk research, expert interviews and observations during the internship. Conducting exploratory qualitative research, I mainly structure, connect and themasize the multiple insights gathered. This way, it is possible to clearly put together the different data points and create a summarizing overview that answers the question.

3.3.2. Research steps for sub question two

"What are the consequences of demand congestion and how do these vary per affected customer segment?"

To research the consequences of demand congestion for large-scale customers, I research the following two scenarios: a denied request for a new contract request or an expansion of the current contract. For both scenarios, I explore what are the most common responses by large-scale customers in general when imposed with a transport restriction. The results are a set of responses. To explore the probabilities of those responses, I make a segmentation of the large-scale customers in a highly populated urban area. Then I use desk research and expert interviews to collect insights that could substantiate the segment-specific distribution of responses. This substantiation is based on the general characteristics and energy needs of the customer segments, researched within the context of Amsterdam.

Answering sub question two is mainly based on the qualitative findings of the expert interviews. The data collected from the interviews are structured and compared to explore the behavior of large-scale electricity customers to transport restrictions as described in sub question two. The transcribed data is used in conjunction with the the qualitative data gathered via desk study.

Segmentation

Segmentation is a useful method for conducting city-wide research on large-scale electricity customers, as it allows for a more comprehensive and nuanced understanding of their behavior. By grouping customers based on relevant characteristics, I can more easily identify patterns and differences in their responses. This is particularly important given the diversity of large-scale customers in highly populated and developed urban areas. Segmentation allows for generalizations to be made about the segment-specific response, and thus the segment-specific societal impacts following from those. Additionally, it is a time-efficient way of conducting research, as individual customers do not need to be studied separately.

There are several ways to segment large-scale electricity customers, one of which is to examine their electricity usage patterns or total electricity consumption. This would reveal distinct consumption behaviors and peak demands, which can be useful when developing policies specific per energy profile to address congestion. Customers can also be segmented by the size of their company, which gives an indication of the scale of their operations and activities. For this research, I make a segmentation based on the sector and business type using the Standaard Bedrijfsindeling (SBI) codes. SBI codes are a standardized classification system for economic activities used in the Netherlands. Examining different sector segments enables the identification of how exactly they are affected by transport restrictions, and how their behavior may vary. Such information is critical when developing targeted policies to mitigate the potential consequences of demand congestion that have significant societal impacts.

The first segment is Industry, which includes the SBI sections Mining (B), Industry (C), Energy supply (D), and Water supply and waste management (E). The second segment is Urban Development, which includes the SBI section Construction (F). The third segment is Commercial Business, which encompasses a wide range of SBI sections, including Trade (G), Transport and Storage including railway transport (H), Hospitality (I), Information and Communication (J), Financial services (K), Rental and trade of real estate (L), Specialized business services (M), Rental and other business services (N). The fourth and last segment is Public Services, which includes the SBI sections Public administration and government services (O), Education (P), Healthcare and welfare (Q), and Culture, sport and recreation (R). It's worth noting that these segments also include some small-scale customers, the results in this section do not apply to them. A description of the segments can be found in appendix B.

3.3.3. Research steps for sub question three

"What are the potential societal impacts of demand congestion in developed societies?"

To answer sub question three, I first explore the potential societal impacts of demand congestion in Amsterdam following the six ambitions set by the municipality of Amsterdam, which should guide their policy-making until 2050. For this I use desk research and expert interviews. Then, I structure the potential societal impacts found and complement them with an extensive literature study to provide a comprehensive overview for developed societies in general. To do so, I choose to follow the Sustainable Impact Assessment. Lastly, I select the most important indicators for the case-specific impact assessment, in consultation with the municipality.

Amsterdam Ambitions

To support the shift towards sustainability, policy makers at both local and national levels draft goals, policies, and plans. Executing these plans in a sustainable manner within spatial-economic limits can be challenging. The municipality of Amsterdam aims to make Amsterdam an inclusive, vital, compact, healthy, sustainable, and livable city (Municipality of Amsterdam, 2021). Qualitative assessment of these ambitions can be used to evaluate the societal impact of demand congestion in Amsterdam, providing guidance for urban planning.

1. an *inclusive* city: there should be an equal spatial distribution of development opportunities and the quality of live should be equally high in all neighborhoods
2. a *compact* city: the public space should be used as smart as possible, with a balance between aesthetics and function, resulting in an attractively appearing but efficiently functioning city
3. a *vital* city: a strong and thriving economic climate, enabled by a strong infrastructure that gives access to essential services. It should be an attractive city for companies and individuals to settle
4. a *healthy* city: a healthy city has a strong health sector, inhabitants that adopt a healthy lifestyle, good air quality and little noise nuisance
5. a *live-able* city: Amsterdam should be live-able for humans and animals, the living environment and the public space should be feel comfortable, there should be enough space for nature, with little nuisance from tourists or partying people
6. a *sustainable* city: the three main pillars of sustainability for Amsterdam are: climate adaptive, circularity and climate neutrality. The focus is not only on mitigation by shifting away from fossil fuels but also on adapting the city to the changing climate

Impact assessment method

The potential societal impacts are assessed following the sustainable development principle. Sustainable development has become a global priority, leading to a growing need for sustainability assessments. These assessments are designed to address and mitigate the pressing social, economic, and environmental impacts of the grand challenges we face today (Nautiyal & Goel, 2021). The Organisation for Economic Cooperation and Development (OECD) has drafted many frameworks for quantifying and comparing short- and long-term policy impacts. Amongst several methodologies and tools, the Sustainability Impact Assessment (SIA) is an approach to explore the combination of economic, environmental and social impacts of a range of projects, processes, plans, strategies and policies. This approach can be applied not only to study the societal consequences of policy initiatives, but also the repercussions of taking no policy action. The aim of a SIA is not to replace policy making, but rather to identify the direction and size of potential impacts in the different pillars to steer decision-making.

The *sustainability* term in SIA does not refer solely to the sustainable use of natural resources, but also to the vitality of society regarding social and economic resources. It refers to sustainability in time, as policies that seem optimal for the short-term may pose to be devastating in the long term, which is a risk that should be explored in the decision making process. Lastly, sustainability also refers to the spatial impact and the potential mismatch of objectives on a local, regional and national scale (OECD, 2010). The abbreviation of SIA should not be confused with the Social Impact Assessment, which is also used to evaluate the potential impact of a project or policy on society. Though both recognize the interconnection of economic, social, and biophysical impacts, the Social Impact Assessment put focus on the social effects on affected communities, whereas the main focus of the other SIA is on sustainability (Nautiyal & Goel, 2021).

In alignment with the principles of sustainable development, the SIA aims to balance economic, social, and environmental considerations to create a more comprehensive and integrated assessment of the impact. The multi-dimensional character of the framework allows for adopting a systems-level approach; This a way of thinking about and analyzing complex phenomena as a whole system made up of interconnected parts rather than isolated components. In my research, there are multiple interconnections between energy use, economic activities, and social outcomes in the city of Amsterdam. This approach allows for a more holistic understanding of the multidisciplinary problem and how changes in one part of the system can affect other parts. The systemic use of indicators are to ensure results are measurable and easily comprehensible.

The SIA approach as described by the OECD is a non-exhaustive guideline that needs tailoring by the level of government authority. As there is no one-size fits-all framework for conducting a SIA, it needs to be adapted to the context of the research. The level of detail may vary per ambition level, resource availability and researcher capabilities, such as knowledge of tools, methods and models but also the project planning. Some tools proposed by the OECD are Multi-Criteria Analysis (MCA), Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA) and modelling. To be effective, a sustainable assessment method should include an assessment scope and objectives, suitable sustainability indicators, assessment techniques, and a process for interpreting and applying the assessment result (Nautiyal & Goel, 2021). The composition of SIA criteria varies by the needs and purpose of the research, the scope, the time, the investment, etc. To keep the analysis manageable, it would be efficient to identify the most significant impacts. The selection of evaluation criteria is project-specific and cannot be easily generalized (Kralisch et al., 2016).

The SIA approach tries to go beyond only hard numerical analysis, by capturing less easily monetised aspects of sustainability (OECD, 2010). It is therefore particularly useful when the impacts cannot easily be measured in monetary terms. It aims to balance qualitative and quantitative information, in line with the mixed-methods approach of this research, to achieve a reliable assessment (Nautiyal & Goel, 2021). It consists of eight steps: (1) Screening the proposal, (2) Scoping the assessment, (3) Selecting tools and methodologies to match the scoping, (4) Ensuring stakeholder participation, (5) Analysing the environmental, social and economical impacts, (6) Identifying synergies, conflicts and trade-offs across these impacts, (7) Proposing mitigating measures and (8) Presenting the results to policy makers (OECD, 2010). In this report, step 1 is reported in chapter 1, step 2 in chapter 2.3, step 3 in 3, step 5 in chapter 4.3 & 4.5, and steps 6, 7 and 8 are reported on in chapter 5.

Indicator selection

Using indicators to evaluate complex information is a useful approach to organize and present the data in a way that is more accessible and relevant to policy making (Palit & Bandyopadhyay, 2016). Indicators serve as message carriers and facilitators for stakeholders to understand and grasp the results and messages of an evaluation (Ilskog, 2008). Whereas criteria are generally more generic and used for ex ante assessment processes, indicators are more specific and used for ex post assessments (OECD, 2010). Research shows that the choice for data parametrization and formulation has great influence on model results regarding the size of congestion and the spatial distribution of the respective policy measures (Hobbie et al., 2022). Though the complexities in the energy system cannot be captured using single numerical values, metrics can still add a lot of value by providing simplified insights. Well defined indicators can point decision makers to the right direction, and spark further in-depth analysis. An indicator-based approach enables comparison of various dimensions for different alternatives (Palit & Bandyopadhyay, 2016). Which dimensions and thus criteria should be used depends on the research context, goals and questions.

I select the "major" indicators for energy decision-making by the principles of Wang et al., 2009 - systemic, consistency, independency, mensurability and comparability -, as well those those prescribed by Ilskog, 2008:

1. *Simple to understand and apply* - users of the assessment should feel comfortable and confident with the chosen indicators
2. *Transparent and inter subjective* - the input data and the definition of the indicators should be easily available and traceable
3. *Robust* - a clear formulation should ensure reproduce-ability
4. *Comprehensive* - the set of indicators should cover most of the major impacts and aspects of sustainable development
5. *Fair* - the indicator should guarantee equality as to impacted groups as well as the fair comparison of alternatives

3.3.4. Research steps for sub question four

"Which areas in Amsterdam are predicted to experience congestion until 2030?"

To address sub question four, the following two pieces of quantitative data are required: 1) the future configuration of feeding areas and the capacity of associated substations in Amsterdam on an annual basis, and 2) the spatial distribution of expected peak-load impact in Amsterdam per year. To obtain the first set of information, a comprehensive list of currently installed substations, along with their locations and installed transport capacity, is necessary. Additionally, future infrastructure plans for Amsterdam, including both expansion of existing substations and the construction of new ones, need to be gathered. These datasets are gathered from the municipality in accordance with Liander as part of the graduation the internship.

Utilizing the current and projected medium-voltage substation infrastructure, feeding areas are created in QGIS through geospatial analysis, employing the Voronoi technique. This allows for the delineation of feeding areas based on proximity to substations. The data set I use for the second point is the Amsterdam Ambition output set of the theme study (Municipality of Amsterdam & Liander, 2021). To make a prediction on whether assets in the network will be able to handle peak-load demand growth, I conduct a geospatial analysis in QGIS, comparing the yearly installed capacities of the feeding areas with the spatial distribution of the minimum and maximum peak load per year.

Scope of analysis

I am only researching the medium-voltage distribution grid of the urban electricity system, more specifically focused on the substations owned by Liander. These are substations transforming levels of 150 or 50 kV to consumption levels, and feed the areas of Amsterdam as shown in Figure 2.3. I am only taking into account those substations with a feeding area within the municipal grounds of Amsterdam. That means I use all substations within the municipal borders, as well as Venserweg and Bijlmer Noord whom are constructed not too far from municipal borders.

Capacity of substations

A substation distributes the incoming electricity on different voltage levels depending on the use-case: it can either feed power to (1) large consumers directly connected to the substation, or (2) the medium-voltage distribution network (transformer houses and cables) to provide electricity to their feeding area, or (3) another substations nearby (Liander, 2023). A 'feeding area' refers to the specific region that a substation caters with electricity services. It is worth noting that some substations may feed areas outside of the city, or some feeding areas in the city may be fed by substations located outside of the city, depending on the specific configuration of network topology. While other parts of town may have sufficient capacity for electricity demand, it's not always possible to transfer electricity from one feeding area to another.

Because of these complex interdependencies, one cannot simply add up the capacities of all substations in the network. Liander uses the total capacity of all 150kV transformers installed in the medium-voltage substations as the truthful total capacity in the system. But, since I am interested in the feeding areas, I cannot use that same line of reasoning; As some of those transformers also feed other substations, I would be double counting capacity. Therefore, for those substations feeding other substations, I use the lowest voltage transformation capacity. These transformers feed only the feeding area through the remaining medium- and low-voltage network assets. By doing so, I miss demand impact from LCs directly connected to the larger transformers. After a discussion with the Liander network architect of the Amsterdam region, this deemed to be the most accurate and convenient approach for this research.

Due to a lack of information on the future topology, I make the assumption that all new substations to be built fully dedicate their installed transport capacity to their feeding area, thus will not feed any other substations nearby. I leave out such interdependencies because this is simply too complex to forecast, since data is not sufficiently available to make a substantiated approximation.

Electricity has to flow through assets on all levels of the electricity grid to get from production to consumption. It is therefore very probable that a congested asset upstream on the high-voltage network would affect the electricity availability of assets downstream the medium-voltage network. Though a substation itself could have sufficient transport capacity left, upstream assets feeding that station could create a bottleneck in the electricity transport process. These complex multi-level interdependencies have a huge influence on electricity availability. For example, if Liander builds three new substations to feed the city, TenneT first has to have stations close by with sufficient capacity to feed those. Additionally, the cables that transport the electricity have to be place. For simplicity, I assume that all transport capacity of the current and future substations in the medium-voltage network can be maximally utilized, thus I do not take into account any bottlenecks upstream.

Feeding areas

To conduct my research, it is crucial to have accurate information about the feeding areas of substations and how they change over time due to newly constructed substations. However, the data available from Liander and the municipality only covers the current network structure (2022) and the to-be network structure (2035). As a result, an approximation of the feeding areas needs to be created. In this study, I will use the Voronoi diagram technique, which is a geometric structure that partitions a given space into a set of regions based on the distance to a specified set of objects, in my case, the substations.

The regions are defined in such a way that each point in a given region is closer to its corresponding substation than to any other substation in the set. The distance between consumer and substation is very important: the length of the path electricity has to travel has to be a short as possible to minimize energy losses. However, it's important to note that this technique doesn't take into account the capacity of a substation, which Liander carefully considers when defining the feeding area of a substation. This involves assessing factors such as the number of small- and large-scale connections in the area, the number of connection points for directly connected LCs to the substation, and whether the substation will feed other stations. Due to the unavailability of this privacy-sensitive information, a Voronoi diagram is deemed an appropriate general approximation.

The quality of the Voronoi diagrams is checked using the intersection analysis. This algorithm extracts the overlapping portions of features in the input and all overlay layers. Features in the output layer are assigned the attributes of the overlapping features from both the input and overlay layers. The map with the current feeding areas as depicted in Figure 2.3 will be used as input layer, which is overlayed by the voronoi diagram. The intersection method returns the orignial feeding areas cut up by the shape of the Voronoi diagram. The largest cut up peace of the input feeding area should fall into the feeding area created by the voronoi diagram. To do this check, a column should be added with the total area of the original feeding area and its cut up polygons.

Minimum and maximum peak-load impact per year

The following steps are undertaken for each year between 2022 and 2030 to assess the minimum and maximum peak-load impact of the Voronoi created feeding areas in Amsterdam. First, the Voronoi created feeding areas are clipped to the Amsterdam boundaries and a column is added to measure the feeding area in square meters. Next, the intersection tool is used to create intersections between the created feeding areas and the input data for the minimum and maximum peak-load impact from the Amsterdam Ambition scenario. The input layer is the scenario data, while the overlay layer is the feeding area layer. For the intersection, only the substation name, the distribution capacity of the feeding area, the district ID, the minimum and maximum peak load, and the surface area in square meters of every district are retained.

Subsequently, a new column is created in the intersection layer to measure the surface area in square meters for each section (the split up district areas from the intersection with the feeding areas). Using this column, weights are calculated for the impact per section by dividing the section area by district area. The peak-load impact per section is then determined by multiplying the weight times the minimum and maximum peak load. Next, the minimum and maximum peak load of all sections that make up a feeding area are added up using the field calculator on the intersection layer. A new field is created using the following code to calculate the total minimum and maximum peak-load impact per feeding area: aggregate(layer:='intersectionlayername', aggregate:='sum', expression:="maxpeakloadpersection", filter:=("substation"=attribute(@parent, 'substation'))).

Finally, the intersection layer is joined to the feeding area layer using the substation name to only take along the minimum and maximum sums. The resulting layer contains the polygon of the feeding area, the distribution capacity, and the minimum and maximum peak-load impact of that area.

Congestion prediction analysis

The maximum peak-load can be used to research demand congestion, the minimum for supply congestion. In QGIS, I create a new field called "Congested" using the field calculator. The expression to use is: if(abs("Max_sum") > "capacity", 'YES', 'NO'). This adds a new column that indicates whether a feeding area is congested based on whether the absolute value of the maximum of minimum peak load column is larger than the "capacity" column.

3.3.5. Research steps for sub question five

"What are the societal impacts of demand congestion by location, customer segment, and year in Amsterdam?"

To explore the societal impacts of demand congestion spatially and over time, I have developed an integrated assessment framework, shown in Figure 3.2. This framework serves as a flexible tool that can be adapted and used to measure the societal impacts of demand congestion in different case contexts. The integrated assessment framework provides a systematic and rigorous approach to examining the societal impacts of demand congestion, enabling insights into the severity of the issue and supporting decision-making processes for mitigating its effects.

First, one should predict the regions that will experience demand congestion over time through geospatial data modeling techniques. This corresponds to the analysis conducted for sub question 4. The second step of the framework involves determining the number of affected customers over time. Building upon the findings from sub question 1, I quantify the magnitude and spatial distribution of affected customers over time in sub question 5. Moving on to the third step of the framework, I map the responses of affected customers to demand congestion. This step is covered in sub question 2, where I examine the various responses available to the affected segments. Finally, the fourth step of the framework is conducted under sub question 3 and concluded in sub question 5. I evaluate the overall societal impacts of demand congestion, taking into account the predicted affected regions, number of affected customers, the responses implemented and the societal impacts of those responses.

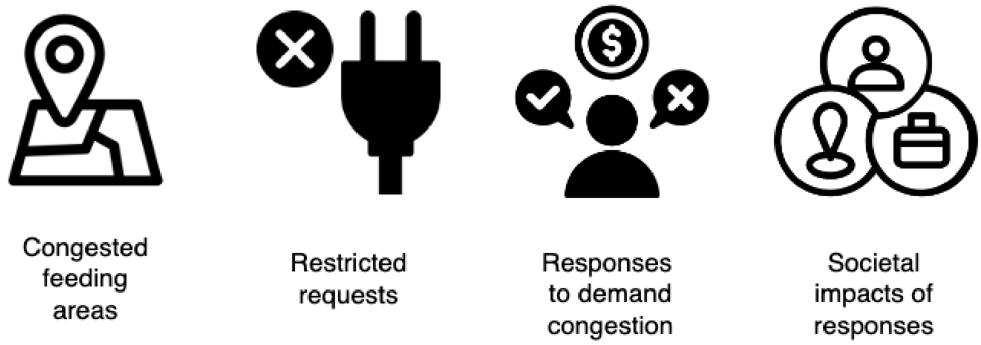


Figure 3.2: A holistic assessment framework for the societal impacts of demand congestion

Addressing sub question 5 is thus additionally done in a two-fold. First, I qualitatively explore how the responses per segment will have an impact on the three selected indicators of the Amsterdam case study. I do so based on the expert interviews. The second part involves a quantification of these qualitative findings, specifically for one segment only. I propose formula's and parameters that could measure the societal impacts of demand congestion over time and spatially. Lastly, I use these quantified segment-specific impacts of their responses to assess the total societal impacts of demand congestion in Amsterdam over time from this segment. This last steps brings together all steps of the framework, building on all findings of the previous sub questions.

The number of affected customers per segment over time

To determine the total expected number of industry parties in Amsterdam per year until 2030, an extrapolation approach is employed based on historical data from the BBGA to make predictions about future trends. To keep it simple, I do not dive into the expected trends of the overall economy in Amsterdam, nor external factors that might influence the frequency of industry parties, such as changes in regulations or economic conditions. As such, this growth number does not include the potential impact of demand congestion on the attractiveness of Amsterdam to settle. To provide an understanding of industry party growth at the neighborhood level, the extrapolation is performed using Microsoft Excel. The "FORECAST" function in Excel is utilized to project future values by fitting a linear trend line using the least squares method. Negative values resulting from the extrapolation are adjusted to zero, as they are considered not applicable for the analysis.

Since the defined customer segments are not 100% large-scale electricity customers, the historical data must be pre-processed with a number that represent the share of LC customers per segment. Then, by analyzing the historical establishment data, it is possible to estimate the number of new LC contracts requested per segment per year. The identified congested feeding areas per year should be used to determine the number of affected customers per segment over time. It should be noted that for this analysis, the assumption is made that there is no accumulation of denied LC contracts.

Subsequently, the Excel file containing columns for each year from 2022 to 2030 for sections B to E, representing the corresponding number of establishments per neighborhood (approximately 500 neighborhoods), is loaded into QGIS. The neighborhood polygons, excluding water areas, are obtained from Municipality of Amsterdam, 2022a. Notably, the "Weesp" neighborhood is excluded from the analysis. To combine the two datasets, the "Join Attributes by Field Value" tool in the vector processing toolkit is employed, allowing for a spatial join of the neighborhood polygons and the Excel table.

In QGIS, the establishment counts of sections B, C, D, and E for all years between 2022 and 2030 are summed for each neighborhood using the Field Calculator. To ensure whole numbers, the summed values are rounded, and null values are replaced with 0. The expression used is: coalesce(round("2022e" + "2022c" + "2022d" + "2022b", 0), 0). The difference between consecutive years is then calculated using the Field Calculator to determine the new contract request made every year. Negative differences are set to zero, reflecting scenarios where no new requests are observed. The expression used for the difference calculation is: CASE WHEN ("Industry_2027" - "Industry_2026") >

0 THEN ("Industry_2027" - "Industry_2026") ELSE 0 END.

To determine the number of requests made, data should be available about the expected quantity and distribution over time and space. Unfortunately, I do not have access to contract request data from Liander, so I have no information on how regularly industry parties request expansions, the reasons behind their requests, or the size of the expansions. Therefore, I make the following assumptions: 1) all industry parties will actively engage in the energy transition and plan to invest in sustainability within the time frame of 2023 to 2030, and thus request an expansion. 2) Expansion requests are distributed evenly across the 8-year period, as no alternative distribution method can be better substantiated at this stage.

Furthermore, I assume that there will be an accumulation of expansion plans that are put on hold during periods of congestion but will be executed once the area returns to a green status. This assumption recognizes that parties may delay their expansion plans temporarily due to congestion, intending to proceed once the conditions improve. Furthermore, an additional assumption for this thesis is that new settlements will prioritize sustainability right from the start and will not require a business expansion. As a result, it is reasonable to exclude expansion requests from newly established parties during the analysis. Likewise, it is reasonable to assume a party will only request an expansion once between 2023 and 2030.

To simulate the distribution of expansion requests over the years 2023-2030, I utilize Microsoft Excel as well. The formula used is "=ALS($C2=0; 0; AFRONDEN($C2/8; 0))", where $C2 represents the total number of industry parties settled in 2022 in a particular neighborhood. This formula divides the total number of parties by eight, representing the 8-year period from 2023 to 2030. The result is rounded to the nearest whole number. The assumption behind this approach is that the expansion requests will be evenly distributed over the 8-year period. To ensure that the sum of expansion requests in each neighborhood does not exceed the total number of parties in the neighborhood, I insert a condition that counts the cumulative sum of expansion requests. If at any point the cumulative sum equals or exceeds the total number of parties of 2022, no more expansion requests are made until after the year 2030.

To determine requests face transport restrictions in the neighborhoods, the layers with the new and expansion contract request per year per neighborhood is joined with the layers created for sub-question two. These layers consist of polygons representing feeding areas experiencing demand congestion for each year. The vector processing tool "Join attributes by location" is utilized to perform the join operation based on the spatial relationship using the intersection method. The attribute value indicating where a neighborhood experiences demand congestion is selected based on the largest overlap between the polygons. For example, if 70% or more of a neighborhood falls within a congested feeding area, it is labeled as congested. Conversely, if e.g. less than 10% falls within a congested feeding area, it is labeled as not congested. To determine the total number of new and expansion contract requests denied per neighborhood between the years 2023 to 2030, I aggregate the requests made specifically during the years when each neighborhood experiences demand congestion. I also calculate for every neighborhood for every year the number of expansions on the waiting list. I did so by adding up the values of the previous year if the current year is congested.

The segment specific societal impacts of a response to demand congestion

The segment specific societal impacts of a response to demand congestion is influenced by multiple segment-specific characteristics, such as the total energy consumption of the party, the energy source mix used to meet their energy demand, the average size of the party's workforce, the type of alternatives that would be employed in response to congestion, as well as the scope and scale of their sustainability plans and business growth plans. These factors collectively contribute to the complexity of understanding and quantifying the specific impacts of each segment.

To facilitate the analysis, general assumptions can be made for all segments. For instance, it could be assumed that the expansion for sustainability always doubles the current electricity demand [expert 12], while the expansion for business operations always constitutes half of the current electricity demand. Additionally, it is reasonable to assume that 25% of the expansion requests are for business operation growth and 75% are for sustainability, considering the focus on energy transition. It is important to acknowledge that these high-level assumptions may introduce some inaccuracies into the results. To enhance the precision of the analysis, segment-specific assumptions are preferable. Validating these assumptions through surveys and interviews with segment parties would provide a more accurate understanding of the impacts and specific dynamics within each segment.

I then calculate the societal impacts using the formulas and parameters of Table D.3 in Field calculator, for every year for every neighborhood.

How to measure CO_2 emissions

To assess the CO_2 emissions accurately, two approaches can be used: the consumption approach and the source approach. The consumption approach attributes CO_2 emissions to the location where electricity and heat are consumed, while the source approach assigns CO_2 emissions to the area where the electricity and heat are produced. The source approach provides a more comprehensive assessment of CO_2 emissions, reflecting the actual net emitted CO_2 in the local air of the geographical scope. By adopting the source approach, the emphasis is placed on the remained reliance on fossil fuels.

Furthermore, using the source approach allows local policy makers to focus on the local emissions of CO_2, providing valuable insights for health and environmental considerations. It is worth noting that the emission factor for electricity is expected to decrease with the integration of renewable energy sources, reaching 0.21 kg/kWh in 2025 and 0.09 kg/kWh in 2030 (Goverment of the Netherlands, 2023). Therefore, considering the research goals and the resources of the project, in this study I choose to adopt the source approach in measuring CO_2 emissions of electricity, and the consumption approach for measuring those of fossil fuel sources.

4
Results

This chapter presents the results obtained from data collection and analysis as described in Chapter 3, addressing the sub-questions outlined in Chapter 1. The findings contribute to a comprehensive understanding of the phenomenon demand congestion, and more specifically in the case-context of Amsterdam. The chapters follow a structured approach, presenting the results corresponding to each sub-question, thereby facilitating a clear interpretation of the research outcomes. The analysis and interpretation of the results shed light on the impacts of demand congestion and lay the groundwork for the formulation of recommendations and strategies for effective congestion management. A summary of the results is provided in Section 4.6.

4.1. Effects on the functioning of the electricity system

To determine the societal impacts of demand congestion, the first step is to describe the effects of the phenomenon on the functioning of the electricity system. I do so by researching the technical and operational implications of congestion. I first explain how transport capacity is reserved and allocated. Then, I identify the operational implication of congestion which is known as ”transport scarcity”. The findings are case-specific, describing the organizational processes unique to Liander. This section aims to answer the first sub-question:

”How does congestion impact the functioning of the electricity system?”

4.1.1. Transport capacity: reservation, allocation and scarcity

A distribution system operator categorizes users into two profiles: small-scale customers (SC) for those with a grid connection of 3*80A or less, and large-scale customers (LC) for those needing a grid connection of more than 3*80A. The electricity capacity that a customer can withdraw from or feed-back to the grid depends on the type of connection they have: e.g. 5,7kW with 1*25A, 17kW with 3*25A or 55kW with 3*80A. The small-scale customers are entitled to withdraw and feed-in as much electricity from and to the grid as their connection allows (Liander, 2021b). Whereas SCs have a contract directly with the energy supplier, LCs need a contract with the DSO. This contract includes the Contracted Transport Power, which refers to the transport capacity they are entitled to use, to either consume or produce electricity. See Appendix A.4 for an extensive overview of the practicalities of electricity distribution in the Netherlands.

Liander reserves a share of the installed transport capacity of their medium-voltage substations for SC contracts. They do so to ensure electricity supply for all households, now and in the future. This reservation is done based on internal models, and urban development plans for housing provided by the municipality [expert 1, appendix C.1]. These internal models take into account natural growth , as well as technological developments such as the electrification of heating and mobility, and the adoption of decentralized renewable energy production [expert 2, appendix C.2]. A reservation works as follows: if the construction of a new building block is finished in 2028, Liander will reserve that capacity from now until 2028. This capacity cannot be utilised in the mean time by other customers [expert 1]. Every

DSO manages their system differently, thus it is possible that other DSOs apply a different reservation method.

A DSO is obligated to comply with their agreements and ensure that customers can always use the transport capacity they are entitled to by contract [expert 2]. Thus, whether a LC contract request can be granted, depends on the left-over transport capacity in the distribution system. The allocation is regulated by a ”first come, first serve” principle, which is a non-discriminatory approach that does not consider the amount of capacity needed nor the date of operation [expert 1 & 2]. Essentially, if a data center that will not be operational until 2025 submits an electricity request earlier than a school that should be operational in 2023, the data center will be allocated their requested capacity first. If there is any remaining capacity, the next in line will be granted it, and so on. It is important to note that filing for an electricity connection and contract well in advance of the operation date incurs expenses. While this principle generally works well when there is sufficient capacity to accommodate all requests, it can result in undesirable outcomes when there is scarce transport capacity (ACM, 2023). As described in section 2.3, the ACM is planning on facilitating a priority principle for projects important to society.

Liander uses a network analysis to determine whether the assets in their medium voltage distribution network are approaching their limits. This analysis considers several factors, including the number of existing customers with small-scale and large-scale connections in the area, the contracted capacity of these customers, the actual current load and voltage management of the network, and the expected growth of impact on the network from the existing customers (Liander, 2021b). To assess the peak-load impact on the system, they take into account the load-profiles of their customers, which show that not all consumers use the maximum transport capacity allocated to them at the same time.

To determine whether LC requests can be complied to, Liander considers the current impact on the network calculated in the network analysis, the SC reservations, and the outstanding LC transport capacities that were given out but not yet employed. Whether a specific LC contract request can be granted depends on the requested capacity and the customer’s load profile. Load-profiles can cancel each other out, as production and consumption on the same network level can compensate for each other (Liander, 2021b). As a result, the combined contracted transport capacities of all LC contracts is usually much higher than the actual capacity of the grid could handle. While this could cause the system to fail if all consumers were to utilize their contracted capacity simultaneously, such a scenario is highly unlikely in reality.

When the network analysis shows that a medium-voltage substation is nearing its maximum capacity and thus is very prone to thermal overloading, Liander declares it as ”congested” [expert 1]. The feeding area of that substation is now subject to the rules of *transport scarcity*, as defined by the DSO. For Liander this means that they stop complying to any further LC requests: a new LC contract request, a LC contract expansion and an expansion from a SC to LC contract [expert 4 & 8, appendix C.4 & C.6]. Since a DSO is legally obliged to provide a physical connection to the grid, the customer is provided a connection but is imposed with a transport restriction: they cannot use their connection [expert 4]. Transport scarcity is either applicable to the withdrawal of electricity from the grid, referred to as demand congestion, or to feeding electricity flows into the grid, referred to as supply congestion (Liander, 2023). Rural sparsely populated areas often experience congestion caused by supply, as they cater sufficient space for renewable energy projects but the electricity grid is not dense enough to transport the production. Urban densely populated areas are more prone to experience congestion caused by explosive electricity consumption.

4.1.2. Technical implications: reliability

Liander wants and has to maintain high reliability rates, thus prevent the actual occurrence of thermal overloading on the grid as much as possible. Since transport scarcity is a preventive measure for the actual occurrence of thermal overloading, the phenomenon of congestion as researched in the context of the city Amsterdam has no influence on the reliability of the system. Physical congestion in Amsterdam is very rare due to transport restrictions [expert 1 & 2]. It should be noted that congestion, network constraints and transport scarcity are used interchangeably and refer to the electricity transport system being at its maximum capacity. If congestion is not prevented, the structural occurrence of thermal overloading could reduce the level of reliability of an electricity system [expert 1 & 2].

4.1.3. Operational implications: accessibility

In Amsterdam, demand congestion is declared for nine out of twenty-two substations in the medium-voltage network as per the end of 2022: their feeding areas cover the whole north and west regions of the city, a little more than half (56%) of the total (the red areas in Figure 4.1). As the figure shows, the limited capacity of the electricity grid in Amsterdam currently only affects electricity consumption. This means that the electricity grid cannot cater for the explosive demand growth, but there is still enough capacity in the assets for additional electricity to be fed back into the grid [expert 2]. Liander does not disclose information about the current status of the waiting list in these congested areas due to privacy concerns.

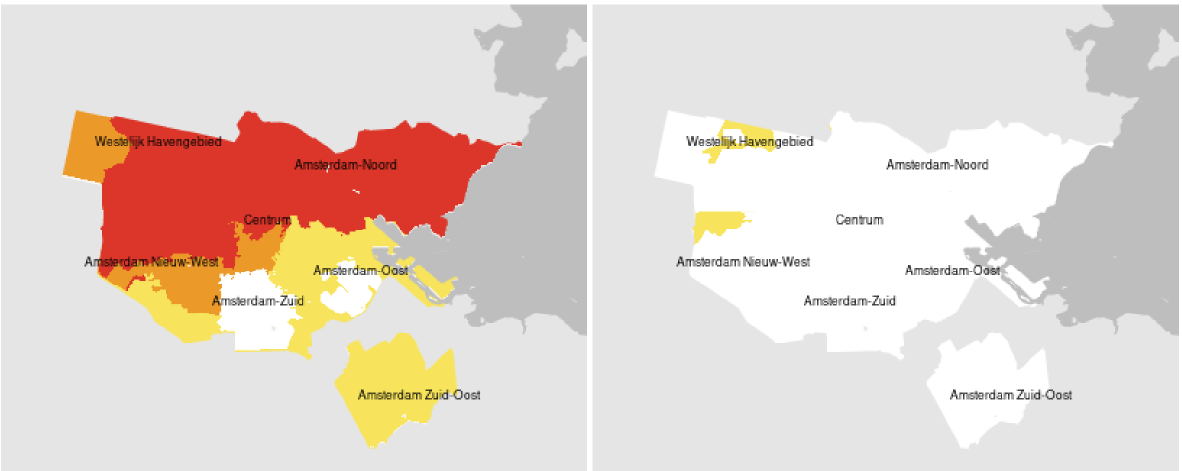


Figure 4.1: Demand- (left) and supply (right) congested areas in Amsterdam per end of 2022 - Yellow: limited capacity, orange: under investigation, red: transport scarcity, maps from (Liander, 2022b).

Large-scale customers established in a ”congested” feeding area are heavily impacted by the phenomenon demand congestion. Those who already hold a contract, signed before the declaration of congestion, are entitled to fully use their contracted transport capacity under any circumstance. However, all new LC contracts requests that are filed after the system's capacity runs out, are subject to the rules of transport scarcity and will be put on a waiting list. When additional capacity is freed up in the region, or expansions of the infrastructure are realized, that new transport capacity will be allocated following the first-come, first-serve principle. This means that electricity accessibility is no longer universal:

- it depends on what region a customer is in,
- when they make the request,
- and what type of connection they require.

Currently, small-scale customers are not directly impacted by demand congestion, as they do not face any transport restrictions and continue to have full access to electricity. Nevertheless, it is unclear whether the small consumption reservations will be a 100% sufficient in future critical situations. Meanwhile, for further analysis in this research, I am assuming that the SC reservations are sufficient.

Though SC reservations of electricity capacity are made on substation level, assets downstream on the low-voltage network may pose to be a bottleneck to SCs in the future. The electricity infrastructure in the urban area is a complex network topology with many inter dependencies. The infrastructure can be congested on every voltage level; When every household in the street connects an electric heat-pump, solar panels and an electrical vehicle (EV) charging station at the same time, it is very probable that the low voltage cables cannot handle this explosive growth [expert 2]. Nevertheless, constructing the low voltage infrastructure and connections to the grid is a relatively quick process compared to the medium and high voltage grid. Currently, Amsterdam is not yet coping with congestion on the low-voltage network.

Lastly, LCs are restricted in how much electricity they can use by the connection they have. Every SC is allowed to request a larger SC connection, e.g. from 1*25A to 3*25A, but the DSO needs technical staff and materials to comply to that request. Because technical staff currently is very scarce, customers sometimes have to wait several months before they can use a larger amount of electricity. This is not a direct influence of the phenomenon congestion, but it is related to the overarching urban challenge of expanding the electricity infrastructure.

4.2. The consequences of demand congestion for affected customers

To determine the societal impacts of demand congestion, the second step is to explore which large-scale customers are subject to transport restrictions and what are their responses to the phenomenon. I do so by exploring what are the most probable consequences of demand congestion in general. Then, I research the segment-specific responses in the following four segments: Industry, Commercial Business, Urban Development and Public Services. The results show which segments are severely confronted with the consequence structural electricity shortage. This section aims to answer the second sub-question:

"What are the consequences of demand congestion and how do these vary per affected customer segment?"

4.2.1. Responses to a transport restriction

A new LC contract is required when a large-scale customer establishes its operation in a new location. This customer may have relocated its operations from within the city or from outside the city, or it could be a new establishment. If the customer is relocating within the same feeding area, it is possible to transfer the contracted transport capacity to the new location [expert 4 & 11, appendix C.7]. Otherwise, a new contract must be applied for, and if there is no physical large-scale connection already in place, it would have to be constructed. If a large-scale customer moves to a location that already has a physical large-scale connection, it cannot inherit the transport capacity of the previous owner of that contract [expert 4]. If an application for a new large-scale contract is denied, the customer has three main options [expert 4, 5, 6, 7, 9, 12]: 1) apply for a small-scale connection, possibly in combination with alternative solutions for electricity production, 2) establish their operations elsewhere in a non-congested area of the city or 3) not operate in the city at all (see Table 4.1).

An application for an expansion, either an LC expansion or an SC to LC expansion, serves several purposes. A common reason to increase electricity consumption is due to a planned growth of business operations [expert 4, 5, 6, 7, 12]. This may include increasing the physical establishment space, the addition of new equipment or appliances, or an increase in the number of employees or occupants. For example, a manufacturing company may purchase new equipment, or a business sees an increase in demand for their products or services, requiring additional resources to meet this demand. Or a company may expand their office space, which could require an expansion of their existing electricity contract to ensure adequate supply for the new space.

The most frequent reason for the expansion of an electricity contract is for matters of sustainability [expert 4, 5, 6, 7, 12]. The increasing global concern over climate change and the subsequent drive towards sustainable energy production and consumption has resulted in many businesses adopting more environmentally friendly practices. One of these practices is the electrification of existing systems, replacing fossil-fuel powered equipment with electrically powered alternatives. This may include the replacement of gas-fired heating systems with electric heat pumps or the transition to electric vehicles for transportation. Additionally, businesses may opt to install their own on-site renewable energy systems, such as solar panels or wind turbines, to generate their own electricity. The latter is not a problem under the circumstances of demand congestion.

When a customer's request for an expansion of their electricity contract is denied, they may explore alternative solutions to meet their energy needs, such as self-generation and batteries, or finding ways to use their current contract more efficiently [expert 4]. Self-generation can either be done sustainably, or with fossil fueled generators, but the latter ”is really a last resort” [expert 4]. However, if these options do not prove feasible, the customer will be unable to achieve their sustainability goals or expand their operations. I assume that traditional energy sources cannot be used to fill additional electricity needs. While gas may be a suitable replacement for some energy needs, it cannot be used to replace electricity in all cases, such as when powering electronic devices like refrigerators. Additionally, it is reasonable to assume that most businesses will want to pursue sustainable development goals, rather than relying on fossil fuels. Investing in unsustainable solutions is a poor business decision in the long run.

Table 4.1 gives an overview of the general responses by large-scale customer to demand congestion. A LC could reach out to the DSO, the local government or a ”fixer” such as expert 4 to seek help in finding congestion relief. Finding a solution for demand congestion is challenging, as everyone is still pioneering: ”Entrepreneurs don’t know what to expect, market players are still figuring out what works best, and the grid operator doesn’t have a fixed process for alternative solutions yet” [expert 4]. People are inclined to opt for sustainable solutions, but a viable business case is often the decisive factor [expert 4]. In general, if they do not find an alternative solution for meeting their electricity demand, they will suffer from structural electricity shortage (category C).

	Respone A	**Response B**	**Responce C**
1. New contract	SC and/or alternatives	Establish elsewhere in the city	Do not operate in the city
2. Expansion	Alternatives	Improve efficiency	Do not expand

Table 4.1: General responses to demand congestion by large-scale customers

What response is ”chosen”, as this is not always voluntarily, depends on the type of LC customer. What response can be expected from a specific LC facing a transport restriction, strongly differs per specific situation. Every customer has different needs, resources and interests, which results in very different responses to demand congestion. ”I’ve encountered several cases where the financial resources that people have for alternative solutions, don’t match the need to solve the problem” [expert 4].

4.2.2. Industry responses

The industry segment in Amsterdam is very diverse and includes sectors such as petrochemicals, food processing, metalworking, and logistics. They range from making chocolate, to storing kerosene or supporting circularity [expert 5 & 6, appendix C.5]. The industrial sector’s operations have significant environmental impacts, such as air and water pollution, as well as greenhouse gas emissions. The industry segment is responsible for 22% of the total CO_2 emitted in Amsterdam (4% from electricity) (the Municipality of Amsterdam, 2020). Hence, the choice of locations for these businesses is constrained by regulations designed to uphold a high quality of living in densely populated areas of the city.

The Port of Amsterdam meets those requirements, and in combination with the convenient options for transportation and shipment, this area is the main hub for industrial activities in the city of Amsterdam. In Figure 4.2, the pink areas depict the appointed ’heavy’ industry areas, with the Port of Amsterdam in the top left and the Schiphol Airport areas in the bottom left. In general, the industries have a ground lease contract allowing them to operate for several decades (± 40 years). Some companies have even been operational for over a 100 years [expert 6]. Therefore, it is not probable that a new LC customer would establish elsewhere (response 1B).

The energy consumption and needs of an industry business depends on the specific activities that are undertaken. Generally, these businesses require a significant amount of energy for their operations. This includes electricity for lighting and powering equipment, as well as fuels such as natural gas or oil for heating, cooling, and production processes. A reliable and stable electricity supply is crucial for their operation, as power outages or fluctuations can cause significant disruptions to production and may

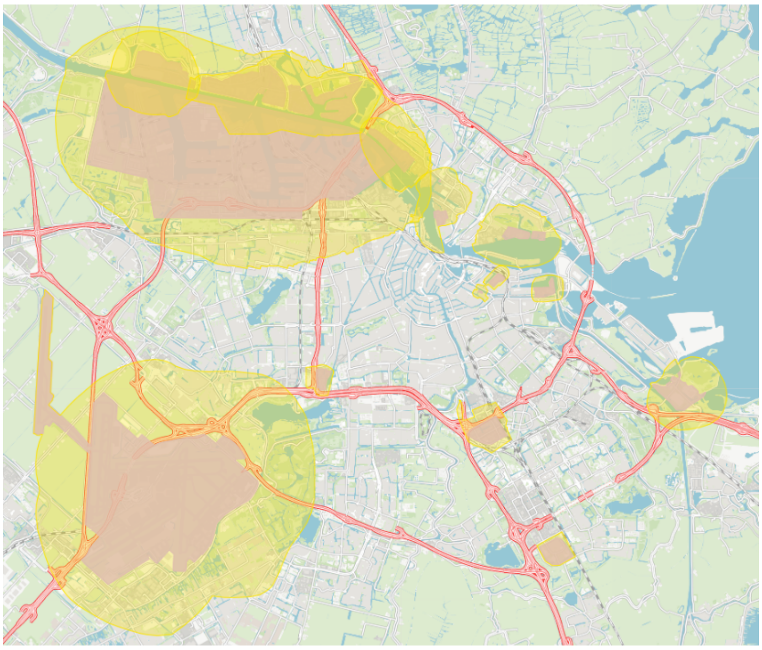


Figure 4.2: Settling (pink) and noise (yellow) zones for industry in Amsterdam (Municipality of Amsterdam, n.d.-a)

result in loss of revenue [expert 5]. Besides energy for production, the distribution process of goods also requires significant amounts of energy. The industry mostly relies on gas, as many processes require large amounts of energy at once, which is not possible with electricity.

"Almost everyone in the industry sector has experienced problems related to electricity transport capacity, this has had an impact on their operations", said by expert 5. The availability of electricity is crucial for the profitability of industrial operations. While backup generators are often in place for emergency situations or maintenance work, relying on them as a long-term solution would not be financially viable. If the industry segment were to face transport restrictions, relying on alternative and potentially expensive solutions would not result in a positive business case, especially since they require large amounts of energy. As mentioned by experts 5 and 6, alternative solutions like steam power and gas turbines may not always be financially attractive, practical, sufficient or readily available due to infrastructure limitations. Additionally, it should be noted that it is unlikely that a party will rely on fossil fuel-based alternative solutions for sustainability expansions. "Electricity, complemented with steam and hydrogen, is absolutely crucial for making the industry segment sustainable", expert 6. Hence, I am assuming that alternative solutions are not a widely adopted response to demand congestion in the industry segment (response 1A & 2A).

Furthermore, I assume that the industry sector, heavily reliant on energy consumption, has already undertaken significant efforts to optimize energy efficiency (response 2B). I take this assumption because efficiency measures can lead to substantial cost savings for the industry sector. The summarized responses of the industry segment to demand congestion are presented in Table 4.2. The expectation percentages of these responses are approximated and based on the qualitative insights obtained from expert interviews, but have not been validated. Responses C are the cases suffering from structural electricity shortage, which applies to the largest share of the industry segment.

Industry	**Resp. A**	**Resp. B**	**Resp. C**
1. New contract	0%	0%	100%
2. Expansion	10%	5%	85%

Table 4.2: An indication of the industry responses to demand congestion

4.2.3. Commercial Business responses

The commercial business market is a diverse sector that includes a wide range of businesses, such as offices, restaurants, retail stores, VVEs (company collective buildings), real estate owners, hospitality establishments, bakeries, shops, office buildings, etc. Within this segment there are many small and medium-sized enterprises. SMEs, defined as businesses with up to 250 employees and a specific revenue threshold, are independent companies that significantly contribute to shaping the business climate in Amsterdam. The parties in this segment are distributed throughout the city (see Figure 4.3). The commercial market segment contributes approximately 28% of CO_2 emissions in the city (21% comes from electricity), highlighting the need for sustainable initiatives (the Municipality of Amsterdam, 2020). In Amsterdam, the duration of commercial businesses' presence can vary, with some establishing long-term roots while others choose to leave sooner [expert 7 & 8, appendix C.6].

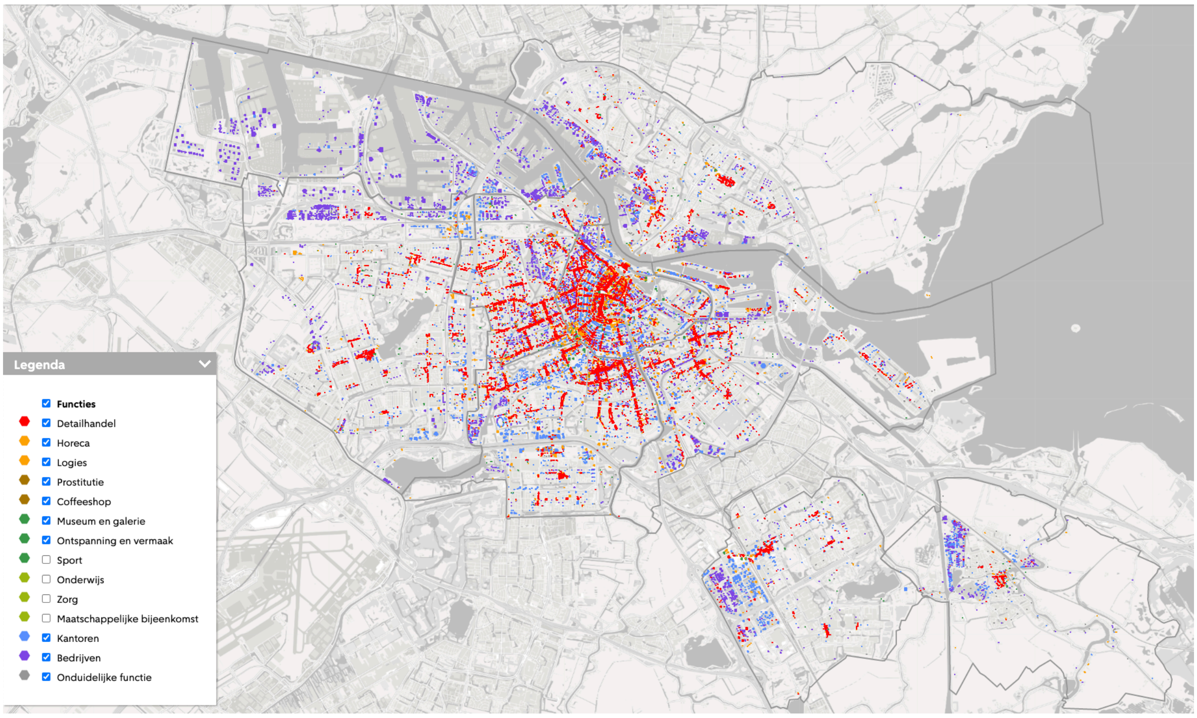


Figure 4.3: Commercial businesses in Amsterdam, map by (Municipality of Amsterdam, n.d.-c) - functions selected top to bottom: retail, hospitality, accommodation, prostitution, coffee shop, museum, entertainment & recreation, offices and businesses

The energy consumption of this segment in Amsterdam varies based on location and business type. In the city center, small retailers, hospitality establishments, and offices operate in historic canal houses with smaller energy profiles. However, businesses in areas like North, Southeast, and West often fall within the LC category [expert 7]. According to expert 8, only 25% of the SMEs require a LC connection. Each business has a unique energy consumption pattern. For example, offices generally have a smaller energy footprint, primarily consisting of computers and servers. On the other hand, bakeries might have higher energy demands due to their specific production processes [expert 8]. The energy is usually consumed during business hours, in a rather steady and continuous manner. Needs for electricity range from heating and lighting to mobility and production. The percentage of electricity in the energy mix varies widely within this segment. While electricity covers a large part of the energy mix, natural gas remains a predominant source due to challenges in transitioning away from gas in older buildings [expert 7]. "For a bakery, it can be 30% electricity, while for larger-scale industries, it may constitute only a few percent of their total energy consumption", expert 8.

According to expert 7 and 8, congestion will definitely influence an entrepreneurs' decision regarding where to operate their business. The attractiveness of the city as a business location will be impacted if grid congestion issues persist. A congested area poses significant challenges, which for some is a reason to avoid the area to prevent any undesired complexities. ”Moving to other areas in Amsterdam may also be difficult due to limited available transport scarcity”, expert 7. Therefore, I assume that response 1C, moving outside of the city is more probable than to operate in a different part of the city (1B). I assume that there is a larger share deciding to avoid a congested area whilst it is still possible, as opposed to the share deciding to settle with an SC connection and use alternatives (1A). The latter does happen: ”... such as the case of a restaurant requiring three times 100 amperes, I would advise them work it out with the largest SC connection, which is three times 80 amperes”, said by expert 8.

A stable and reliable electricity supply is of great importance to this segment, as mentioned by both expert 7 and 8. Nonetheless, they have some ability to cope with reduced electricity availability for an extended period. This flexibility has to be achieved through coordinated efforts for alternative solutions (1A and 2A), but it is absolutely crucial that there is a viable business case behind it. Adding to that, the party must have sufficient financial resources to make such an investment [expert 4, 7]. Subsidies play an important role in providing the initial push towards sustainable alternative solutions. Battery systems can quickly amount to hundreds of thousands of euros. Backup solutions like diesel generators are not commonly utilized among SMEs, as there are no incentives or financial attractiveness for such alternatives due to the absence of subsidies and the high cost of diesel [expert 7].

For some parties in this segment, improving efficiency (2B) has proven to be a solution: ”We look at efficiency, so how you can better utilize your current contract. ... Liander discovered that the dock company had another location nearby with sufficient left-over capacity in their contract, so they were able to provide that remaining capacity to the dock company’s other location”, said by expert 4. The same was mentioned by expert 8: ”By optimizing their energy efficiency, they can often accommodate an expansion within their existing transport capacity”. But there is definitely also a significant share that is forced to endure structural electricity shortage, and thus cannot expand (2C): ”There are companies that cannot expand because they don’t receive additional transport capacity”, said by expert 4, and ”Some businesses receive a ”no” from the grid operator, limiting their ability to invest and grow. .... If the alternative options are no longer feasible, a different situation arises”, said by expert 8.

The summarized responses of the commercial business segment to demand congestion are presented in Table 4.2. The expectation percentages of these responses are approximated and based on the qualitative insights obtained from expert interviews, but have not been validated.

C.B.	**Resp. A**	**Resp. B**	**Resp. C**
1. New contract	30%	30%	40%
2. Expansion	30%	20%	50%

Table 4.3: An indication of the commercial business responses to demand congestion

4.2.4. Urban Development responses

Urban development plays a crucial role in shaping the landscape of a highly populated urban area. It encompasses the process of project development, which can range from creating new neighborhoods, to constructing office buildings or housing blocks. These projects often aim to achieve a mix of residential dwellings and various facilities, fostering a sense of a ”complete city” where people can live, work, and access amenities within close proximity. Urban planning is a collaborative effort between the municipality and project developers, which consists of four phases: initiation, feasibility, design and execution. It does not always entail empty plots, it also involves transformations and renovations [expert 10, appendix C.7]. While the municipality provides guidelines and regulations, the actual construction and development work is undertaken by project developers, in the fourth and final phase [expert 10]. The number of dwellings expected to enter phase 4 per year in Amsterdam is shown in Figure 4.4.

Urban development for housing and non-housing projects requires electricity for both the construction and operation phases [expert 9 & 11, appendix C.7]. During the construction phase, electricity is needed to power heavy equipment and tools, lighting for workers, and temporary structures such as trailers and offices. This is known as ”bouwstroom” (construction power). The amount of energy

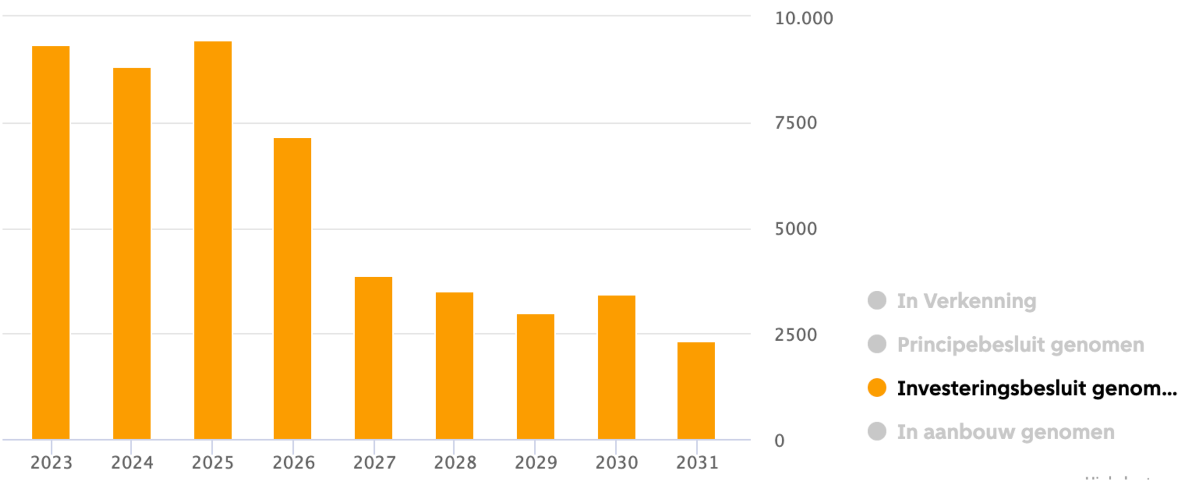


Figure 4.4: Number of dwellings in the housing stock entering the last phase, per year in Amsterdam (Municipality of Amsterdam, n.d.-b)

required during the construction phase can vary depending on the size and complexity of the project, as well as the duration of the construction period. This need almost always exceeds the 3*80A limit, making it an LC connection prone to transport scarcity [expert 9]. For every new project that is constructed, a new, but temporary, contract for construction power has to be requested. If the type of project includes dwellings, the total reserved SC capacity can usually be used temporarily to power the construction of it [expert 9].

Once the project is developed, electricity is needed for the operation of various systems and appliances. In this segment, this is almost always a new contract, except for transformations of already owned property: this requires an expansion. An electricity request for operation is usually made as late as possible, to be sure about the energy necessities and thus avoid any unnecessary expenses. This should be done 18 weeks before construction latest [expert 9]. The housing part of development falls within the SC segment and thus is reserved for, as are small shops and offices. However, the rather energy-intensive non-housing program requires LC contracts, such as large office spaces. In a mixed-use project, there are thus parts who will receive electricity, and parts that will not [expert 9]. Most projects are somewhat mixed: "The distribution of mixed projects in the two areas I work in primarily consists of a combination of residential units with commercial spaces located at the ground level, sometimes including office spaces. The ratio of non-residential to residential elements varies, ranging from 10% to 30% depending on the specific location", said expert 9. The mix of functions in such development cannot be viewed in isolation; it is a comprehensive whole, that must be constructed all at once [expert 11 & 12].

The response to congestion in this segment strongly depends on the phase the project is in. "In practice, congestion is a real issue for this segment. ... As a result, some project developments are currently at a standstill because they have not been assigned a construction power request and are unable to proceed", said by expert 9. Expert 10 said the same: "If the request for a temporary connection is not made on time or is rejected, construction cannot proceed." Expert 11 mentioned an example of an office building owner intending to renovate, but who was not granted bouw stroom (nor an expansion to operate with after). This project is now halted. When electricity is requested for construction power under demand congestion, response 1C is highly probable.

Responses 1A and 2A are not very probable, neither for construction nor for operation power. "One specific project that is currently on hold is the renovation of an office complex. They considered using diesel generators as an alternative, but it was not financially viable and not environmentally desirable. The decisive factor was the financial aspect", said by expert 9. Expert 10 mentioned the same, saying that in terms of alternative solutions for construction power, it is unlikely that options other than electricity will be widely used. Besides alternatives, there is only one situation where using a SC connection could work; Project developers sometimes have the possibility to strategically divide and structure their spaces, in order to make them small enough for a SC connection [expert 9]. This will probably not occur frequently. ”Ultimately, it always comes down to cost considerations. If a developer already knows that they would need expensive alternatives for power supply for two years, they are unlikely to proceed with the project.”, said by expert 10.

Adding to that, there are no evident congestion relief options at hand for this segment. Expert 11 mentioned there is research being conducted on solutions for demand congestion: ”One approach is to flatten the peaks of electricity consumption, which can lead to more efficient utilization, ... alternatives include the use of batteries or generators, smart contract sharing, and optimizing the utilization of residual heat. Implementing these solutions requires collaboration at the area level. Additionally, the feasibility of these alternatives depends on whether the project developer or the tenant covers the associated costs.” It might be slightly more probably that a transformation project is able to supply the structural electricity shortage with alternatives, but for new projects, this is simply not viable.

For this segment, it is not possible to simply settle somewhere else (1B). Urban development is a lengthy process that involves many permits, analyses and regulatory hurdles. Adding to that, there is little to no space in a highly populated urban area. I assume that response 2B is possible, but negligible: the only case where this would work, is for a transformation where the property owners also holds and keeps the electricity contract, ánd they can make improvements to work more efficiently with the current transport capacity. The summarized responses of the urban development segment to demand congestion are presented in Table 4.4. The expectation percentages of these responses are approximated and based on the qualitative insights obtained from expert interviews, but have not been validated. Responses C are the cases suffering from structural electricity shortage, which applies to the largest share of the urban development segment.

U.D.	**Resp. A**	**Resp. B**	**Resp. C**
1. New contract	0%	0%	100%
2. Expansion	10%	0%	90%

Table 4.4: An indication of the urban development responses to demand congestion

4.2.5. Public Services responses

The public services segment encompasses essential societal facilities such as schools, healthcare & welfare facilities, community centers, social care, sports amenities, safety & security services, public transportation, critical infrastructure, government services and public lighting. The public services are equally distributed throughout Amsterdam, strategically located to cater to the needs of the city’s residents (see Figure 4.5). A sufficient range of facilities is crucial for a densely populated city like Amsterdam. The demand for such facilities is substantial, leading to waiting lists for hospitals, schools, and other services. This situation can create societal unrest as the city undergoes the inevitable growing pains associated with urban development [expert 12, appendix C.8].

This segment primarily utilizes energy for standard building-related facilities like heating, cooling, lighting, computers, alarms, and charging points. The energy consumption falls within the average range for buildings. The energy usage pattern follows a typical 8-to-5 work profile, similar to offices, with peak demand in winter for heating and some peaks in summer for air conditioning. They use electricity and gas, but the new constructions rely solely on electricity as they are no longer built to use gas. The larger establishments generally fall under the LC category, with the exception of e.g. small medical clinics with one waiting room [expert 12].

”Given the societal importance at stake, many stakeholders are willing to cooperate to find solutions for a public service”, mentioned by expert 12. Because of that high societal importance, this segment is highly likely to use alternative solutions for operating new establishments (1A). Technically, there is always a solution, but these are not always financially or sustainably desirable [expert 12]. Sometimes, using the base of a SC connection is already a good start: ”for example, in the case of the sports hall

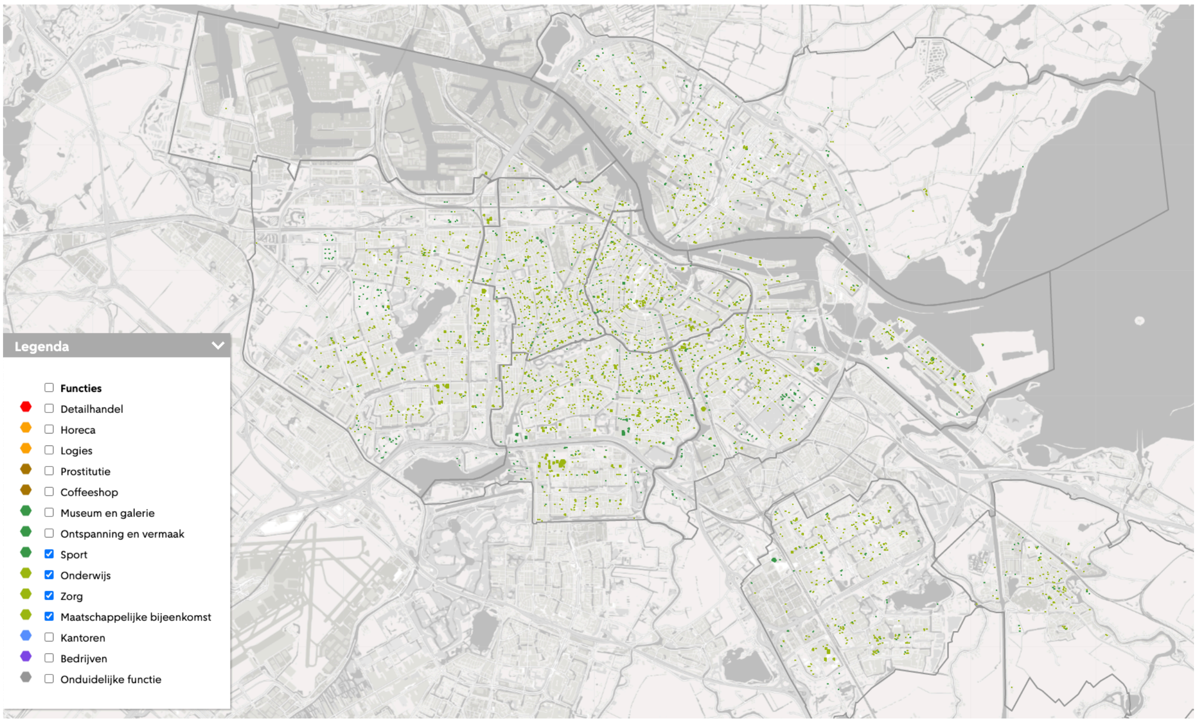


Figure 4.5: Public services in Amsterdam, map by (Municipality of Amsterdam, n.d.-c) - functions selected top to bottom: sport, education, healthcare, social gathering

that requires 120 kW, we can meet their basic needs with a 55 kW SC connection" [expert 12]. This would have to be supplemented with energy production, for which the most common technique are fossil-fueled generators: "We often see the combination of storage and the utilization of a generator as a backup", expert 12.

Municipalities act as facilitators of area development by leasing or selling land to market players, generating income for the municipality. The transfer of land includes specific requirements for urban planning such as housing, healthcare facilities, and schools. If demand congestion is declared before a project reaches phase 4, the urban development team of the municipality has to decide whether a project should continue and they will have to bear the costs for the alternative solutions (1A). The municipality will generally always give prioritization to facilitating such public services, under any (fairly reasonable) cost. From phase 4 on wards, it is up to the developer or property lessees/purchasers to find and pay for solutions or to decide to delay or halt the project (1A or 1C). For them, prioritization is usually financial viability. The municipality of Amsterdam has no standardized approach yet as to whether they should (financially) support this segment with the facilitation of congestion relief.

In this segment, it is more likely for parties to consider postponing or cancelling a project (1C) rather than changing its location (1B) once a new contract cannot be granted and an alternative cannot be found (1A). When selecting a site for construction, there is a clear rationale and philosophy behind the decision-making process. Deviating from the original plan due to factors like inadequate electricity supply, would be impractical and not in alignment with the established norms set by the city of Amsterdam regarding the provision of public services based on the number of inhabitants [expert 12].

Efficiency (2B) works well, but would only work for lager buildings [expert 12]. Whether 2A or 2C is chosen, depends on the purpose of the upgrade. If it is a sustainability objective, it is expected that parties in this segment will choose to delay their plans. However, when it pertains to an essential expansion for operations, such as an additional building wing, there is a higher sense of urgency. In that case, alternative options will be consulted. Whether the municipality would assist financially, has not yet been decided.

The summarized responses of the public services segment to demand congestion are presented in Table 4.5. The expectation percentages of these responses are approximated and based on the qualitative insights obtained from expert interviews, but have not been validated. Responses C are the cases suffering from structural electricity shortage, which is the largest response to a denied expansion. It should be noted that the ACM is planning to prioritize societal parties when allocating transport capacity, hopefully minimizing the need for these responses.

P.S.	**Resp. A**	**Resp. B**	**Resp. C**
1. New contract	80%	0%	20%
2. Expansion	20%	10%	70%

Table 4.5: An indication of the public services responses to demand congestion

4.3. Potential societal impacts of demand congestion

To determine the societal impacts of demand congestion, the third step is to explore range of possible societal impacts. First, I describe the impacts using the ambitions of the municipality of Amsterdam. Then, I explore the potential societal impacts of demand congestion in developed societies in general, using the Sustainable Impact Assessment. This assessment methods allows to evaluate sustainable development with three dimensions: social, economic and environmental. Lastly, I select three important impacts that serve as case-specific indicators, which are CO_2 emission, employment and housing. It aims to answer the third sub question:

"What are the potential societal impacts of demand congestion in developed societies?"

4.3.1. Impact of demand congestion on the Amsterdam ambitions

Inclusiveness is directly impacted by demand congestion because the spatial distribution of congested areas is unequal. A selection of neighborhoods (currently in North and West, Figure 4.1) experience more negative impact on the quality of life than others. The ambition inclusiveness also incorporates the wish of creating 'complete' neighborhoods, that should have a balanced mix of functionalities [expert 10]. This includes social amenities such as schools, and care-, culture-, and sports facilities, in both existing and new neighborhoods. This is hard to achieve in congested areas where new households can be connected, but LCs have to be put on hold. In general, the municipality aims to create neighborhoods were there is a right balance between living, working and recreation (Municipality of Amsterdam, 2021). The *compactness* is not directly impacted by demand congestion. Nonetheless, the usual solution of expansion that solves congestion does put a lot of pressure on keeping a neat appearance, especially because of the haste and scope of challenge.

The *vitality* of the city is heavily impacted by demand congestion. The electricity infrastructure is a key component of the urban infrastructure supporting the daily activities of the economy. Companies wanting to grow their current business operations cannot do so and new businesses cannot settle in congested areas [expert 4, 5, 6, 7, 8]. As a consequence, employment growth is inhibited. Congestion affects the attractive character of the city, which may cause project developers or businesses to choose another destination over Amsterdam. The *health* of the city is directly impacted in congested areas where newly built hospitals or general practitioners cannot operate or expand [expert 12]. Adding to that, the additional air pollution from the remained reliance on fossil fuels affects public health.

The *live-ability* is decreased in congested areas where there is less opportunity for social facilities to grow, such as for youth, shelter, culture, sports or community cohesion. The city aims to provide a total function mix instantly, instead of building homes first and facilities later. The municipality wants to prevent so called "sleeping neighborhoods", thus can decide to postpone construction of urban development. As a result, there would be less offering on the housing market [expert 1, 10, 12]. Lastly, the *sustainability* of the city is greatly impacted by demand congestion. Businesses wanting to electrify cannot do so, for example no charging stations for electric vehicles can be built or processes cannot be electrified. Furthermore, instances that cannot receive their desired amount of electricity may choose to resort to polluting short-term solutions, such as diesel generators [expert 4, 8, 12].

While these qualitative values allow for a holistic description of the city's status, the municipality lacks a concrete assessment framework for quantifying congestion-related problems. This means that there are no concrete metrics or models to evaluate the extent of the issue numerically, nor is there a threshold to identify 'no go' situations that require intervention. This complicates the validation and substantiation of decision-making for alternative solutions that address the consequences of demand congestion. At this point, individual cases are signaled, discussed and evaluated by the civil servants of program EVA. If deemed necessary, these cases receive extra attention and case specific solutions are sought. Policies are then drafted for city-wide implementation, or solutions are found the specific cases [expert 1].

4.3.2. Potential societal impacts of demand congestion per dimension

Below, I provide a list of potential societal impacts in developed societies in highly populated urban areas, categorized by the three dimensions of sustainable development. This list provides a comprehensive metric-based representation of the societal impacts of the consequences of demand congestion. It is not 100% exhaustive, but contains the most mentioned potential impacts during my research. I have derived these insights from literature, desk research, the expert interviews, and conversations and observations during my internship.

The objective of the *environmental* dimension is to minimize the impacts of human activities on the natural environment (Bhattacharyya, 2012; Ilskog, 2008). This includes issues related to biodiversity, climate change, pollution, and resource depletion. According to CE Delft, 2022a, demand congestion slows down the energy transition as it influences the acceleration of electrification. The effect is that the reliance on fossil fuel remains [expert 1, 3]. The remaining reliance on fossil fuels has a great impact on the natural environment, as it results in increased air pollution and greenhouse gas emissions. Other indicators for the environmental impact in this specific research context can be:

- Additional emission of greenhouse gasses - used by Adefarati and Bansal, 2019; Ali et al., 2023; Ilskog, 2008; Wang et al., 2009; Wassie and Adaramola, 2021; Wicaksono et al., 2020, mentioned by [expert 1, 3, 7]
- Missed electrical kilometers in mobility - mentioned by [expert 1]
- Additional air pollution, such as particulate matter or nitrogen oxides - used by Adefarati and Bansal, 2019; Bhattacharyya, 2012; Wang et al., 2009; Wicaksono et al., 2020
- Degradation of the natural environment - used by (Bhattacharyya, 2012)
- Noise pollution from alternative electricity generators - inspired by [expert 3]

The *social* dimension considers the impacts on people and communities, including issues related to health, safety, human rights, and social equity. It pertains to the need to ensure that societal needs are met, including access to basic services, equal opportunities, and social cohesion. Social sustainability also refers to the ability of solutions or actions to be accepted and accessed by a wide range of people (Bhattacharyya, 2012). This is the most complex dimension to measure, as it is difficult to assign social impacts to one specific project or policy alternative (Ilskog, 2008), and they are difficult to quantify (Kralisch et al., 2016). The unavailability of electricity can lead to social inequities, as certain groups of people may be disproportionately affected caused by the spatial distribution of congested areas. This can exacerbate existing inequalities in the urban area, also known as "distributional energy justice": a fair distribution of the costs and benefits from the energy system. Demand congestion may also impact public health, the operation of social services and the completion of housing construction (CE Delft, 2022a). Indicators for the social impact in this specific research context can be:

- Number of inhabitants living in congested areas
- Level of public dissatisfaction with living circumstances in the area
- Spatial distribution of congested areas and congruence with socio-demographic parameters, such as low-income households - used by Kumari et al., 2021; Wicaksono et al., 2020
- Number of missed beds in health institutions - inspired by Bhattacharyya, 2012; Custodio et al., 2023; Ilskog, 2008; Lenz et al., 2017; Wassie and Adaramola, 2021; Wicaksono et al., 2020 and mentioned by [expert 1]

- Number of missed study places in educational institutions - inspired by Custodio et al., 2023; Ilskog, 2008; Kumari et al., 2021 and mentioned by [expert 1]
- Number of missed sport facilities
- Delayed construction of houses - mentioned by [expert 1]
- Decreased accessibility, connectivity and mobility due to affected public transport
- Decreased public health due to air pollution
- Decreased levels of income - used by Custodio et al., 2023; Kumari et al., 2021; Wassie and Adaramola, 2021
- Number of ”sleeping neighborhoods” versus ”complete” - mentioned by [expert 1]

The *economic* dimension considers issues related to employment, income, and economic growth that is inclusive, equitable, and responsible. Achieving economic sustainability involves mitigating major disruptions and avoiding instabilities and discontinuities (Ilskog, 2008). In the context of demand congestion, the structural unavailability of electricity can have significant economic consequences. It can lead to losses in productivity and revenue for businesses and industries, resulting in limited economic growth. It also affects the character of the city and its attractiveness, which in turn may have an influence on the offering of employment [expert 1]. Indicators for the economic impact in this specific research context can be:

- Number of businesses affected in a congested area
- Missed business development - used by Ilskog, 2008 and mentioned by [expert 3]
- Economic welfare decline (GDP)
- Attractiveness of business climate (spatio-economic circumstances)
- Total economic losses incurred by affected parties
- Total unmet electricity demand - used by Ilskog, 2008; Wassie and Adaramola, 2021 and mentioned by [expert 1]
- Missed job creation - used by Custodio et al., 2023; Wang et al., 2009; Wicaksono et al., 2020 and mentioned by [expert 4, 8, 10]
- Delayed construction and/or operation of commercial services
- Imbalanced function mix (offering of opportunities for work, housing and facilities)
- Costs of interim solutions - mentioned by [expert 1]

4.3.3. Selection of societal impact indicators

To conduct the impact assessment for the case of Amsterdam, I have made a selection of important societal impacts, which I validated with my company supervisors. This selection is based on similar research conducted in developed and developing countries on electricity availability, the ambitions of the municipality of Amsterdam, interviews conducted with representatives from different LC segments, and observations made during my internship. I have selected these ”major” indicators for energy decision-making by the principles of Wang et al., 2009 and Ilskog, 2008 as described in Section 3.3. While a sustainability analysis could include additional indicators, the indicators selected offer a reasonable representation of the multi-faceted nature of the challenge. I have made a rather small selection to maintain the manageability of the assessment framework.

CO_2 emission

It is commonly known that the emission of CO_2 gas contributes significantly to the greenhouse effect, which is a major concern for governments, researchers, and the public. CO_2 is a gas that is invisible, odorless, and tasteless, and is a naturally occurring part of the Earth's atmosphere. It is released into the atmosphere through natural processes such as respiration and volcanic activity, as well as through human activities: when fossil fuels such as coal, oil, and natural gas are burned in energy systems. The amount of CO_2 emissions varies depending on the type of energy system used. Evaluating the amount of CO_2 emissions is an important criterion when assessing the sustainability of an energy system. It was mentioned in literature by Adefarati and Bansal, 2019; Ali et al., 2023; Ilskog, 2008; Wang et al., 2009; Wassie and Adaramola, 2021; Wicaksono et al., 2020. In general, CO_2 emissions are a tangible metric that is commonly used to guide policy formulation and decision-making processes. This metric was named by several experts as an important and potentially large impact of demand congestion [expert 1, 3, 7], and it was referenced to by expert 3 as ”an obvious indicator of societal impact”. This impact indicator is categorized under the *environment* dimension, and is a proper indicator for Amsterdam Ambition of '*sustainable* city'.

Employment

When assessing the societal impact of demand congestion, one important criterion is its effect on job creation and local economic development. The lack of universal access to electricity and subsequent structural electricity shortages can have significant negative consequences for energy-intensive businesses, such as reduced productivity and decreased competitiveness. Additionally, restrictions on expansion and new contracts due to electricity shortages can hinder business growth and thus hinder employment creation in the region. Conversely, improving the grid's capacity presents opportunities for job creation. This indicator is categorized under the *economic* dimension, and is a proper indicator for Amsterdam Ambition of '*vital and inclusive* city'. Evaluating the employment creation is an important criterion when assessing the sustainability of an energy system. It was mentioned in literature by Custodio et al., 2023; Wang et al., 2009; Wicaksono et al., 2020. In general, job creation is a tangible metric that is commonly used to guide policy formulation and decision-making processes. This metric was named by several experts as an important and potentially large impact of demand congestion [expert 4, 8, 10].

In interpreting the employment indicator within the specific case context, decision-makers should consider the existing labor market conditions, including the availability and shortage of skilled workers in the affected areas. While demand congestion may potentially lead to job reduction, if there is a shortage of workforce, the impact of job reduction may not be as severe. In the greater Amsterdam area for instance, there is a severe labor market shortage, and the personnel shortage is persistent. This shortage is particularly prominent in sectors such as technology, health and education (UWV, 2022).

Housing

Demand congestion could have a significant impact on the decision-making of urban development and the construction of housing developments. This is especially problematic in highly populated urban areas such as Amsterdam, where there is a structural housing shortage. Projects that are still in the planning phase and for which no commitments have been made may potentially be halted or delayed. However, when agreements have already been signed and obligations have been made, it is rather complex to stop or delay projects. In these cases, congestion can lead to a deteriorated relationship between developers and municipalities, and discussions may take place regarding possible solutions to reduce costs and complete the project. The missed construction of housing is an important indicator for the impacts of demand congestion, especially since the municipality aims to built 7.500 houses per year, preferably with a mixed offering (Municipality of Amsterdam, 2021). This indicator can be categorized under the *social* dimension, and is a proper indicator for Amsterdam Ambition of '*vital and inclusive* city'. It can be measured in delayed square meters of dwelling floor area. This indicator was found from expert interviews, as it was mentioned by [7, 9, 10, 11, 12].

4.4. Future prospects of congestion in Amsterdam

To determine the societal impact of demand congestion in Amsterdam, the fourth step is to research where and when there will be insufficient capacity in the medium-voltage urban electricity network. To identify which regions in Amsterdam will suffer transport scarcity, it is necessary to know which feeding areas will be labeled as congested in which years. To do this, I gather the expansion and construction plans of the substations, along with the corresponding updated feeding areas for each year. I combine this data with the expected maximum and minimum peak-load impact per year in the feeding areas, to determine which assets will not be able to carry the growth and when. This section reports the data analysis conducted for answering the fourth sub question:

> *”Which areas in Amsterdam are predicted to experience congestion until 2030?”*

4.4.1. Medium-voltage substations in Amsterdam

Following the scope defined in chapter 3, I'm doing the analysis with medium-voltage distribution substations in the Amsterdam region owned by Liander. I am thus leaving out the substations located in Weesp, and all other stations not located on municipal grounds. I make an exception for Bijlmer Noord and Venswerweg, because they feed a large part of Amsterdam and I have the data for them. Lastly, I left out Hemweg. The final list of substations used and their capacity as installed per the end of 2022 is shown in Table D.1 in Appendix D. Please note that this list should be considered as an approximation of the truth due to the challenges in collecting accurate data. The information was gathered from multiple sources, some of which have provided conflicting details. An overview of the substations per 2020 in Amsterdam is giving in Figure 4.6. It excludes IJburg, since that substation was constructed end 2022.

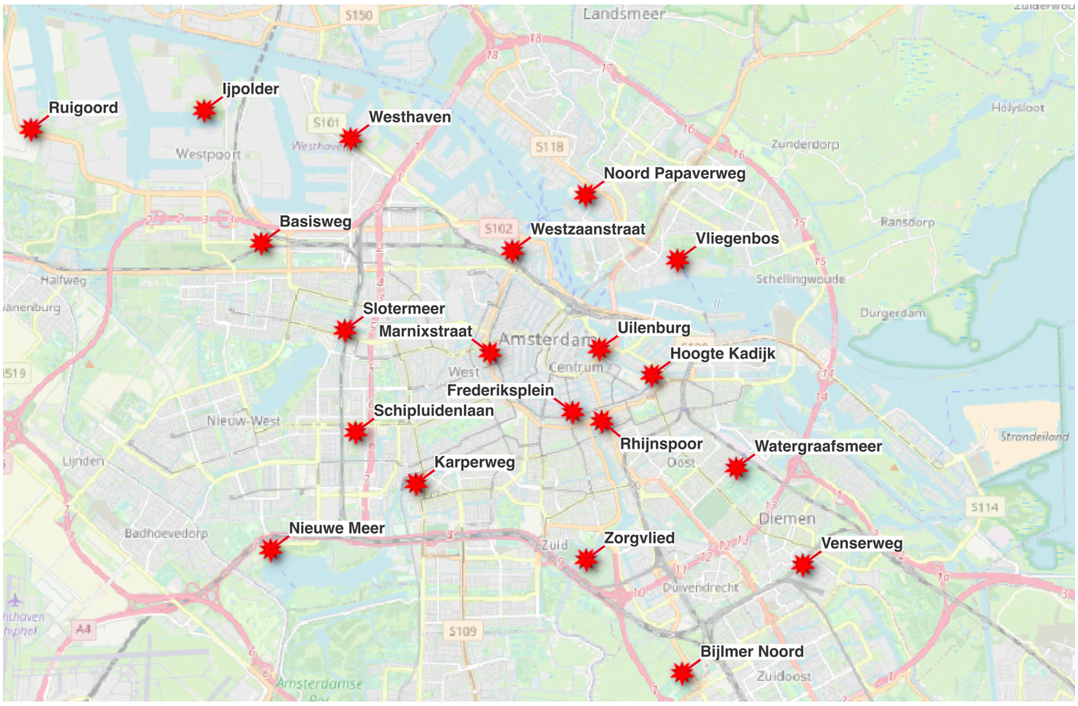


Figure 4.6: The substations in Amsterdam owned and operated by Liander in 2020

I utilize a dataset provided by the municipality in collaboration with Liander to serve as the input data for the future medium-voltage electricity grid of Amsterdam (see Table D.2). However, it is important to note that this list should be regarded as indicative only. The expansion and construction of the medium-voltage network is a complex challenge, which introduces a degree of uncertainty to the plans. There may be changes to the time frames, substation capacities, network routing, and exact locations that could affect the accuracy of this dataset.

I have compared this data set to the publicly accessible Development Framework, which outlines the development of the electricity infrastructure in Amsterdam until 2035 (The Municipality of Amsterdam et al., 2022). This report also addresses the expansion of the substations Hoogte Kadijk, Vliegenbos, and Westzaanstraat, and the construction of six new ones, but this will happen after my time scope of 2030 (The Municipality of Amsterdam et al., 2022). An overview of the substations I've used to be installed by 2030 in Amsterdam is shown in Figure 4.7. Unfortunately, the available data for the construction date was only provided at an annual aggregation level. Consequently, I had to assume that the capacity installed per year becomes available on the first day of January. This high-level approach may have caused some inaccuracies in the analysis.

4.4.2. Feeding areas of Amsterdam

The feeding area of a substation refers to the geographical region that receives power from a specific substation. In other words, it is the zone that is directly connected to and supplied with electricity from

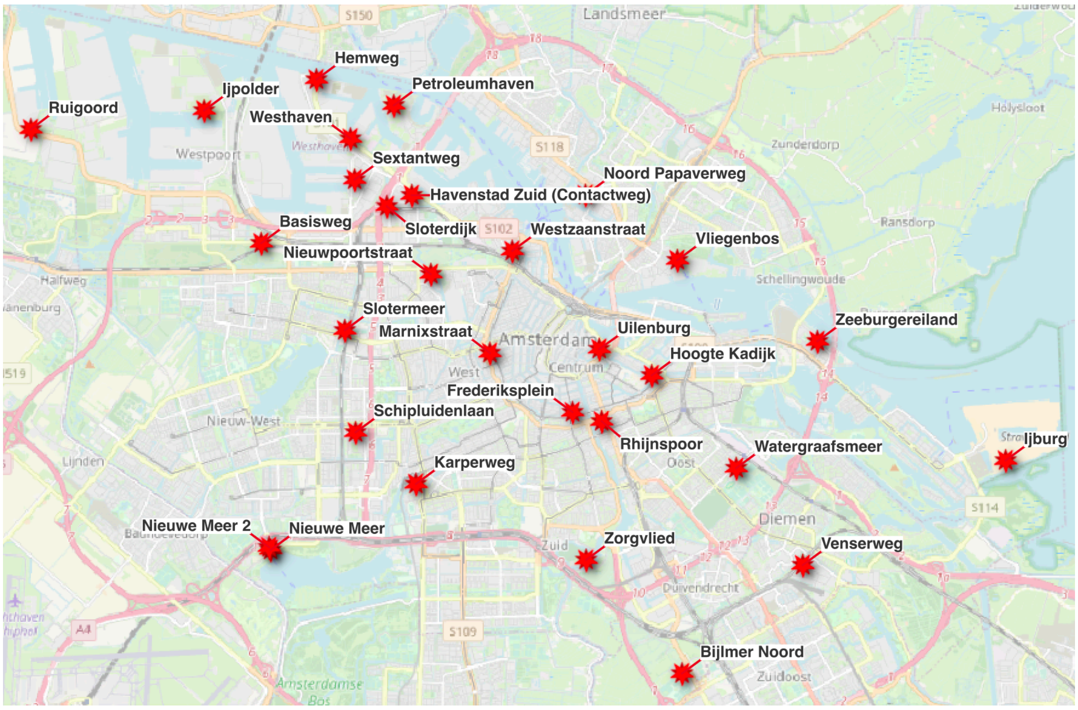
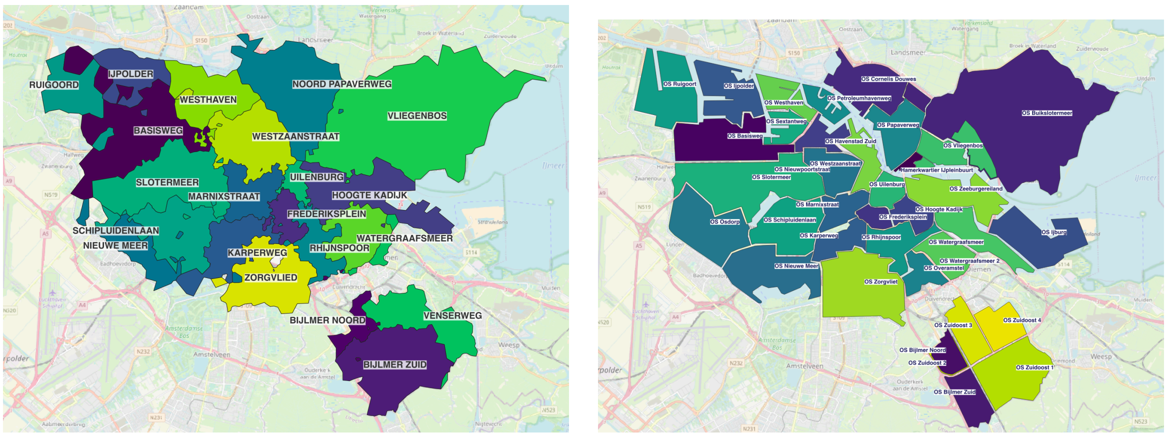


Figure 4.7: A possible scenario of the future medium-voltage substations in Amsterdam in 2030 (excluding Weesp)

that particular substation. In the context of demand congestion, the definition of feeding areas is critical, as it determines which areas are affected by transport scarcity. For instance, a company located on the border of two feeding areas could be fortunate or unfortunate depending on which side of the border they are situated. Figure 4.8a displays the feeding areas in Amsterdam as of 2020. A future vision of the feeding areas in 2035 is depicted in Figure 4.8b, provided by the municipality in collaboration with Liander. It illustrates a possible scenario of the feeding areas in the future electricity network structure. This map comes with some uncertainty, as various variables and unknowns may impact the actual completion of expansion and construction plans.



(a) The feeding areas in Amsterdam in 2020 **(b)** An approximation of the feeding areas in Amsterdam in 2035

Figure 4.8: Indication of feeding areas of Amsterdam

There is no data available on the development of the feeding areas in Amsterdam over the years between now and 2030, therefore I use the Voronoi diagram technique to create an approximation. To verify its usefulness, I compare the Voronoi diagram created for the network topology of 2020 to the map shown in Figure 4.8a. The grey areas in Figure 4.9 show the created Voronoi feeding areas, the red outlines show the actual Liander defined feeding areas. I have tested what percentage of the Liander feeding area falls into the right Voronoi feeding area, these are the colored areas: the name of the original cut up piece matches the name of the Voronoi feeding area.

Sixteen out of twenty-one original feeding areas fall within the correct Voronoi area with more than 50%. For nine-teen out of twenty-one feeding areas, the largest cut up Liander area matches the name of the Voronoi. The Voronoi technique only wrongfully predicted the areas for Hoogte Kadijk and Slotermeer, as the largest part of the original falls within the wrong Voronoi; 47% of the Slotermeer original falls into the Basisweg Voronoi (but 39% is right), and 33% of the Hoogte Kadijk original falls into the Watergraafsmeer Voronoi (but 29% is right). Although these two cases are undesirable, the overall approximation in the map shown in Figure 4.9 is satisfactory.

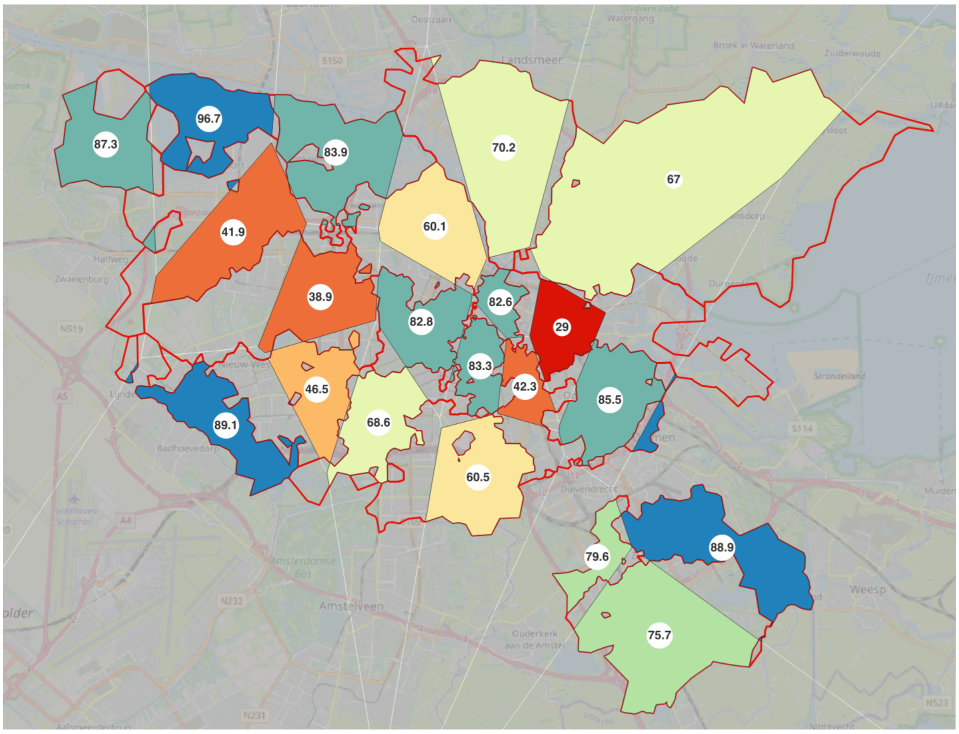


Figure 4.9: A validation analysis of using the Voronoi technique for creating feeding areas - the grey areas show the created feeding areas with the Voronoi technique, the red outlines are the actual feeding areas defined by Liander, the colored areas show the part of the Liander feeding areas that fall within the right Voronoi feeding area.

4.4.3. Growth of electricity demand of Amsterdam until 2030

When measuring electricity consumption and production, there is an important differentiation between measuring in kilowatt hours and megawatts (MW). Kilowatt hours represent the total amount of energy consumed or produced over a given period of time, while megawatts represent the instantaneous power being consumed or produced at a given moment. This distinction is particularly important when analyzing peak-load, which refers to the maximum level of electricity demand and supply in a given period. Measuring peak-load in megawatts allows for the measurement of simultaneousness, which refers to the degree to which different load-profiles have their peak at the same time. When load-profiles are more simultaneous, the peak-load is reinforced or enhanced. However, when load-profiles are less simultaneous, the peaks can cancel each other out, which can free up capacity. See more information on this matter in appendix A.3.

Section 4.1 describes the process of labeling a feeding area as "congested," which is determined through a network analysis conducted by the DSO. While the DSO uses internal models to predict the impact on the asset, I do not have access to these models. Fortunately, I was able to obtain the input and output data from the latest theme study conducted by the Taskforce (Municipality of Amsterdam

& Liander, 2021). This study quantifies the future peak-load impact on the medium-voltage network of Amsterdam between 2020 and 2050. The study used six themes to describe and structure the future trends of electricity usage in Amsterdam: mobility, data centers, urban development, heat transition, renewable energy production, and industry. Within every theme, supply and demand projections were predicted, differentiating in three possible degrees of growth. These developments were then aggregated to create three scenarios of future net impact: a low, medium, and high growth scenario. A fourth scenario maps the expected total impact if the ambitions and objectives of the municipality were successfully accomplished. Assuming that the plans and regulations of the municipality are drafted with the interest of the society of Amsterdam in mind, the output data of this fourth scenario provides an interesting context to research the main research question. Figures D.1 & D.2 in Appendix D show the maximum and minimum peak-load impacts used in this analysis, expressed in MW, per area cluster as defined by Liander.

4.4.4. Demand congestion in Amsterdam per year until 2030

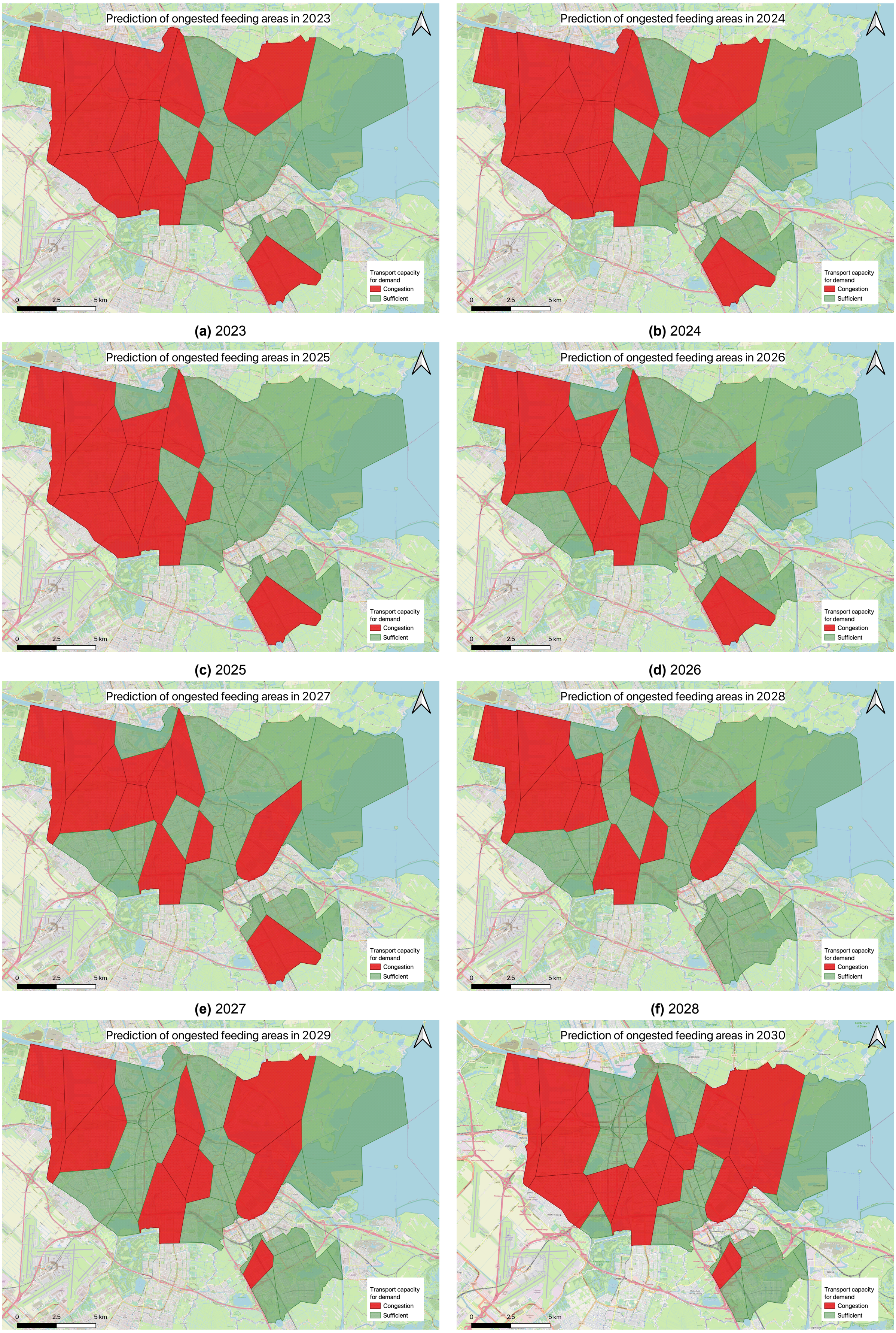
The results of the analysis on the number of congested feeding areas between 2022 and 2030 are presented in Table 4.6. The analysis predicted only one instance of supply congestion, which occurred in the Slotermeer feeding area during one year, where the minimum peak load (+51.849) exceeded the maximum capacity of the substation. Upon further investigation, it was determined that the method used to calculate congestion in the analysis has caused this error. Specifically, the use of absolute values for both the minimum and maximum peak loads led to this miscalculation. In this case, the minimum peak load was not negative, but positive. This indicates a demand congestion, where the demand for electricity exceeds the available transport scarcity, rather than a supply congestion, which should be a negative number. There will thus be no supply congestion in Amsterdam until 2030. The calculation of total demand congested area in km^2 per year includes water surface area.

	2022	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Number of feeding areas	22	22	22	23	25	25	29	30	31
Demand congested feeding areas	11	12	12	11	11	11	9	10	14
Supply congested feeding areas	0	0	1	0	0	0	0	0	0
Demand congestion [km^2]	107	122	122	94	90	91	73	95	123
Demand congestion [%]	49	56	56	43	41	42	33	43	56

Table 4.6: Predicted congested feeding areas in Amsterdam between 2022 and 2030

The prediction maps shown in Figure 4.10 display the feeding areas in Amsterdam that are predicted to experience transport restrictions due to demand congestion each year between 2023 and 2030 (shown in red). The green areas represent regions with sufficient capacity in medium-voltage substations to serve the maximum peak-load under the Amsterdam Ambition scenario. The affected regions vary significantly from year to year, with the exception of 2023 and 2024. The results reveal an unequal spatial distribution of affected regions, with a concentration in the west and south-west of Amsterdam. The maps only indicate whether transport restrictions are necessary and do not provide information on the amount of unmet electricity demand. Figure 4.11 aggregates the congestion prediction maps into one single map. The red region represents the areas of Amsterdam that are expected to experience demand congestion at some point between 2023 and 2030, covering 80% of Amsterdam.

The year 2022 was included in the analysis to validate the calculation's accuracy. As expected, the analysis did not accurately predict all congested areas in Amsterdam during that year. Among the congested stations at the end of 2022 were Basisweg, Hemweg, IJpolder, Ruigoord, Slotermeer,



(a) 2023

(b) 2024

(c) 2025

(d) 2026

(e) 2027

(f) 2028

(g) 2029

(h) 2030

Figure 4.10: Prediction of regions experiencing demand congestion per year in Amsterdam until 2030 - Red: demand congestion, green: sufficient capacity

Westhaven, Westzaanstraat, Noord Papaverweg, and Vliegenbos (Liander, 2022b). The analysis correctly predicted the congestion in Westhaven, Westzaan, IJpolder, Ruigoord, Slotermeer, and Vliegenbos, but missed the congestion in Basisweg and Noord Papaverweg. Additionally, the analysis falsely predicted congestion in Karperweg, Frederiksplein, Bijlmer Zuid, Uilenburg, and Nieuwe Meer. The Voronoi technique used to create feeding area boundaries have partly contributed to these errors, emphasizing the importance of comparing areas on the map, as shown in Figure 4.12.

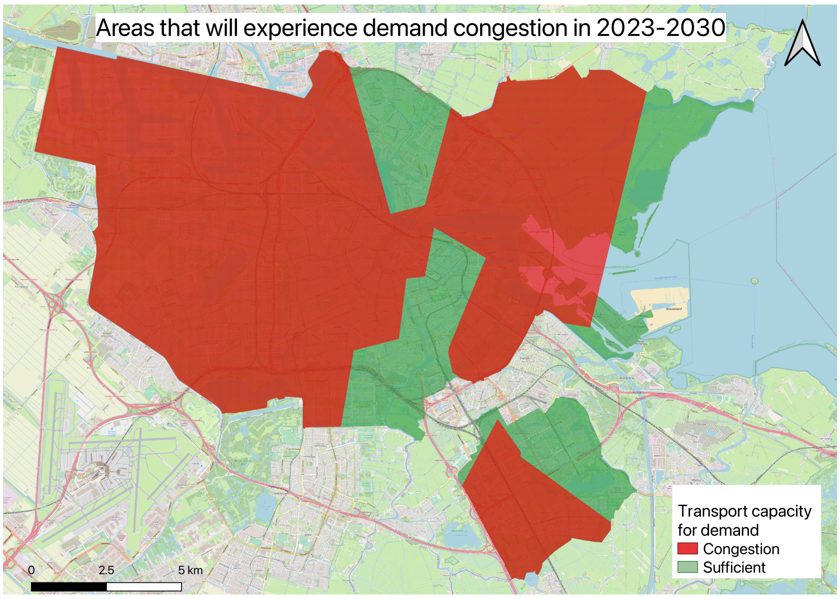


Figure 4.11: An aggregation of all regions experiencing demand congestion sometime between 2023-2030 - Red: demand congestion, green: sufficient capacity

The red areas depict the congested feeding areas in 2022 from the analysis, the yellow areas are the Liander feeding areas that were actually congested end of 2022. The orange areas are the overlapping areas, meaning that those areas were correctly predicted to be congested. The map shows that the congested Vliegenbos area was smaller in the analysis than in reality because a large part of the area was taken over by IJburg in the Voronoi analysis, though IJburg was only operational at the very end of 2022.

The analysis missed the congestion in the areas of Basisweg and Noord Papaverweg, most likely due to not taking into account the impact of LCs. According to Liander's congestion announcements, Noord Papaverweg had an installed capacity of 66 MVA and total LC demand of 53 MW, whereas the input data predicted a maximum peak-load of 37MW. Similarly, Basisweg had 66 MVA versus 64 MW LC demand, whereas the input data predicted a maximum peak-load of 58MW. Furthermore, the falsely predicted congested areas results from either incorrect capacity numbers or incorrect demand predictions. The latter seems more probable since the Amsterdam Ambitions scenario assumed the ideal situation where all municipality plans succeed without considering their feasibility.

4.5. Societal impact assessment of demand congestion

To determine the societal impact of demand congestion in Amsterdam, the fifth step is to determine the segment-specific societal impacts by region and year. First, I identify if and how the six identified responses in general will impact the three indicators selected for the case study. Then, I propose a quantification of the qualitative insights found. For this, I developed a holistic assessment framework, that can be used as a tool to assess the societal impact of demand congestion in a highly populated urban area in a developed society. By applying the framework to the industry segment, I showcase its potential and efficacy. This section reports the data analysis conducted for answering the fifth sub question:

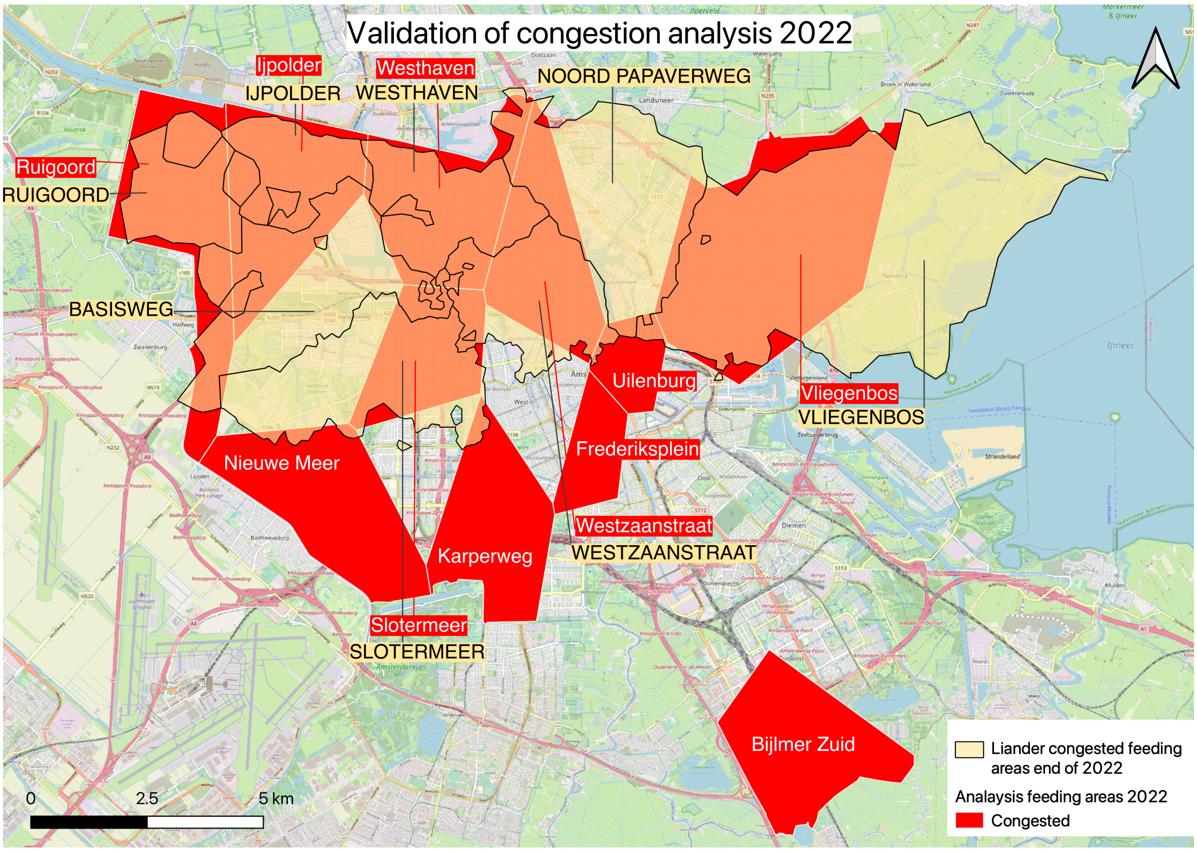


Figure 4.12: Validation of the demand congestion predictions in Amsterdam for 2022 - Red: predicted congested feeding areas, yellow: actual congested Liander feeding areas, orange overlap: correct predictions

"What are the societal impacts of demand congestion by location, customer segment, and year in Amsterdam?"

4.5.1. Impacts of the segment responses to demand congestion

I have selected CO_2 emissions, employment and housing as indicators to measure some of the most important impacts of demand congestion in the case of Amsterdam. To assess the societal impact of demand congestion from four segments and six responses, a total of seventy-two calculations are required. Luckily, not every response has an direct impact. In this section I describe how the responses of large-scale electricity customers affect the three indicators. Table 4.7 presents an summarizing overview of these finding. This table clearly demonstrates the significant societal impact of structural electricity shortage, represented by response C. Conversely, it highlights that responses B have no discernible societal impacts. The table does not provide information regarding the magnitude or direction (positive or negative) of these impacts, as they vary across segments due to a range of factors.

	CO_2	Jobs	Housing
1A	Impact	-	-
1B	-	-	-
1C	Impact	Impact	Impact
2A	Impact	-	-
2B	-	-	-
2C	Impact	Impact	Impact

Table 4.7: General effects of responses on the selected indicators

CO_2 emissions

The six responses discussed in this study exhibit varying impacts on this indicator. The extent to which CO_2 emissions are saved or increased varies across different segments and heavily depends on the specific energy requirements of each business. The A responses propose alternative solutions to meet the unfulfilled electricity demand. The impact of alternative solutions on CO_2 emissions varies depending on the specific technology chosen. Through expert interviews, four primary alternatives for facilitating electricity consumption under transport restrictions have been identified: batteries, fossil-fuel driven electricity generators, distributed renewable energy production (such as solar PV), and smart contracting [expert 4, 8, 11]. The choice of alternative solution determines whether the impact on CO_2 emissions is positive or negative.

When employing battery storage or smart contracting, more electricity can be consumed in total, resulting in an increase of the CO_2 emissions when following the consumption approach, but no net impact when following the source approach. Opting for sustainable alternatives can lead to significant CO_2 emission reductions. The amount of CO_2 saved depends on the total electricity produced by variable renewable energy sources and the CO_2 coefficient of the electricity mix. However, following the source approach to measure CO_2 emission, this reduction is not taken into account. The use of fossil-fuel driven electricity generators will result in additional CO_2 emissions, both with the source and consumption approach.

Response B, on the other hand, has no net impact on CO_2 emissions. If a business relocates within the city (2B), there would be no difference in CO_2 emissions compared to a scenario without congestion. Similarly, if a business improves its efficiency, it can either consume more electricity with its current contract or require less electricity for the same operations. In both cases, following the source approach, no additional CO_2 would be emitted.

If businesses are unable to operate in the city (response 1C) or expand their business operations (response 2C), it would lead to a reduction in CO_2 emissions compared to the non-congestion scenario if the consumption approach is followed. This is because the total energy consumption of the city would be lower. However, if these businesses decide to relocate to a different city, the CO_2 emissions would simply be shifted elsewhere in the country. Therefore, including the effect of response 1C in the measurement of CO_2 emissions could create a distorted perception of its positive impact. However, excluding it would fail to provide an accurate representation of the net CO_2 emissions resulting from demand congestion in the local scope. When presenting the results of the SIA to policy-makers, it is thus crucial to clearly explain these measurement choices to facilitate a proper interpretation of the results.

The 2C response of no expansion for sustainability has the most significant impact on CO_2 emissions as it hinders the progress of electrification: "If businesses aim to step away from fossil fuels but lack the necessary electricity capacity, they will continue with their current practices, resulting in persistent CO_2 emissions.", said by expert 7. "..it hampers our ability to achieve our goals of becoming more sustainable and greener in the coming years. ... Those who delay the installation of heat pumps and the transition away from gas will continue emitting CO_2 in the foreseeable future.", said by expert 12.

Employment

The six responses discussed in this study exhibit varying impacts on this indicator. I am assuming that the adoption of alternative electricity consumption solutions (response A) does not lead to significant job growth. Nor will responses B, relocating or efficiency, impact employment rates. This indicator is thus only impacted by structural electricity shortage (the C responses). The impact of demand congestion on employment reduction varies significantly per segment, as there are large differences in responses; I have assumed that almost all parties in the industry and urban development segment will respond with C, but for the other two, this is less evident.

The extent to which job creation is impacted in the city if a business cannot operate (1C), depends on the average size of a party in that segment; "Well, imagine if there is no more construction happening, then you'll naturally miss out on a lot of jobs", said by expert 4. Expert 5 confirms this: "for a new industry actor not to settle, it will have an impact [on job creation]". If a business does not receive an expansion for business growth (2C), the influence on job creation again differs per segment. "If an expansion cannot take place [in the industry segment], it will probably have a negligible influence on new jobs, as one new piece of equipment does not create a lot of new jobs.", said by expert 6. The relationship between expanding an electricity contract in the commercial business segment and job opportunities is likely correlated, although the exact strength of this correlation remains uncertain [expert 7 & 8]. The impact on employment from the public services segment will be lower than that of the commercial businesses [expert 12].

Housing

Responses A and B identified in this study do not have any direct impact on the housing indicator. This indicator is primarily influenced by response C, which pertains to the occurrence of a structural electricity shortage. Furthermore, this indicator is only impacted by the urban development and public services segments. If congestion is declared prior to the land tendering phase (phase 4), the responsibility for deciding to postpone urban development lies with the municipality. Expert 10 emphasized the importance of creating complete neighborhoods with essential amenities like schools. Considering Amsterdam's strong commitment to developing a "complete" city, it is likely that if there is insufficient electricity capacity to support public services (response 1C), the municipality will opt to delay urban development [expert 12]: "If we are unable to build the necessary schools, it also halts the construction of houses, bringing the entire area development to a standstill." This decision serves to prevent the situation of a "sleeping neighborhood", maintain positive relationships with project developers, and mitigate potential high public costs. However, such delays result in a setback for the much-needed housing supply, leading to a postponement of meeting the desired housing targets, and substantial missed land revenue for the municipality [expert 12].

When congestion is declared in phase 4, the decision to proceed with a project is up to the project developer. Research showed that urban development will mostly respond C, thus will face structural electricity shortage. If projects do not receive their requested construction power (1C or 2C), which is usually requested not far ahead of the start of the construction, the construction of the project will have to be delayed until further capacity frees up. If a project is this far in phase 4, it is unlikely that the project will be cancelled at whole, as many investments have been made: "Contracts have been signed, and there are lease agreements in place" [expert 9]. Construction usually takes two years, thus the societal impact on housing will have a delay of two years. Though capacity reservations have been made for the operation of dwellings, most projects in urban area development are mixed-use projects, encompassing dwellings, offices, public services and commercial rentals on the ground floor. For mixed-use projects, it is simply not possible to construct only the dwellings part and not the non-housing part, as it is a comprehensive whole [expert 11, 12].

"If, for example, 20% of the commercial space remains without electricity, project developers fear years of missed income. While there haven't been cases where the entire project was halted due to this issue in combined developments, it remains uncertain whether this trend will continue in the coming years", said by expert 9. Expert 11 hinted the same: "If developers foresee potential electricity-related issues, they may choose to delay their plans at a whole, possibly until the problem is resolved. This cautious approach helps to mitigate the financial risk associated with having empty properties". It is probable that project developers are not keen to take such financial risks: "For instance, the Sloterdijk 2 project is likely to be put on hold, greatly affecting housing development", expert 12. But as mentioned by expert 11, it is very difficult to make definitive statements about the choices project developers will make. Some possess the necessary financial capabilities to delay a determination of a project. Conversely, smaller developers may lack the financial capacity to assume significant risks and will have to halt a project entirely [expert 11]. It also depends on the profit model, namely which percentage will not be able to operate [expert 10]. It is thus difficult to draw assumptions on how exactly the development of housing will be impacted by demand congestion in the urban development segment.

4.5.2. Demonstration of holistic assessment framework

To demonstrate the potential and efficacy of the holistic assessment framework proposed in Section 3.3, I showcase its ability to capture and evaluate the societal impacts of demand congestion in urban energy systems by using the example of the industry segment in the Amsterdam case study. The first step of the framework has been conducted and reported in Section 4.4, the third in Section 4.2.

The number of affected customers per segment over time

Figure 4.13 shows the results of the extrapolation based on historical data, to predict the total number of industry parties in Amsterdam per year until 2030. Determining the exact percentage of large-scale electricity consumers requires access to specific data on the distribution of electricity connections and their respective sizes. Unfortunately, such privacy-sensitive data is not available to me. Considering that this segment encompasses parties in the sectors of Mining, Industry, Energy supply, and Water supply and waste management, which typically have high energy demands, it is reasonable to estimate that a significant proportion of the industry segment qualifies as large-scale consumers. To prevent excessive rounding of establishment numbers and thus safeguard accuracy of the analysis, I assume that 100% of the industry segment in Amsterdam is categorized as large-scale consumers.

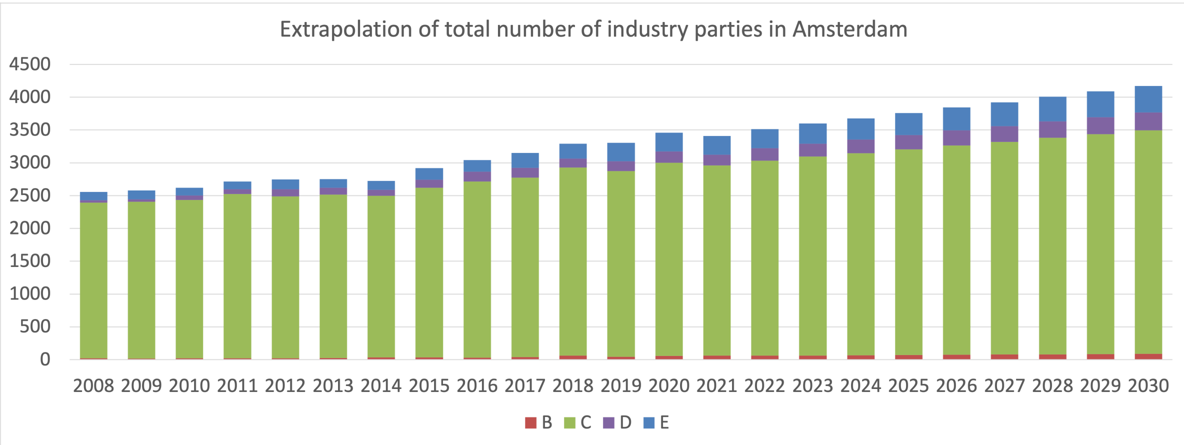


Figure 4.13: Extrapolation of number of parties in the industry segment in Amsterdam

Table 4.8 shows the total number of new industry parties that will want to settle in Amsterdam per year and how many of those settle in congested areas. Furthermore, it depicts the total number of LC expansion request made in Amsterdam, and how many of those are made in congested areas. These are based on the the total number of industry parties settled in Amsterdam in 2022, which is 3.176. For expansion, the tables includes an additional row that displays the total number of expansion requests pending on the waiting list. These requests are aggregated for neighborhoods experiencing congestion over consecutive years. If the area turns green, all requests from the waiting list are accommodated.

	2023	2024	2025	2026	2027	2028	2029	2030
New LC contract requests made	110	100	93	98	107	111	96	123
New LC contract requests denied	59	56	46	47	53	45	42	72
LC expansion requests made	472	472	472	472	450	313	242	151
LC expansion requests denied	247	247	211	201	199	114	135	107
LC expansion request waiting	247	494	633	735	874	861	900	1.007

Table 4.8: Sum of large-scale customer requests denied in the industry segment in Amsterdam in 2023 - 2030

Figure 4.14 provides a neighborhood-level visualization of the cumulative sum of denied new LC contracts for the years 2023 to 2030. Figure 4.15 does the same for the cumulative sum of denied LC expansions requests. The figures highlight the uneven spatial distribution across different neighborhoods.

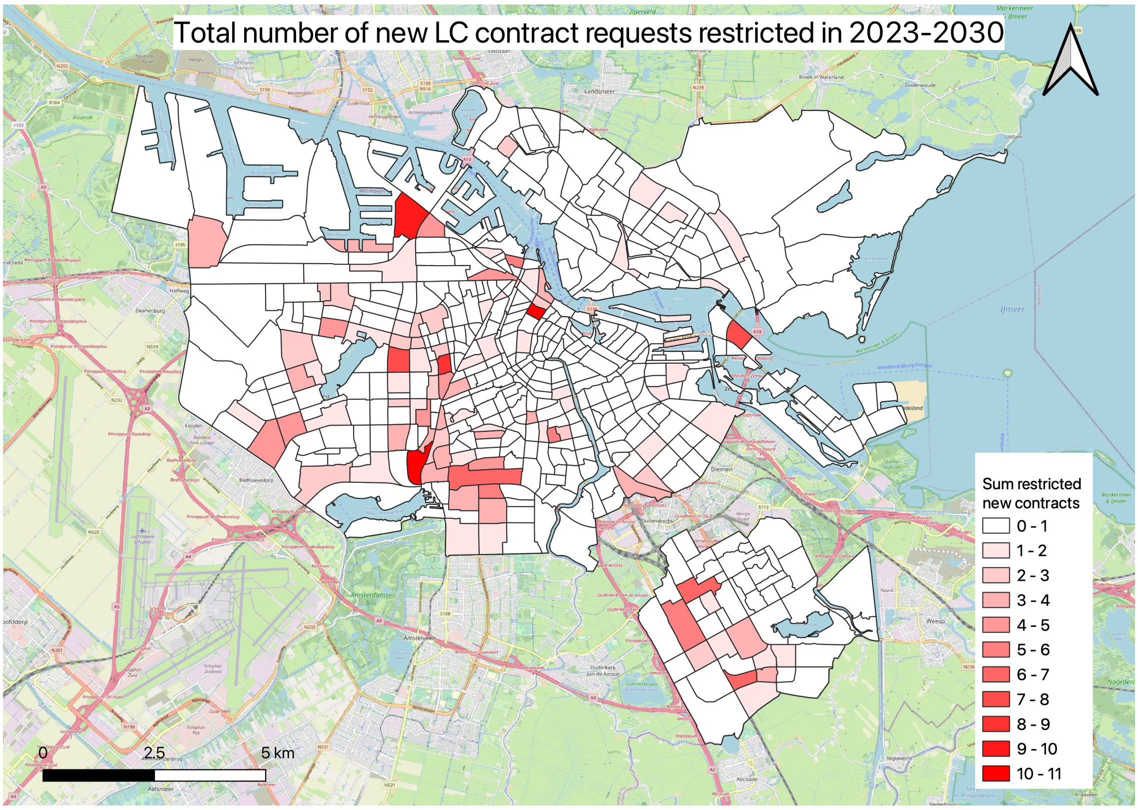


Figure 4.14: Total number of new industry large-scale customer requests denied in Amsterdam 2023 - 2030

The segment specific societal impacts of a response to demand congestion

Industry parties often serve as major employers, offering a wide range of job opportunities, including skilled labor and managerial positions. The consequences of industries not settling in the city (1C) can extend beyond direct employment, impacting indirect jobs in the supply chain and service sectors that rely on the operations of these large-scale industry customers. This domino effect can lead to a decline in overall employment and economic activity within the region (equation 4.1). When considering the expansion of business operations by industry parties (2C), the impact on job creation may not be proportionate. While significant expansions, such as the introduction of large-scale equipment, can generate additional revenue, they may only require a minimal increase in the workforce which is negligible [expert 5& 6]. The societal impact of demand congestion in the industry segment on the employment indicator can be calculated with equation 4.1:

$$\text{Employment (1C)} = \text{Denied new LC contracts } [-] * \text{Response 1C } [\%] * -\text{Average number of employees } [-] * \text{Domino effect} \quad (4.1)$$

If a large-scale electricity customer in the industry segment is unable to settle (1C), this would lead to a notable decrease in the city's CO_2 emissions. Following the source approach for electricity emissions and the consumption approach for fossil fuel sources, their fossil fuel CO_2 emissions would cease within Amsterdam's boundaries. This reduction in emissions could have positive implications for the city's sustainability goals and environmental performance. However, it is essential to consider the potential trade-offs associated with job losses and economic impacts, as well as the overall effectiveness

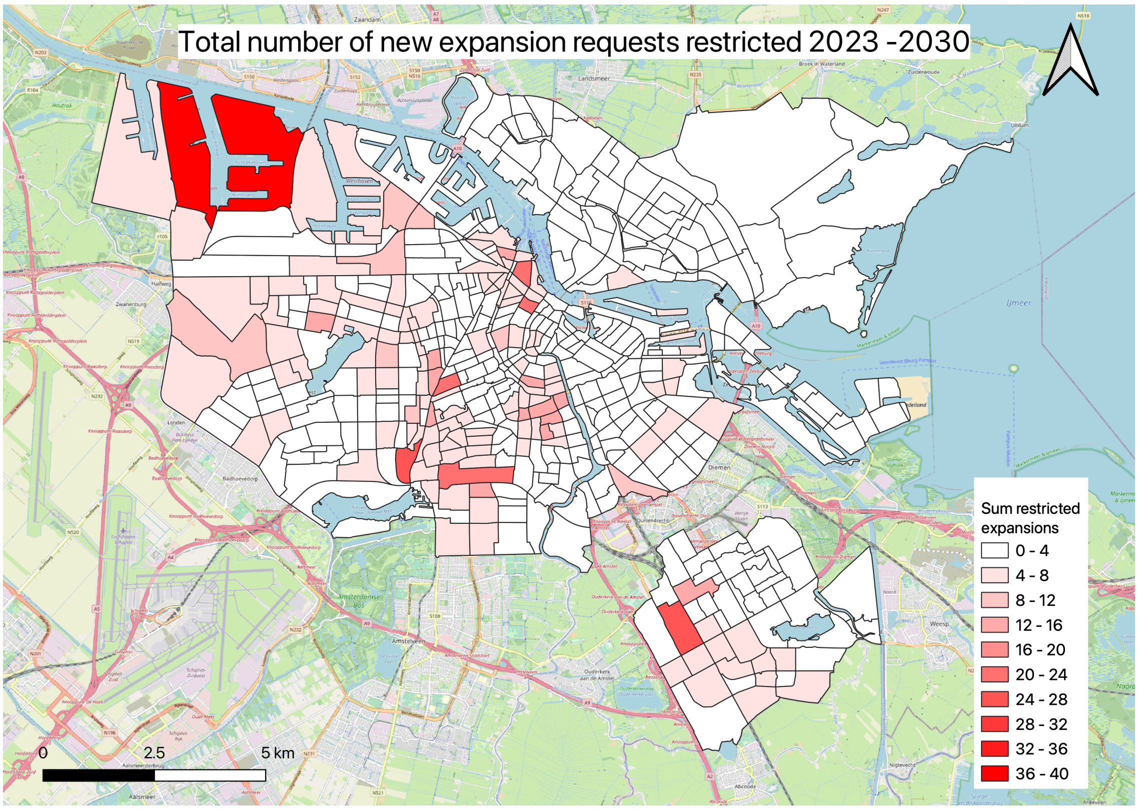


Figure 4.15: Sum of industry large-scale customer expansion requests denied in Amsterdam 2023 - 2030

of emission reduction efforts in light of Amsterdam's broader energy and climate strategies.

"If an industry party did not have access to the electricity it needs, they might consider alternative solutions such as gas turbines or steam power. However, these solutions may not be practical, financially viable or even sufficient to meet the shortage." [expert 5 & 6]. This segment will not resort to diesel generators, but to alternatives such as gas turbines, steam and hydrogen [expert 5 & 6]. I am assuming that response 2A is only chosen for business growth, which determines the size of the expansion requested. The emissions associated with 2A can be calculated with equation 4.3.

The industry segment in Amsterdam is responsible for emitting approximately 23% of all CO_2 emissions, with only 4% attributed to electricity usage. Consequently, if sustainability plans within the industry segment cannot proceed (2C), the industry will maintain their heavy reliance on fossil fuels. Equation 4.4 measures the sustained emissions from energy consumption from gas following the consumption approach. This could be complemented with other fossil fuel sources if needed. When an expansion is requested for business growth, I assume it will be done sustainably, meaning that it is not accompanied with additional usage of fossil fuels. As such, electricity shortage for business expansion (2C) has no impact on the CO_2 indicator. The societal impacts of demand congestion in the industry segment on the CO_2 indicator can be calculated with equations 4.2, 4.3 and 4.4.

$$\text{CO}_2 \text{ (1C)} = \text{ Denied new LC contracts } [-] * \text{Response 1C } [\%] * - \text{ Total gas consumption } [m^3/year] * \text{ CO}_2 \text{ coefficient of gas } [kg\ CO_2/m^3] \quad (4.2)$$

$$\text{CO}_2 \text{ (2A)} = \text{ Waiting LC expansions } [-] * \text{Response 2A } [\%] * \text{Total electricity consumption } [kWh/year] \\ \text{Expansion request } [\%] * \text{Gas turbine alternative } [\%] * \text{CO}_2 \text{ coefficient of gas turbines } [kg\ CO_2/kWh] \quad (4.3)$$

$$CO_2 \text{ (2C)} = \text{ Waiting LC expansions } [-] * \text{ Response 2C } [\%] * \text{ Sustainability reason } [\%] * \text{ Total gas consumption } [m^3/year] * \text{ Electrification } [\%] * CO_2 \text{ coefficient of gas } [kg\, CO_2/m^3] \quad (4.4)$$

As this analysis serves as a demonstration of the framework, estimated values are utilized for the variables. A comprehensive outline of the parameters employed and the data sources on which they are based can be found in Table D in Appendix D. Given the simplicity and linearity of the formulas used, a sensitivity analysis at a 10% threshold is not conducted. The outcomes of the analysis are presented in Table 4.9. It illustrates the societal impacts of denied new LC contracts on an annual and cumulative basis. It is worth noting that the societal impacts of denied expansions are calculated with consideration of the cumulative waiting list. Consequently, these emissions are already accounted for cumulatively until the expansions are taken from the waiting list (represented by the area turning 'green').

	2023	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Jobs (1C) #/year	- 1.866	- 1.770	- 1.455	- 1.486	- 1.676	- 1.423	- 1.328	- 2.227
Jobs (1C) # cum.	- 1.866	- 3.636	- 5.091	- 6.577	- 8.253	- 9.676	- 11.004	- 13.280
CO_2 (1C) kt/year	- 3,076	- 2,920	- 2,398	- 2,450	- 2,763	- 2,346	- 2,190	- 3,754
CO_2 (1C) kt cum.	- 3,076	- 5,996	- 8,394	- 10,844	- 13,607	- 15,953	- 18,143	- 21,897
$CO2$ (2A) kt/year	+ 1,391	+ 2,782	+ 3,565	+ 4,139	+ 4,922	+ 4,849	+ 5,068	+ 5,671
CO_2 (2C) kt/year	+ 3,718	+ 7,435	+ 9,527	+ 11,063	+ 13,155	+ 12,959	+ 13,546	+ 15,157

Table 4.9: Total societal impacts in the industry segment per year in Amsterdam

Figure 4.16 provides a neighborhood-level visualization of the cumulative sum of missed employment for the years 2023 to 2030. Figure 4.17 provides a neighborhood-level visualization of the cumulative sum of "saved" CO_2 emissions for the years 2023 to 2030 caused by response 1C. The figures highlight the uneven spatial distribution across different neighborhoods. Since the equations used for this analysis are linear formulas and based on the number of new LC requests, this distribution is equal to that shown in Figure 4.14. Considering that option 1C is estimated to be 100%, the analysis can be performed on a neighborhood aggregation level. However, since responses 2A and 2C are less than 100% and most neighborhood values of waiting expansion requests are below 10, conducting the analysis at such a low aggregation level would requires excessive rounding and thus not yield accurate results.

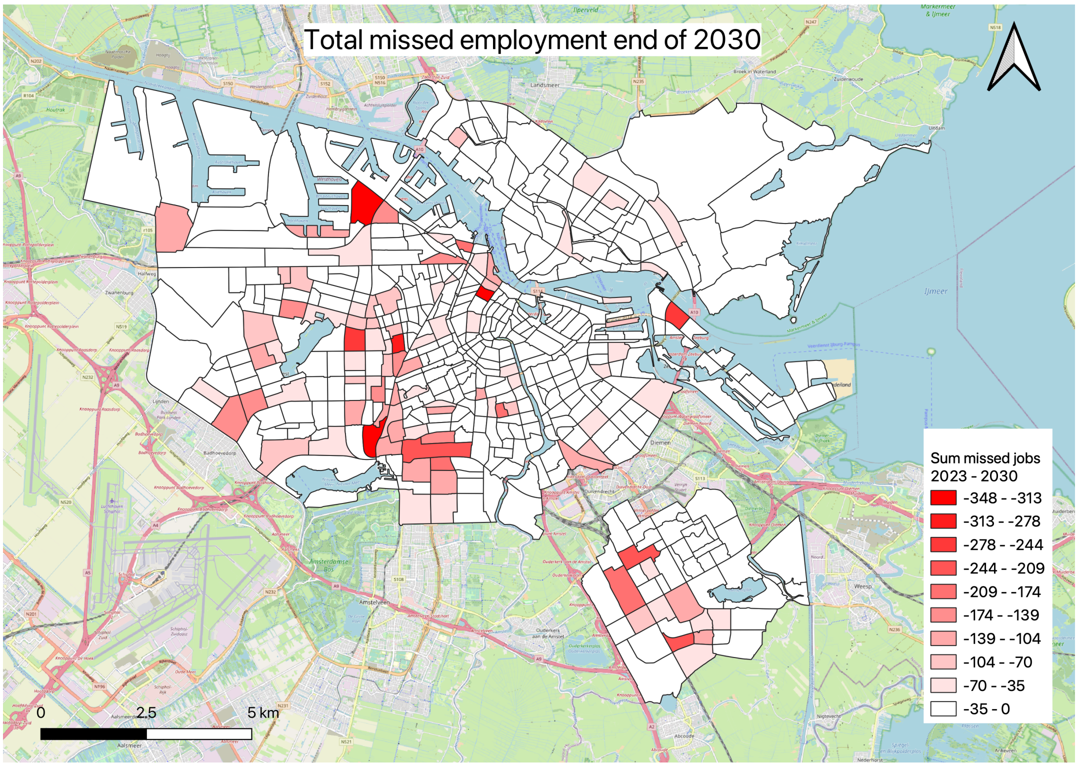


Figure 4.16: Sum of missed employment in the industry segment in Amsterdam 2023 - 2030

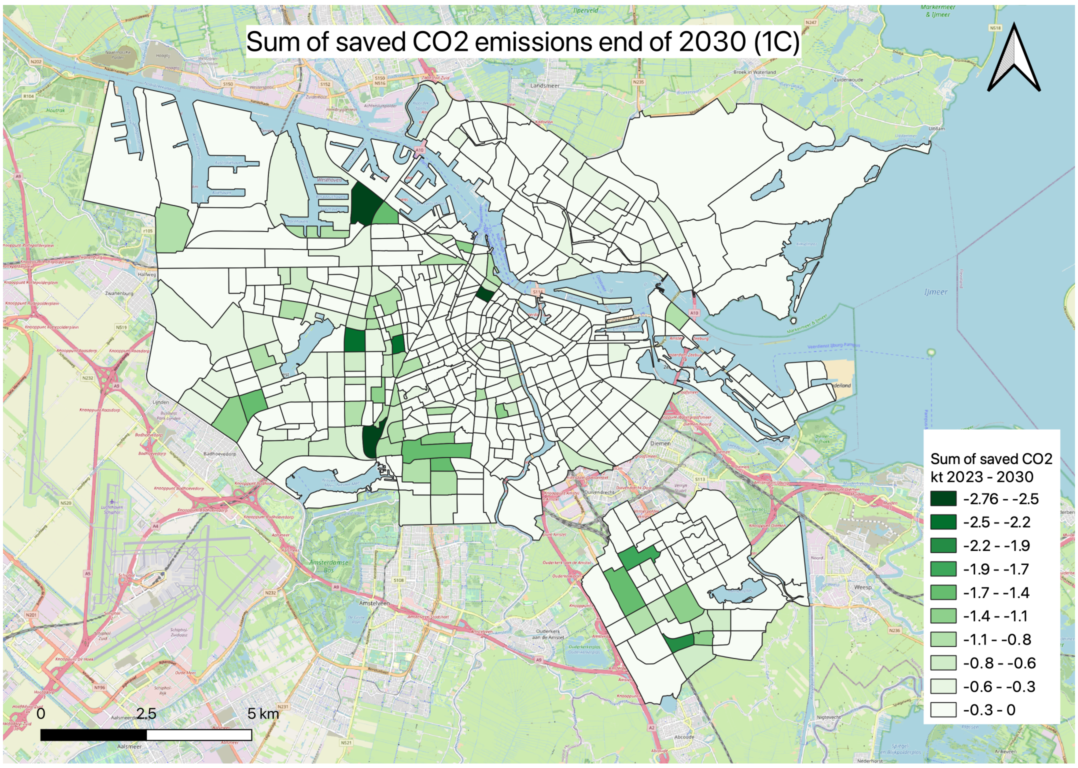


Figure 4.17: Sum of saved CO_2 emissions (1C) in the industry segment in Amsterdam 2023 - 2030

4.6. Summary of results

SQ1: *"How does congestion impact the functioning of the electricity system?"*

Firstly, it is observed that thermal overloading, which could jeopardize the reliability of the electricity system, rarely occurs. This indicates that congestion does not significantly impact the overall reliability of the system. In terms of accessibility, this research shows that small-scale customers (SC) generally enjoy an uninterrupted access to electricity services. Transport capacity is reserved specifically to cater to the needs of SCs, ensuring that their accessibility remains unaffected. However, certain circumstances are identified that could lead to challenges in SC accessibility. For instance, SCs may face delays of several months in obtaining a larger SC connection due to limited availability of technical staff. Furthermore, there is a potential risk that capacity reservations may prove inadequate, or congestion may arise on the low-voltage grid, directly impacting SCs.

Although SCs themselves may not experience direct impacts, they can be indirectly affected by the transport restrictions imposed on large-scale customers (LC). When a feeding area is designated as "congested", the rules of transport scarcity come into effect. Transport restrictions are being placed on LC contract requests, including new contracts, LC expansions, or expansions from SC to LC. Consequently, the notion of universal access to electricity services is called into question. The findings suggest that accessibility is no longer guaranteed for all consumers, as it becomes spatiotemporal-specific and dependent on the type of connection required. LCs either have access to electricity 99.99% of the time, or 0%. The DSO provides no specific information regarding the end-date of congestion or the position of the request on the waiting list.

SQ2: *"What are the consequences of demand congestion and how do these vary per affected customer segment?"*

Two general scenarios are identified: the rejection of a new contract request and the rejection of a expansion request. For each scenario, three response categories (A, B, and C) are identified, resulting in a total of six responses. I exclude certain less probable responses, such as the decision to relocate from a current location to another location in the city if an expansion is not granted. The choice of response by the large-scale customer is sometimes involuntary due to force majeure circumstances. Category A and B encompass responses where alternatives are found to consume the requested electricity. Category C represents a structural electricity shortage. This hinders operations within the city, restricts business expansion, and impedes sustainability plans that rely on electricity. Segmenting the customers into four categories —industry, commercial business, public services, and urban development— revealed varying responses to demand congestion.

Within the industry segment, the options are limited to either face shortages or resort to fossil fuel alternatives. These alternatives are costly and environmentally detrimental, which are thus often not chosen by the industry due to their high energy consumption profile. As a consequence, this segment is left with a substantial amount of unmet electricity demand. In contrast, the commercial business segment possesses more flexibility in responding to demand congestion. With lower energy intensity and the ability to make investments with reasonable payback periods, this segment has a wide range of opportunities to explore alternatives, which are ultimately based on financial considerations.

The urban development segment faces a significant risk of experiencing shortages, as project developers base their decisions primarily on financial viability. In many cases, the alternatives prove to be insufficient of their cost prohibitive. The absence of new contracts for bouwstroom for non-housing projects will result in the stagnation of construction. In the public services segment, the decision-making process varies depending on the level of involvement of the municipality. Before phase 4, the municipality is decision maker, whom are likely to pursue alternatives, resulting in high public costs. On the other hand, if project developers have decision-making authority, they may opt to cancel projects. When expansion is necessary for sustainability, the choice is most likely to face structural shortages. The municipality of Amsterdam is currently in the process of developing an approach to clarify its responsibility in providing assistance to congestion relief in this specific segment.

Experts in the field emphasize the uniqueness of the phenomenon, with little comparable examples in other cities. As a result, drawing strong assumptions and making generalizations is challenging. The responses to demand congestion are highly case-specific of nature, thus such overarching conclusions take away some nuance.

SQ3: *"What are potential societal impacts of demand congestion in developed societies?"*

I first followed the context of the six ambitions of the municipality of Amsterdam -inclusiveness, vitality, health, livability, sustainability, and compactness- to explore the potential societal impacts of demand congestion. I found that all ambitions, except for compactness, are affected by demand congestion. However, the current procedure for assessing congestion impacts, managed by Team EVA, lacks specific metrics, making it difficult to compare the effectiveness of policies, analyze different years, or compare findings across different neighborhoods. To address these challenges, an indicator-based approach is proposed as a means of evaluating the societal impact. I use the sustainable impact assessment method due to its holistic nature, incorporating environmental, social, and economic dimensions. By aligning with the principles of sustainable development, this approach aims to maximize societal welfare as a whole. It can be adapted to various analysis tools, ensuring flexibility in its application.

I identify a range of potential societal impacts caused by demand congestion spanning across the dimensions of sustainable development, although their severity may vary. Policy makers must consider their own specific context and priorities when determining the importance of these impacts and selecting them as indicators. The comprehensive list of impacts generated in this study serves as a valuable resource for policy makers in their decision-making processes. For my case study, the key indicators are housing, CO_2 emissions, and employment. These are particularly important in the context of Amsterdam, where housing shortages and sustainability goals are of high importance.

SQ4: *"Which areas in Amsterdam are predicted to experience congestion until 2030?"*

The examination of supply congestion indicated that there is no supply-related congestion in Amsterdam. The existing capacity of the medium-voltage substations is deemed sufficient to meet the minimum peak-load under the Amsterdam Ambition scenario from now until 2030. However, the analysis revealed that demand congestion is a significant problem, anticipated to occur in almost every part of the city. Despite the planned expansions, approximately 80% of the Amsterdam area is predicted to experience congestion sometime between 2023 and 2030. The spatial distribution of affected regions is not uniform, with a concentration of congestion projected in the western and southwestern areas of Amsterdam.

The validation of 2022 highlights discrepancies between the scenario and actual observations, indicating that it does not comprehensively capture the complex dynamics of electricity usage. Nonetheless, this does not diminish the significance of the analysis, which serves as an example of an undesirable scenario among multiple potential futures. The findings shed light on the impacts of the municipality's current plans on the electricity grid and underscore the need for proactive measures to address congestion issues. These results provide valuable insights into the predicted areas that may experience congestion in Amsterdam until 2030, allowing decision makers to make area-specific efforts.

SQ5: *"What are the societal impacts of from demand congestion by location, customer segment, and year in Amsterdam?"*

In general, the impact on CO_2 emissions is primarily driven by electricity shortage and alternative solutions. The magnitude of the impact is contingent upon the specific alternatives chosen and the energy needs of the affected segments. My findings shows that the biggest impact on this indicator are likely to come from the industry and commercial business segment. This indicator is greatly affected in regions where many expansion plans for sustainability (2C) are denied. Following the source approach for electricity consumption and the consumption approach for fossil fuel consumption, the net CO_2 emission impact is predominantly attributed to fossil fuel-driven generators and remained reliance on fossil fuels. However, when considering this measurement approach, electricity shortage will also significantly reduce CO_2 emissions where companies choose not to settle in congested areas (1C).

Regarding the impact on employment, electricity shortage has the only effect on this indicator, with 1C playing a pivotal role. Segments most affected by job losses will be industry and urban development, with the magnitude of the impact being dependent on the average workforce size per segment. Response 2C, which includes no business growth, is expected to have a lesser impact on jobs compared to response 1C.

In terms of housing, the shortage responses in the public services and urban development segments have the only direct effect, primarily response 1C. The decision to postpone urban development lies with the municipality if congestion is declared before the land tendering phase (phase 4). This decision will likely be to not proceed with severe congestion, thereby avoiding the creation of "sleeping neighborhoods." If a project is already in phase 4, the response of the project developer determines the impact on the housing indicator. Mixed-use projects may face delays or even be halted if the commercial parts are unable to operate due to congestion, consequently impacting the overall housing construction timeline. Experts indicate that this decision-making process is very challenging and thus it is difficult to predict accurately.

Response B has no significant impact on any of the chosen indicators, while response A only affects CO_2 emissions if dirty alternatives are employed. Response C has wide-ranging impacts across all three dimensions. The magnitude and direction (positive or negative) of these impacts vary across segments due to several factors. These factors include the total energy consumption, the energy mix, the average workforce size, the types of alternatives employed, as well as the scope and scale of their sustainability and business growth plans. These segment-specific societal impacts of demand congestion can be measured with the developed holistic assessment framework, which allows for a comprehensive but comprehensible evaluation. It serves as a valuable tool for policymakers, stakeholders, and researchers to assess and address the challenges associated with demand congestion and guide decision-making processes towards more sustainable and efficient energy management in the city.

The demonstration of the framework shows that between 2023 and 2030 a total of 420 new contracts requests will be denied in the industry segment, with an average of 53 per year. It makes sense that there are not so many parties settling per year, as there is already little space and the investment costs are high. As a consequence, the city will have endured a employment reduction of a total of 13.280 jobs in the industry segment by the end of 2030. This is accompanied with CO_2 emission reductions of -98 kt by the end of 2030. The analysis further more shows that by the end of 2030, a cumulative total of 1.007 parties are awaiting the approval of their expansion request. This accumulation is highest in the region of the Port of Amsterdam. As a result of fossil fueled alternatives, demand congestion causes an increase of 32 kt to be emitted between the years 2023 and 2030. Furthermore, due to a lack of electrification, this segment will emit 87 kt more emission between 2023 and 2030 as opposed to a situation without a waiting list.

5 Discussion

First, I explore the scientific contribution of the research findings and their alignment with and enrichment of existing literature. Shifting to the second section, I examine the data collection and analysis process, evaluating its limitations. Based on these limitations, I propose directions for future research to deepen our understanding of demand congestion and its implications. In the third section, I provide targeted recommendations for decision-making, starting with the municipality of Amsterdam and subsequently extending them to municipalities more broadly. Additionally, I offer recommendations specific to Distribution System Operators (DSOs) and regulators.

5.1. Discussion of the results

This study makes a valuable contribution to the literature on electricity grid congestion by addressing the societal implications of demand congestion, which is a relatively new and understudied phenomenon. While previous studies have predominantly focused on technical solutions for supply congestion and renewable energy curtailment, this research provides unique insights that can assist decision-makers in improving their congestion management strategies. It also complements the existing literature on the relationship between energy consumption and sustainable development. Through qualitative and quantitative methods, the research enhances our understanding of the consequences of unmet electricity demand in urban areas of developed societies.

More specifically, this research significantly contributes to the understanding of the medium voltage distribution network serving the urban area and its strains. Most congestion literature concentrates on low or high voltage networks, underscoring the value of the pioneering demand congestion prediction analysis developed in this study. It is important to note that the generalizability of this analysis is contingent upon the presence of similar management systems and styles for the electricity grid in other highly populated urban areas. Nevertheless, this analysis can serve as inspiration for other researchers focusing on congestion in the urban electricity grid.

Adding to that, this research addresses a significant gap in literature by introducing a holistic impact assessment framework that was previously absent. This framework provides decision-makers with a quantitative tool to assess the societal impacts of demand congestion in highly populated urban areas. By demonstrating the usability of the framework, this work validates its effectiveness as a decision-making support tool. The framework can be adapted and utilized for similar research in other urban areas, offering a valuable contribution to the field.

By adopting a case study-mixed methods approach and incorporating the valuable perspectives taught in the MSc. Engineering and Policy Analysis program, this study presents a comprehensive and multidimensional analysis. By employing a social, environmental, and economic lens, as well as governmental and organizational perspectives, this research goes beyond the conventional focus on purely technical aspects. This unique research approach expands the understanding of electricity grid congestion and positions it within a broader context. The insights and recommendations generated from this analysis significantly contribute to the improved management of this complex urban challenge.

5.2. Discussion for future research

It is important to acknowledge certain limitations and considerations associated with the data collection and analysis process. By addressing these aspects, this study gains clarity and enhances its contribution to the field. Future research can build upon this work, but it is essential to address the limitations as discussed below.

5.2.1. Limitations of data collection & analysis

Interviews

One of the data collection methods of this research is conducting semi-structured interviews. The sample size of interviews was determined based on time constraints and stakeholder availability, constricting the validation of assumptions and behaviors found and limiting the diverse representation of perspectives. These limitations can be mitigated by broadening the participant selection to other networks, such as from different key stakeholders in the multi-actor arena. This could potentially be done through surveys to enhance the sample size. However, obtaining participation from the appropriate individuals within these parties can be challenging.

Furthermore, as this is a relatively new phenomenon, interviewees have been hesitant to discuss demand congestion with parties from the affected segments. As a result, at times they were unsure what the responses could be, making it difficult to draw definitive conclusions. Adding to that, the insights from the interviews and the assumptions taken might be subject to change. This highlights the need for further research to capture a more nuanced understanding of segment behaviors.

Segmentation of affected customer groups

The segmentation conducted for sub-question two yields four distinct segments, providing an initial basis for analysis. However, it is important to acknowledge that certain generalizations had to be made due to the diverse nature of the parties within each segment. For example, the commercial business segment comprises a wide range of parties, making it difficult to make precise assumptions about their behavior.

Impact indicator exploration and selection

Regarding the exploration of potential impacts, it would be beneficial to conduct a brainstorming session with all stakeholders in the multi-actor network, to ensure independence and incorporate diverse perspectives. However, given the focus on societal impacts, initial discussions were primarily held with public government representatives, who prioritize societal interests rather than individual financial interests. While indicators were validated with my supervisors of team EVA, further validation with a wider range of stakeholders would be thorougher.

Demand congestion prediction analysis

Analyzing the peak-load impact on the electricity grid involves various limitations to consider. The analysis was based on the Amsterdam Ambition scenario, which represents the impact scenario following the municipal plans and regulations. However, it does not necessarily reflect the most plausible electricity usage scenario. Additionally, the analysis did not consider the impact of large-scale customers (LCs) directly fed by a substation, which potentially leads to later congestion in certain areas than in reality. Furthermore, the exclusion of demand and supply from outside Amsterdam that is fed through the city's grid infrastructure, may also impact congestion patterns.

The exclusion of upstream bottlenecks from the analysis is a necessary simplification to focus specifically on the issue of transport scarcity caused by demand congestion in the medium-voltage network in the urban area. While this simplification limits the realism of the analysis, it enables a deeper understanding of the predicted areas that will suffer from transport scarcity caused by demand from within the city, which facilitates the development of local targeted strategies.

Challenges were encountered in obtaining accurate data related to substations, as datasets sometimes provided contradictory information. The construction plans for substations are subject to change, and uncertainties exist regarding the exact capacity, location, and operational timelines of newly constructed substations. The expected allocation of capacity of new substations for feeding the feeding area was also not known. In the absence of specific information, it was assumed that all capacity of new substations would be used for feeding the area. Additionally, the data provided for the construction dates of substations was aggregated at an annual level, limiting the granularity of analysis. Adding to that, the Voronoi technique employed to create feeding areas, while reasonable, is not without limitations and may introduce some uncertainty in delineating the exact boundaries. As such, it is crucial to be aware of the approximation involved in the Voronoi approach.

The validation of the congestion prediction analysis indeed reveals that the findings are not 100% conclusive. Therefore, the results of the analysis should be regarded as indicative of one possible future scenario, but it should not be considered as the definitive or a sole representation of the future. Despite these limitations, the aggregated analysis presented in this study provides a initial insights into the predicted areas that are prone to transport scarcity due to demand congestion in Amsterdam, based on the plans of the municipality. It is recommended to undertake further validation and refinement of the congestion prediction methodology to improve the accuracy of future assessments.

Holistic assessment framework for a societal impact analysis

Since the holistic assessment framework encompasses four segments and three indicators, conducting a comprehensive assessment for the case of Amsterdam within the given time constraints was not feasible. Consequently, a decision was made to focus solely on the industry segment. While the assessment was limited to a single segment, it is important to recognize that the findings serve as a valuable starting point. They demonstrate the potential and efficacy of the holistic assessment framework, showcasing its ability to capture and evaluate the societal impacts of demand congestion in urban energy systems.

To forecast the natural growth of the industry segment in Amsterdam, an extrapolation is performed using historical data. It is important to acknowledge that extrapolation, while providing an estimate, is inherently limited and uncertain in nature. Therefore, it should be regarded as a rough approximation rather than an exact prediction. Thorough validation and refinement of the projections, including trend analysis, research on the economy, and consideration of congestion's impact on the city's attractiveness for settlement, can enhance their accuracy and reliability.

Due to time constraints, the analysis relies on various assumptions, some of which have been substantiated while others have not. One notable assumption is that 100% of the industry segment in Amsterdam requires a LC connection. This assumption was made to avoid excessive rounding, especially considering that most neighborhoods had values below 10. Taking a higher aggregation level, such as districts, could be an alternative solution. By considering 85% of 150 establishments at the district level, a more robust analysis could be conducted instead of relying on small sample sizes of 5 establishments per neighborhood.

The prediction of the number of LC expansion requests made per year is based on several assumptions, in absence of an alternative. The input values reported in Table D.3 were collected to the best of my ability, but could not be validated. To address these limitations, conducting a targeted survey focused specifically on the industry sector is advisable. This survey should collect data directly from industry parties and help refine our understanding of electricity consumption within the industry segment in Amsterdam. This survey should delve into the factors considered by segment parties when making decisions regarding the expansion of their business operations or sustainable investments. It would enhance the accuracy and reliability of the analysis by validating the assumptions made.

It is important to interpret the results of the analysis while considering these limitations. The societal impacts identified heavily rely on the input values used for the variables and thus should be seen as one of many possible future scenarios. To accurately quantify the precise impact resulting from this segment, conducting a more detailed analysis and validation is required. Nevertheless, the generalizations and assumptions made in this study enable a comprehensible assessment of the potential societal impacts, to provide preliminary insights into the severity of the problem at hand.

I would recommend to conduct the holistic assessment framework for all four segments and three indicators: industry, commercial buildings, public services, and urban development, and CO_2 emissions, jobs, and housing. This could either be done by expanding this case study, or selecting another case. This would provide a more thorough understanding of the societal impacts of demand congestion in a highly populated urban area in a developed society.

5.2.2. Research avenues to explore

Several areas warrant further exploration based on the findings of this study, presented in no particular order of importance:

- Conducting a comparative analysis of transport restriction rules employed by other Dutch or international DSOs would provide valuable insights into effective strategies for managing demand congestion.
- Future studies could explore the impact of low-voltage congestion and investigate potential societal impacts in that context.
- Expanding the analysis to consider multiple impact scenarios, such as low, medium, and high, would provide a more comprehensive understanding of the potential variations in demand congestion and enable the development of targeted strategies for different scenarios.
- Case studies focusing on specific neighborhoods or segments heavily affected by demand congestion, such as the regions identified in this research, would offer valuable detailed insights into the specific challenges and potential solutions within those contexts.
- Investigating the societal impacts of demand congestion through a thorough Social Cost-Benefit Analysis (SCBA) would provide a comprehensive assessment of the costs and benefits associated with different strategies and interventions.
- Comparing Amsterdam's experiences with other cities or regions facing similar challenges related to electricity system transport scarcity would allow for cross-context analysis and identification of lessons that can inform Amsterdam's approach.
- To enhance collaboration in the multi-actor network, conducting a Multi-Criteria Analysis (MCA) that incorporates defined indicators and weights based on an actor analysis would facilitate informed decision-making and resource allocation.
- Investigating the spatial distribution of the societal impact of demand congestion and its implications for spatial equity and social justice would contribute to a more comprehensive understanding of the challenges and opportunities for addressing congestion-related disparities in Amsterdam.
- It would be valuable to conduct further research to clarify roles, responsibilities and resources within the multi-actor network specifically in context of congestion.

These avenues of future research could build upon the findings of this study and provide valuable insights for policymakers, stakeholders, and researchers working towards sustainable and equitable solutions to address demand congestion in the electricity grid.

5.3. Recommendations for decision making

These recommendations aim to mitigate demand congestion and to minimize its societal impacts. They are directed towards the municipality of Amsterdam, to municipalities in general and to DSOs and regulators. Due to the novelty of this phenomenon, there are still many unknown aspects, such as the division of responsibilities, accountabilities and associated costs. It is important to clear this up, to accelerate decision making on congestion management. Whilst this remains unclear, collaboration and resource pooling among actors in this multi-actor arena is therefore recommended.

5.3.1. Recommendations for the municipality of Amsterdam

The municipality of Amsterdam and Liander have made substantial efforts to facilitate the rapid expansion of the existing electricity infrastructure. However, despite these endeavors, my research has revealed that congestion is anticipated to occur in numerous regions over the coming years, even with the planned expansions. Recognizing the limitations in accelerating the infrastructure development even further, I recommend that the municipality also prioritizes congestion relief measures to mitigate the societal impacts of this emerging phenomenon. With an estimated 80% of Amsterdam projected to experience demand congestion between 2023 and 2030, immediate action is imperative to alleviate the repercussions associated with demand congestion.

This research creates a first exploration of the negative societal impacts of demand congestion, highlighting the wide-ranging impact of demand congestion. In Amsterdam, impacts such as CO2 emissions, housing, and employment are particularly important, given the municipality's ambitious sustainability goals and the target of constructing 7.500 dwellings annually. Demand congestion poses a significant risk to achieving these objectives. It is found that five out of the six ambitions of the municipality of Amsterdam will be affected by demand congestion. Therefore, it is advisable that the municipality prioritizes impacts they aim to mitigate, and develop area- and segment-specific strategies to effectively alleviate these impacts. To accomplish this, further research is needed to quantify these specific impacts, in order to inform decision-making and allocate resources effectively.

The results show that many affected large-scale customers will struggle when imposed with a transport restriction. Some are forced to face the implications of electricity shortage, others may be able to find an alternative to meet their energy demands. I highly recommend allocating resources towards establishing a specialized team dedicated to addressing the consequences of, and developing solutions for, demand congestion. This team could be structured following the large-scale customer segments provided in this research. Given that demand congestion is expected to persist in the coming years, it is crucial to build a repository of generalizable knowledge to expedite the problem-solving process. This approach will reduce the time required to address individual cases and enhance the overall success rate.

Additionally, it is essential to ensure that the other divisions in the municipal organization are well-informed about this significant urban challenge as well. By fostering a broad knowledge base across the organization, the city can better tackle the multifaceted nature of the problem.

My study has revealed an inequitable spatial distribution of affected regions, with a notable concentration in the western and southwestern areas of Amsterdam. In order to uphold the objective of maintaining an inclusive city, it is imperative for policymakers to address these disparities. This can be accomplished through area-targeted investments in congestion relief solutions, that are specific to particular segments or impacts. This should ensure a more balanced distribution of congestion impacts.

An example for this is the concentration of industrial areas in the Port of Amsterdam. This segment is very likely to experience structural electricity shortage, with many negative societal impacts as a result. My analysis shows that by the end of 2030, the city will have 13.280 less job offerings in the industry segment due to demand congestion. Furthermore, with many parties on the waiting list for an expansion for sustainability, it can be expected that this segment will emit a total of 87 kt more CO_2 between 2023 and 2030 as opposed to a situation without demand congestion. An area-targeted and segment-specific solution could alleviate these impacts, such as the development of alternative energy infrastructures. This may involve the construction of infrastructure for hydrogen and steam, to prevent sustainability plans from being halted in the industry segment.

The analysis did not identify any significant supply congestion issues in Amsterdam during the studied period. Therefore, at present, it is not necessary to prioritize efforts specifically towards supply congestion. However, it is advisable to monitor the future growth in electricity supply and infrastructure development to reassess the need for addressing supply congestion after 2030.

5.3.2. Recommendations for municipalities in general

These recommendations are based on the research findings and my internship experience at the municipality of Amsterdam. They are specifically aimed at decision-makers in municipalities already facing or seeking to mitigate demand congestion. They are applicable to other Dutch municipalities with densely populated areas, but can be relevant to countries with similar multi-actor network structures and electricity system management as well. Decision-makers should benefit from the lessons learned in Amsterdam and improve their approaches to demand congestion management.

Collaboration in the multi-actor network: Engaging with key stakeholders, such as the DSO and Transmission System Operator (TSO) through a task force, but also with the regulator and other key actors, leads to more effective problem-solving and decision-making when dealing with grid congestion. It allows the actors in the multi-actor arena to overcome their limitations and benefit from shared resources and information.

Provision of information: I observed that in general there is significant confusion surrounding congestion, particularly for those affected by it. The key stakeholders, such as the DSO, TSO, regulator and governments, should prioritize providing information and clarity, explaining the problem to the public so that they can improve their anticipation and responses.

Assessment of societal impact of congestion: I recommend municipalities to establish an indicator-based assessment framework to evaluate the impacts of demand congestion. The framework proposed in this study could serve as a valuable base to work with. They should carefully select indicators that are relevant, feasible to measure, and align with the priorities of the city. When making such a selection, they should consider their resources and constraints, such as data availability and measuring tools. I advice to focus on key impact indicators that provide meaningful insights into the consequences of demand congestion, tailored to the specific circumstances of the case.

The assessment framework should consider the environmental, social, and economic dimensions. This holistic approach will provide a comprehensive understanding of the overall impacts and facilitate substantiated and robust decision-making that promotes long-term sustainability and societal welfare. It is important to regularly monitor and evaluate the effectiveness of implemented policies and measures of congestion management. This ongoing assessment will help identify emerging trends, measure progress, and inform evidence-based decision-making. By gathering data and feedback, policymakers can make necessary adjustments and improvements to their strategies.

Minimize societal impact with congestion relief: I recommend municipalities to focus on congestion relief solutions that optimize efficiency and facilitate relocation to less congested areas, as these have no direct negative impact on any of the chosen indicators in this research. Efforts should also be focused on supporting sustainable alternatives to electricity production, particularly in the segments of commercial businesses and public services. It should be recognized that structural electricity shortage has widespread impacts across all three dimensions, but this issue cannot be easily resolved without expanding and upgrading the electricity grid infrastructure.

Segment-specific solutions: Local policy makers should leverage the opportunities and goodwill of stakeholders involved in the public services segment to prevent shortages and ensure the continuous operation of critical facilities. Furthermore, I would advice to put the main focus on the urban development and industry segments, as they are particularly vulnerable to structural electricity shortages. Prioritize solutions that address their specific needs, taking into account the requirements and characteristics of these sectors.

My study has shown that commercial businesses have various options to respond to congestion, minimizing the experience of structural electricity shortages. Actively assist them in exploring their alternative solutions, such as by providing support through a 'fixer' like Amsterdam is doing, or by facilitating collaborations between the segment and the right people at the DSO. It is important to avoid reliance on diesel generators. Municipalities should ensure that the burden of addressing congestion does not disproportionately fall on entrepreneurs. Subsidies and financial support, such as provided by the current efforts of the city of Amsterdam, can provide valuable assistance.

Impact-specific solutions: It is recommended to actively search for innovative solutions to enhance sustainability, that can (temporarily) replace the need for electricity, as currently it is often a boundary condition. These efforts should particularly focus on the segments public services and industry, which most frequently have to decide to delay sustainability expansions. Solving the impact on jobs, resulting from companies unable to settle, is challenging in the short term. Municipalities could monitor and track this impact, especially considering the spatial distribution.

To minimize impacts on the housing indicator, policy makers should acknowledge the financial risks faced by project developers, and maintain a close relationship to understand their challenges. Municipalities should actively work together with project developers to mitigate the decision to cancel project plans. The recommendation to provide financial support to the public services segment serves to prevent ”sleeping neighborhoods” and to maintain the liveability of the city. If housing is a priority to decision makers, they could consider constructing temporary ”sleeping neighborhoods” during congestion periods if necessary, to prevent delays.

5.3.3. Recommendations for DSOs and regulators

Following the example set by Amsterdam, I recommend that other Dutch DSOs make reservations specifically for small-scale customers (SCs). This proactive measure ensures accessibility to electricity services for SCs, such as residents, thus helps to avoid challenges they may face once confronted with demand congestion.

The current non-discriminatory reservation system in the Netherlands, based on a ”First-Come, First-Served” (FCFS) principle, has resulted in network congestion despite underutilization of reserved electricity. To address this, I recommend considering changes to the reservation system that take into account the start date and capacity requirements of projects. This would require collaboration and involvement from all stakeholders, including ACM, DSO, TSO, and governments. I would furthermore recommend to consider prioritizing new contracts over expansion contracts when allocating capacity. This approach sustains new business opportunities and enhances efficiency in capacity utilization, benefiting both existing and future customers.

Adding to that, it would be advisable for the regulator in collaboration with DSOs to explore the possibility of utilizing reserved capacity that is not expected to be used in the short term. This could include both the reserved capacity for SCs and the unused capacity of LCs within a certain timeframe. By allowing the temporary utilization of this unused capacity, transport restrictions can be delayed, providing some relief during periods of high demand.

I also recommend that DSOs consider the temporary nature of construction power and ensure its consistent availability. Currently, Liander allows project developers to utilize the reserved SC capacity that was reserved for the dwellings in mixed-use projects, as construction power for a maximum of two years. However, to maintain uninterrupted construction activities and prevent job losses within the construction sector, I advise making an exception for construction power in general, recognizing its temporary nature, rather than relying solely on a first-come, first-served principle. By guaranteeing timely and reliable access to construction power, the negative impacts of electricity shortages on construction projects, and consequently on housing shortages, can be mitigated effectively.

In regions affected by demand congestion, clear and effective communication between DSOs and their customers is crucial. I strongly recommend that DSOs establish a privacy-safe approach to provide regular updates to companies regarding their position on the waiting list for electricity connections. This transparent flow of information will empower companies to assess risks, plan their operations, and make well-informed decisions. By prioritizing such communication, DSOs can enhance the relationship with their customers, instilling a sense of control and addressing the frustrations that may arise from congestion. Maintaining a strong relationship among all stakeholders is paramount as it will facilitate collaborative efforts in finding effective solutions.

While demand curtailment is currently in place to prevent thermal overloading, it is important for DSOs to explore alternative options. One option is to utilize redundant capacity more effectively, maximizing the existing infrastructure. Additionally, adjusting the reliability levels from the current 99.99% to a slightly lower threshold, such as 98%, can potentially free up more transport capacity. These alternative measures should be carefully evaluated in terms of their impact on system reliability and the overall balance between capacity availability and congestion management.

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A

Background on the electricity system of the Netherlands

This subchapter contains four sections, that should provide a comprehensive understanding of the electricity system in the Netherlands and the various factors that contribute to the problem of transport scarcity in urban areas. The first section explains the assets of the electricity system, and discusses their physical and technical characteristics. The second section explores the multi-actor system involved in managing the electricity system, including the DSO, TSO, regulator, government, producers, and other stakeholders. Thereafter I describe the dynamics of supply and demand in the electricity system, including the concept of peak load and the flexibility of the system from both supply and demand perspectives. Finally, I discuss the distribution process of electricity, which provides an explanation on the concepts congestion and transport scarcity.

A.1. The urban electricity infrastructure

Electricity is transmitted at different voltage levels from the source to the end-user. At the first level, the national high-voltage grid carries electricity at a voltage between 50 and 400 kV to minimize energy losses over long distances and maximize transport capacity. From there, the voltage is brought down to a medium-voltage level of 10 to 50 kV for the regional grid. Substations, referred to as 'OS' in Figure 2.1, transform the voltage from high to medium. The electricity is then distributed using medium-voltage cables to smaller substations called 'transformer houses,' referred to as MSR in Figure 2.1), where the voltage is transformed to levels of 230 to 400 voltage on the local low voltage grid, which is the appropriate voltage level for consumption. All assets are crucial to ensure uninterrupted power supply. If an upstream asset lacks capacity or is down, the whole infrastructure downstream is affected.

The capacity of substations is a critical characteristic in the urban electrical power system. Substations are key assets that play a vital role in transforming and distributing electricity across the grid. They are equipped with various assets, including transformers, switchgear, and protection devices, which define their capacity. Depending on the specific needs of the substation and its feeding area, the most common types of transformations conducted are 150/50/10 kV, 50/20 kV, and 20/10 kV. A substation distributes the incoming electricity on different voltage levels depending on the use-case: it can either feed power (1) to large consumers directly connected to the substation, or to (2) transformer houses (MSRs) in their feeding area to provide electricity to the local distribution network, or to (3) another substation nearby (Liander, 2023). A 'feeding area' refers to the specific region that a substation caters with electricity services. It is worth noting that some substations may feed areas outside of the city, or some feeding areas in the city may be fed by substations located outside of the city, depending on the specific configuration of network topology. Because of these complex interdependencies, one cannot simply add up the capacities of all substations in the city.

Expanding the infrastructure of the electricity system in densely populated urban areas is a significant challenge. Amongst others, this is due to the considerable amount of public space required to accommodate it. A substation has an average surface of 3 km^2, with a range from 1 to even 5 km^2. Furthermore, the planning and development of a new substation comprises 5 to 8 years, which is a huge bottleneck for solving congestion problems on the short-term (Liander, 2023). Nonetheless, these primary assets of the urban power grid grid are expected to last, with proper maintenance, several decades. A substation occupies space above and below surface level. It is preferably located as close as possible to the consumer to improve efficiency and thus decrease electricity cost. An MSR has an average surface of 6 to 10 m^2 (Municipality of Amsterdam & Liander, 2021), of which a city needs in general several hundreds to thousands. The Dutch electricity grid is made up of more than 100.000 MSRs and 310.000 kilometers of cables (Netbeheer Nederland, 2021). These assets are constructed whilst making as little impact on public health as possible, complying to measurements set by health institutions such as the electromagnetic field (EMV) (Jetten, 2022).

The Dutch electricity system is one of the worlds most reliable. In 2021, the Dutch national grid was operational for 99.9997% of the time (Netbeheer Nederland, 2022). System operators have taken many measures to safeguard this percentage. One of the precautions taken is the incorporation of redundancy, similar to an emergency lane on the high way. This redundant capacity is solely addressed during outages and maintenance. Operators take these precautions, because they are both technically and regulatory limited to impact electricity flows on the grid. The innovation of the 'smart grid', which is the result of digitization by smart metering technologies, promises new opportunities for system operation (IqtiyaniIlham et al., 2017). The bidirectional information flow gives systems operators access to real-time data insights on the load behavior of the local network. This enables them to improve and innovate their management activities for network capacity, such as the deployment of flexibility. Adding to that, it allows consumers to adapt their consumption pattern based on actual market prices, increasing consumer participation and demand flexibility (Enexis, 2019). In general, it will lead to a more efficient and transparent system. The progress of this system transformation needs a systemic but contextual approach and will depend on funding, policy making, the economy and knowledge (Heymann et al., 2023; IqtiyaniIlham et al., 2017).

A.2. The multi-actor system

The liberalization of the electricity sector in the Netherlands marked a significant shift in the way the electricity system is structured and organized (Verbong & Geels, 2007); This new electricity law in 1989 followed the European guidelines. The separation of commercial activities from transmission and distribution system operation aimed to foster competition, reduce costs, and improve efficiency. The resulting multi-actor network consists of six independent roles: generation, transmission, distribution, supply, metering, and trading. A network, either intra- or inter-organizational, is a collection of individuals or entities with unique objectives, resources, and interests that rely on one another to achieve their respective goals (De Bruijn & Heuvelhof, 2018). This structure has enabled various producers and suppliers to offer electricity, providing consumers with the freedom to choose their own provider. However, in order to ensure the quality of grid management, system operators are not allowed to carry out any commercial activities other than managing the energy systems. The Dutch electricity grid is currently managed by one national transmission system operator and several regional distribution system operators (Netbeheer Nederland, 2019).

A.2.1. Distribution System Operator

In the Netherlands, the regional distribution grid is operated by six Distribution System Operators (DSOs), with three of them - Liander, Enexis, and Stedin - holding almost 95% of all connections (Figure 2.2). Every DSO is appointed a region to operate in to avoid competition because of the high investment costs. As per the law, the primary responsibilities of DSOs are to manage and maintain the medium and low voltage network infrastructure and efficiently invest in infrastructure expansion. They are legally obligated to always provide a client request with a physical connection to the grid in a non-discriminatory manner and to always deliver electricity as the agreed-upon capacity. Moreover, DSOs facilitate the functioning of the regulated electricity market along with the other stakeholders (Netbeheer Nederland, 2019). Since the governments (national, regional and local) are their shareholders, their focus is not on generating profits. Instead, their primary goals are to keep overall costs low, minimize power losses, and maintain the highest level of reliability and stability in electricity supply (Liander, 2023). Nevertheless, DSOs operate independently of the government, and their decisions are made by their own management and supervisory boards.

The changing nature of the electricity network - which now comprises more distributed generating units powered by volatile renewable energy sources - requires the role of DSOs to evolve (Hadush & Meeus, 2018). Distribution network management now requires a more active role rather than a passive one as before (Haque, Vo, et al., 2017). However, the implementation of this new role is not always straightforward as it requires significant changes in operations and processes. Moreover, the law and regulations imposed by the regulator make it difficult for DSOs to change , as they need to comply to strict rules regarding grid stability, security, and quality of supply. As a result, DSOs do not always have adequate instruments or resources to effectively manage the distribution networks. Nevertheless, they are actively seeking ways to adapt to the changing landscape by exploring innovative solutions such as smart grids, demand response, and energy hubs (IqtiyaniIlham et al., 2017).

A.2.2. Transmission System Operator

The Transmission System Operator (TSO) is responsible for the management, maintenance, and development of the high-voltage transmission network. The high voltage grid is connected to all regional networks within the Netherlands, as well as to other national networks in Europe. The TSO, TenneT in the Netherlands, ensures the safe, secure, and reliable transmission of electricity across the country. Another critical task of the TSO is the balancing of electricity supply and demand in real-time, which is crucial for maintaining the stability and quality of the electricity grid. Grid disruptions result from flows that breach technological restrictions and capacity mismatches. Therefore they have to precisely control the electrical power injection into and withdrawal from the grid, including the exchanges with other countries. Furthermore, they ensure that the grid is available to all market parties on equal terms, providing a level playing field for market competition. The TSO is subject to the supervision of the regulator, to ensure that they comply with the legal and regulatory framework.

The integration of renewable energy sources into the electricity mix has brought about changes in the role of the TSO. As renewable energy production becomes more decentralized, the TSO is faced with the challenge of balancing this trend with the need for centralized coordination to ensure the stability and reliability of the national grid. To address this challenge, closer coordination between the TSO and DSOs is required to manage congestion and ensure grid stability, as highlighted by (Hadush & Meeus, 2018). However, there are several issues that hinder effective cooperation between the TSO and DSOs. Firstly, both parties lack visibility into congestion situations in other parts of the grid, which limits their ability to predict and manage congestion effectively. Furthermore, strict data sharing regulations can discourage data sharing practices. Secondly, the TSO and DSOs have different objectives and priorities, which can create a lack of incentive for cooperation. This means that solutions for congestion in the high voltage grid may create problems at the local level, and vice versa. Lastly, technology does not currently allow for optimal communication between systems, making it difficult to coordinate actions in real-time across different levels.

A.2.3. Regulator

The electricity market in the Netherlands is regulated by the Authority for Consumers & Markets (ACM). As a supervisor, they monitor the market to ensure functionality and protect consumer interests. They do so by setting a maximum to tariffs that operators can use to charge their customers for selling or transporting energy. As a consequence, the decisions made by the ACM affect investments that can be made in the grid. The ACM holds the position that investments are only efficient and effective if its use of capacity can be substantiated. This has caused a rather reactive than proactive expansion of the grid in the past years in the Netherlands (Netbeheer Nederland, 2019). They take this position to minimize costs in the interest of the consumers. The complex multi-actor system of the Dutch electricity grid makes it difficult for the regulator to assign responsibilities and enforce compliance. Moreover, the regulatory framework and procedures can be time-consuming and bureaucratic, which limits the flexibility and responsiveness of the ACM to changes in the market.

A.2.4. Government

After the liberalization of the electricity market, the role of the Dutch government in the electricity sector has changed significantly (Verbong & Geels, 2007). While the government still has the responsibility for setting the overall framework for the electricity market, it no longer has a monopoly on the generation and supply of electricity. The government's role has shifted towards regulating the activities of electricity suppliers and grid operators to ensure the security, reliability and sustainability of the national electricity system. This includes establishing policies and regulations for renewable energy development and setting targets for reducing greenhouse gas emissions. The national government plays a rather guiding role, providing support in the form of subsidies, in combination with regulation and enforcement. The regional governments are responsible for developing and implementing energy strategies that are in line with the national energy goals. They work closely with the TSO and DSOs to ensure that the regional electricity grids can accommodate the growing electricity demand and number of renewable energy sources. The local governments are responsible for promoting sustainable energy initiatives within their communities, such as energy cooperatives and community-based renewable energy projects.

Though the governments are stakeholders of the DSO - Liander is owned for 45% by the province of Gelderland, 13% by Friesland and 9% by Amsterdam - they do not have the responsibility of maintaining, managing and planning the electricity system. Nevertheless, they are involved in the permitting process for new infrastructure and energy projects, such as wind turbines parks. With these permits, they have a role in spatial planning and can influence the location of new energy infrastructure. Regional and local governments are responsible for coordinating and integrating the electricity system within their respective regions, including the development of regional energy strategies and the establishment of local energy cooperatives. By working together with other stakeholders, such as energy companies, residents, and businesses, the regional and local governments have a crucial role as facilitator, enabler of societal engagement and promoter in addition to that of policymaker (Borrás & Edler, 2020). The Dutch government's coordination efforts between all levels of government and other stakeholders are crucial to ensure the long-term stability and sustainability of the Dutch electricity system.

A.2.5. Producer

Electricity production can be divided into two categories: centralized and decentralized. Centralized production refers to large-scale power plants, typically operated by energy companies. Decentralized production involves smaller-scale generators such as solar panels, wind turbines, and combined heat and power units, which are owned and operated by individuals, households, and communities. These decentralized production sources are typically connected to the distribution grid and can provide power to nearby consumers, reducing the need for electricity transmission over long distances. As the transition towards renewable energy sources gains momentum, the emergence of distributed renewable energy sources has changed the nature of the electricity infrastructure from a simple central system to a decentralized system with many connections (Figure A.1). The increasing share of decentralized production has challenged the centralized model since the infrastructure was not built for this increased bi-directional flow.

A well-known form of decentralized production is the small-scale solar photovoltaic (PV) rooftop system installed on residential and commercial buildings. This has created the role of prosumers: consumers that produce energy. Prosumers can sell surplus energy they generate back to the grid, effectively becoming small-scale electricity producers. This has created a complex multi-agent distribution system where all actors in the future smart grid have their own objectives and operate accordingly (Haque, Vo, et al., 2017).

A.2.6. Others

Consumers are a key player in the electricity market, as they drive demand for electricity and can influence the direction of the market. In the Netherlands alone, there are over 8 million end-consumers (Netbeheer Nederland, 2021). Traders, brokers, and aggregators also play a significant role in the electricity market by facilitating transactions and balancing supply and demand. These actors are particularly relevant in the context of the increasing share of renewable energy sources, which are more variable and less predictable than conventional sources. To address the challenge of grid stability posed by this volatility, new roles have emerged in the electricity system; Energy capturing refers to

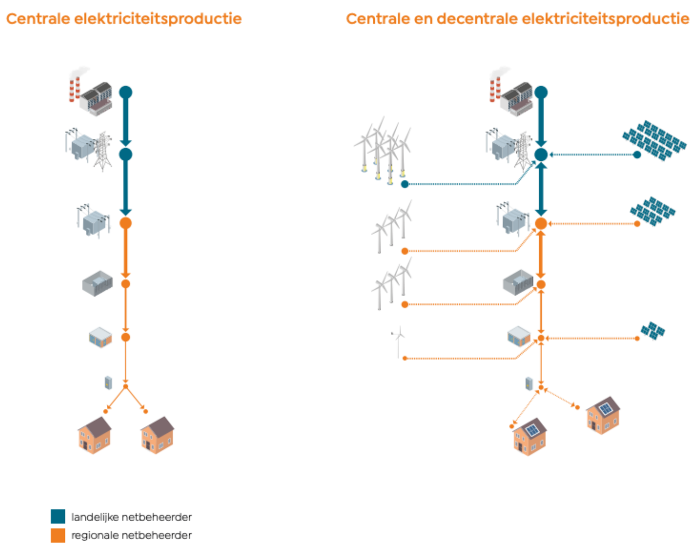

Figure A.1: Central electricity production (left) and the inclusion of decentral production into the original infrastructure (right) (Netbeheer Nederland, 2019).

the ability to store energy when it is available and release when needed, flexibility providers on the other hand offer flexibility in electricity consumption or production. Lastly, research institutions and academic organizations contribute to the development of new technologies, market models, and regulatory frameworks that can shape the future direction of the electricity system.

A.3. The dynamics of supply and demand

The electricity market is a balance between the supply and demand of energy which must be maintained at all times to ensure a stable and cost-effective system. Supply and demand of electricity have different characteristics when it comes to timing and location, these differences must be managed actively to complement each other. To save on transportation costs and losses, it's preferable to produce electricity as close as possible to where it's consumed. Balancing the time difference between supply and demand requires adjustments in either of the two. In the past, electricity production levels were altered to match the predicted demand. The production of electricity occurred in centrally managed conventional power plants that were reliant on fossil fuels, thus could be easily adjusted. With the growing use of variable renewable energy sources (VRES), the market is shifting from being a demand-driven to supply-driven. This has resulted in the need for new market mechanisms and innovative solutions to provide flexibility in supply and demand, as well as for stakeholders to adapt and embrace a more flexible and dynamic electricity market (Ministry of Economic Affairs and Climate Policy, 2022).

The electricity mix in the Netherlands is constantly evolving, driven by various factors such as economic, environmental, and technological developments. Historically, the country has been heavily reliant on natural gas for electricity production, but recent years have seen a growing emphasis on renewable energy sources. As of 2021, fossil fuels still make up a significant portion of the electricity mix, with natural gas being the most commonly used fuel source. However, renewable energy is becoming increasingly important, with over 41 billion kWh of electricity being produced from wind energy, hydropower, solar energy, and biomass in 2021, accounting for 34% of total electricity consumption (CBS, 2022a). The Dutch government has set ambitious targets for the share of renewable energy in the electricity mix. In the Climate Agreement, the government has agreed to aim for a 70% share of renewable electricity in total electricity production by 2030 (Ministry of General Affairs, n.d.). Renewables are dependent on weather conditions, resulting in non-constant and volatile production levels throughout the day and year, causing big peaks of supply during sunny or windy hours (Netbeheer Nederland, 2019). This volatility is difficult to predict: the amount of power generated can fluctuate rapidly and unexpectedly. Due to this inherent volatility, it has become more challenging to meet demand based on traditional generation methods, that could easily correct for day-ahead demand predictions.

Electricity is a vital resource for a wide range of purposes, including lighting, heating, cooling, cooking, transportation, and communication. Electricity demand varies widely across different sectors and end-users, depending on their specific needs and activities. Residential (22%), commercial (31%), and industrial (33%) sectors are the main consumers of electricity in the Netherlands, with a total consumption of 121 billion kWh in 2021 (CBS, 2022a, 2022b). The amount of electricity needed by each sector depends on several factors, such as the size of the building, the type of appliances used, and the level of activity. The importance of electricity is highlighted by the fact that it is a critical resource for many essential services and activities, such as hospitals, schools, and water pumping stations. Despite its importance, electricity has a limitation in its energy density. It requires a much larger volume or mass than natural gas to produce the same amount of energy, making it impractical for some industrial processes or high-energy applications.

The demand for electricity varies throughout the day and year due to changing patterns of human activity and weather conditions. End-users can be categorized by their electricity consumption load profile, which is a graph depicting their electricity demand (and supply in the case of prosumers) in quantity and over time. Industrial users have a steady and high level of electricity consumption, while the commercial sector has a more variable consumption pattern, with peak demand during working hours. The load-profile of a prosumer is calculated by aggregating their supply and demand profiles. An example of the load profile of a home with an electric vehicle charging station and solar panels is given in Figure A.2. In the Netherlands, peak-hours are between 5 PM and 8 PM. The electricity infrastructure is designed to cater to the maximum impact on the system during peak hours, known as peak-load. As a result, there is abundant unused capacity during non-peak periods.

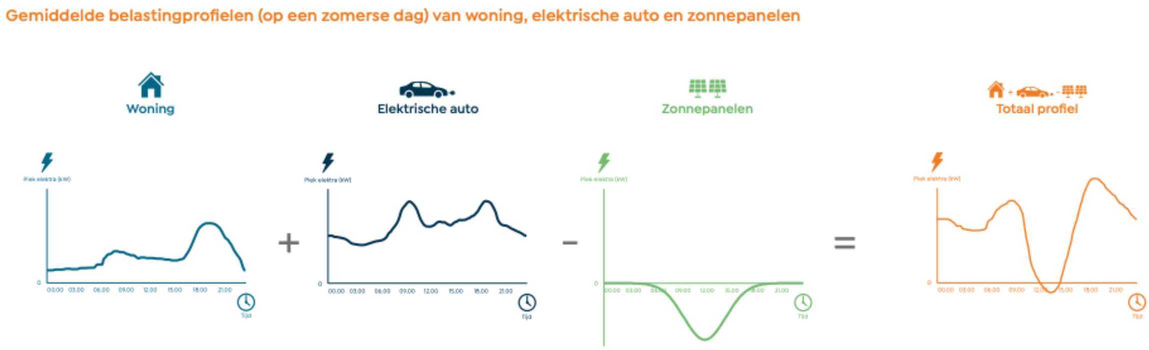

Figure A.2: Overview of relevant demand profiles and the aggregation to peak-load (Netbeheer Nederland, 2019)

A.4. The electricity distribution process

The electricity path from distributor to consumer starts with a physical connection to the grid. Individuals or organisations can request a connection from their local DSO. The DSO is legally obligated to provide every client request with a physical connection to the grid infrastructure. The size of the connection varies depending on the expected usage. The DSO categorizes users into two profiles: small-scale consumption (SC) for those with a connection of 3*80A or less, and big-scale consumption (BC) for those needing a connection of more than 3*80A. Newly constructed homes are typically provided with a 3*25A connection, to allow for future technological developments and trends such as electrical heating, solar panels, and personal charging stations for EVs. Meanwhile, older homes are often provided with a 1*25A connection, which is only capable of catering to standard household appliances. A quick refresher: ampere is the unit of amperage (I) and indicates how much electricity, thus the number of electrons, flows through a device. Volt is the unit for voltage (U) and indicates how much energy the electricity carries. Watt is the unit of power (rho), and is calculated as follows:

$$\rho = U * I$$

The electricity capacity that a consumer can withdraw from the grid depends on the type of connection they have. Physical cables that distribute electricity have a limited capacity and different connection types can handle different amounts of power. The maximum power that a 1*25A connection can handle is 5.7kW, a 3*25A handles 17kW and a 3*80A handles 55kW. For small consumers, such as households and small businesses, the energy supplier typically manages the contract with the consumer, purchasing electricity from the wholesale market and then selling it to the consumer. Small-scale consumers have access to the full capacity of their connection for consumption and delivery by definition. Due to the ”capacity tariff”, no contracted capacity is determined based on desired transport capacity (Liander, 2021b). In contrast, large consumers, such as industrial and commercial customers, manage their contract directly with the DSO. They sign a contract called the Connection Transport Agreement, ATO in Dutch (Liander, 2023). This agreement includes terms and conditions such as the voltage levels required, the duration of the contract, and the Contract Transport Power, GTV in Dutch, which refers to the capacity required.

A DSO is obligated to comply with their agreements and ensure that consumers can always receive their contracted capacity of electricity (P. Begemann, personal communication, February 22 2023, appendix C.2). Nevertheless, since a GTV is requested based on the maximum electricity needs of their load profile, a consumer almost never uses their full capacity at every hour of the day. A DSO aims to precisely predict the cumulative impact of all electricity users on the system's assets during peak hours by aggregating their load profiles (Liander, 2021b). They use this forecast of total peak load and the amount of unused capacity in the system outside of peak hours to calculate whether a new contract can be given out. This is based on the capacity requested and the accompanying load profile of the consumer (Enexis, 2019). As a consequence, the capacity of the summed up outstanding GTVs is often way greater than the physical capacity of the grid can handle at once. This means that if all consumers were to use all their contracted capacity simultaneously, the system would fail. In reality, this never happens.

Operating the system within limits involves the careful analysis of available capacity in the system. When a part of the system approaches its maximum capacity, we speak of the phenomenon transport scarcity: the system's assets can either not handle the peak demand or supply, or both (Liander, 2023). Rural sparsely populated areas often experience congestion caused by supply, as they cater sufficient space for renewable energy projects but the electricity grid is not dense. Urban densely populated areas are more prone to experience congestion caused by explosive electricity consumption. When a substation nears its maximum capacity due to excessive demand, the DSO must stop accepting capacity requests of large consumers (BC) only in that substation's feeding area. As a DSO is legally obliged to provide a physical connection to the grid, the client is imposed with a transport restriction: they cannot use their connection. While other parts of town may have sufficient capacity, it's not always possible to transfer electricity from one feeding area to another. The DSOs work with a color coding scheme to indicate the severity of transport scarcity in an area: in a yellow-coded area, there is still limited capacity left thus new or expansion requests for electricity are complied to if possible. If the request for capacity can't be met anymore, the color code changes to orange. In an orange-coded area, the DSO conducts research whether congestion management can unlock additional capacity. If it is feasible, new requests are granted as long as capacity limits allow. However, if it is not possible to unlock additional capacity, the color code changes to red. A red-coded area is declared as congested, and no new contracts can be signed or expanded (P. Begemann, 2023).

The electricity infrastructure in the urban area is a complex network topology with many inter dependencies. The infrastructure can be congested on every voltage level; If every household in the street connects an electric heatpump, solar panels and an EV charging station at the same time, it is very probable that the low voltage cables cannot handle this explosive growth (P. Begemann, 2023). Nevertheless, constructing the low voltage infrastructure and connections to the grid is a relatively quick process compared to the medium and high voltage grid. The high voltage network can be congested when large wind or solar parks are connected, the medium voltage network when there are many new large consumers in one feeding area, such as an industrial company and a datacenter. Since electricity has to flow through the assets on all levels to get from production to consumption, it is very probable that a congested asset upstream affects the assets downstream. For example, if the DSO builds three new substations to feed the city, the TSO first has to have stations with sufficient capacity to feed those three. Additionally, the cables that transport the electricity have to be place.

B Segmentation

The industry segment encompasses a wide range of economic activities involved in the production, manufacturing, and distribution of raw materials, semi-finished goods, and finished products. The ”heavy” industry is known for their extraction, production, and distribution of natural resources, their large-scale operations, and the high level of automation. These businesses, such as large manufacturing plants, typically require significant amounts of energy to power their operations and rely heavily on machinery and specialized equipment. Therefore, they can be labelled as ”energy-intensive”. Businesses in this segment require a consistent and reliable supply of electricity to operate effectively. Any disruptions or shortages in the electricity supply can have significant negative impacts on their operations and productivity.

The second segment focuses on the commercial business sector, which encompasses a very wide range of businesses, including those involved in trade, transportation, hospitality, information and communication, financial services, and real estate. These businesses have unique electricity consumption patterns, which can vary significantly within the segment. The successful operation of these businesses is critical to the smooth functioning of the economy and society at large, as they provide essential services, create a thriving economy, and offer employment opportunities. Demand congestion in this segment could cause operational disruptions, economic losses, and a slowdown in sustainability plans, and can thus have significant societal impacts.

The third segment is urban development, which includes both housing and non-housing construction activities. Urban development is a vital part for the urban planning of modern cities, and the construction industry is a significant contributor to the economic growth of urban areas. Ensuring the successful operation of businesses in this segment is also essential for social reasons, as adequate housing is a fundamental human need that plays a critical role in people’s overall well-being and quality of life. It’s important to consider this segment in the context of demand congestion, since it involves a significant amount of energy usage, constantly requiring new LC contracts.

The fourth and final segment of this research is focused on public services, which comprises various societal facilities that are of great public importance. This includes institutions and organizations critical to societal vitality such as education, healthcare and sports, but also emergency responses such as the police and the fire department. These businesses play a vital role in providing essential services, promoting social well-being, and maintaining public safety. These facilities are considered fundamental for the functioning and development of the society as a whole. They rely on electricity to provide their services.

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C Interviews

C.1. Municipality of Amsterdam

- Date: February 16th 2023 13:00 - 14:00
- Place: municipality of Amsterdam, Weesperplein 8
- Interviewer: Julie van den Brink
- Expertise 1: working on demand congestion for the municipality of Amsterdam

What does Team EVA do and what is your role?
Team EVA is a collaboration program between the municipality of Amsterdam and the Amsterdam regional team of Liander, which already existed prior to the grid congestion issue. It was established based on the research reported in the first thematic study. Until two years ago, before the first report of congestion, the focus was on improving general cooperation, with projects like TSA 1.0 and 2.0, market consultation on flexibility, and improving the electricity grid. The second thematic study made the issue of congestion clear, and shortly after, the first announcement of congestion on the Amsterdam grid was made. From then on, the focus shifted to solving and preventing congestion urgently. This is done through information exchange, both of data and plans, to identify bottlenecks and streamline the process of grid expansion. The EVA program expanded to the Taskforce, a collaboration between the municipality of Amsterdam, Liander, TenneT, and the Port of Amsterdam. I am involved in visualizing and aligning the plans of the municipality and Liander, in data collection for the thematic study, and in the municipal organization of congestion.

What is the role of the municipality in grid congestion?
The municipality's role is not well-defined, and there is some ambiguity. The municipality has the responsibility to ensure a healthy economic climate and create a livable city for its citizens. The grid operator is responsible for maintaining the grid. The problem of grid congestion is not only caused by delayed investments but also by unforeseen growth in electricity demand. It is a shared interest to provide electricity to the city. The municipality of Amsterdam has sufficient resources (manpower, funds, knowledge) and a high sense of urgency, which has led to a relatively large role compared to other municipalities. The municipality can facilitate by freeing up sufficient space in the public domain for the grid operator to build and ensuring timely completion of permit processes. It is not necessarily the municipality's responsibility, but they have taken on an active role at the moment. This was initiated by Ruben Voerman, who recognized the need for it.

What is the relationship between the municipality and the grid operator in Amsterdam?
Liander requests information from the municipality, such as the percentage of realistic housing plans and the capacity they need to reserve. They request substantive data from the municipality that they need to reserve. The collaboration has grown over the years because they serve the same interest, although this was not predetermined. I do not feel that Liander primarily acts out of commercial interest but rather out of societal interest. However, they must be able to commercially justify certain choices, such as investing in the expansion of a substation. This investment is made using public funds, and the

costs are passed on to end-users. If there are so-called "additional costs" for an alternative solution that may be more socially attractive but not optimal commercially, those costs should be borne by another party such as the municipality. An example of this is the substation in the Zuidas area, which has been built in a more aesthetically pleasing manner, and the costs were covered by the Zuidas. Decisions about additional costs are challenging to justify from the municipality's perspective and are made by the city districts.

Could the congestion issue have been anticipated earlier?
According to people in the field, they believe that the investments in the grid were delayed for too long. However, it should also be noted that the growth of ambitions and the pressure on the grid have been greater and faster than expected. For example, the impact of district heating networks or electric cooking is larger than initially calculated by Liander. It is important to note that congestion is announced based on predictions. By improving the accuracy of these predictions, the maximum capacity is reached earlier than previously thought. The physical occurrence of congestion has not happened yet, except for occasional concerns at one station. Congestion is announced, also known as transport scarcity, in order to prevent physical congestion. The grid assets can be temporarily overloaded, but if that happens for too long or too frequently, it can lead to outages.

Can other cities learn from Amsterdam?
Amsterdam is ahead in terms of congestion issues compared to the rest of Liander's service area, so it serves as a testing ground for solutions. Amsterdam has a large workforce dedicated to learning and finding solutions.

Who is affected by transport scarcity, and for whom has Liander reserved capacity?
Liander reserves capacity for planned residential buildings with a small consumption connection. Even when these buildings are aggregated, such as in residential towers, Liander reserves capacity for them. However, Stedin, another network operator, follows a different policy. Residential towers with higher consumption connections, which include additional electricity-consuming facilities like elevators or heat-cold storage systems (WKO), reserve 3 kW per dwelling. Of this, 2 kW is allocated for the dwelling's consumption, and the remaining 1 kW is for the other electricity-consuming elements. Therefore, accurate information exchange regarding the construction plans of new residences is crucial.

Does transport scarcity impact housing construction?
Yes, because developers cannot derive commercial profits from the ground floor of buildings. In Amsterdam, we have mixed-use buildings with commercial rentals on the ground floor, such as shops and restaurants. Often, these buildings no longer fall under the category of small consumption connections, especially since new construction projects are often gas-free. Consequently, these businesses cannot operate. This leads to residential areas without the necessary facilities, resulting in "sleeping neighborhoods." The interim solutions, such as using generators for schools, are polluting and expensive, costing around €150.000 per year. As a result, housing construction projects may be halted, which also affects the value of the properties and existing facilities in the neighborhood. The timing of the construction is crucial because a project's construction can sometimes coincide with the expansion of the grid. However, there is a risk that the grid expansion schedule may be delayed, leaving the developer without power for several months. Some projects have already started construction without prior knowledge of congestion issues, causing them to unexpectedly be unable to utilize the ground floor. It is currently unclear who should bear the costs of interim solutions, whether it should be the project developer, Liander, or the municipality.

Is there a threshold for "this causes too much pain"?
No, there is no policy or decision framework in place. Often, when I encounter a severe problem, such as a specific case, it is escalated to higher levels. The EVA program specifically focuses on electricity supply, but decisions regarding the implementation of other solutions often involve other departments, such as Land & Development.

How has team EVA made decisions regarding network expansion so far?
The grid operator demonstrates where, how much, and how large a new substation or expansion should

be, supported by technical justification. Subsequently, a search process is initiated to find a location and a plan is developed. Currently, this process takes place at the administrative level in consultation with the Taskforce. Subsequently, the procedures for zoning plans and permits take place. Ruben and Gemma have the details regarding substations, while Nabil is responsible for MSR. The prioritization of assets is discussed in the Taskforce's consultations, and the goal is to reach a consensus at the administrative level.

How has team EVA made decisions regarding alternative solutions rather than expansion?
Within the Taskforce, extensive research has been conducted on alternative solutions to meet the "remaining challenge" of the unmet electricity demand. This research was conducted at a higher level, focusing not only on behind-the-meter solutions but also on neighborhood- and city-wide grid solutions, often specific to each substation. The municipality takes an advisory role regarding behind-the-meter solutions, partly because it has a better understanding of the expected duration of congestion in certain neighborhoods. There are potential solutions that could free up capacity, but the question is who should bear the cost. If it's a temporary grid solution, Liander rejects it because they are already investing in structural expansion and do not want to invest in the short term. Furthermore, the implementation of such solutions can delay expansion, as scarce technical personnel are also needed for this purpose. Additionally, it sometimes takes quite a long time, several months, to roll out such alternative solutions. This is partly due to their novelty, and various administrative processes are involved, such as the energy community in the harbor. It is difficult to determine whether the investment in short-term alternative solutions is socially responsible, especially considering that they may be needed for only two years of congestion. Each grid operator follows a different decision-making framework. Apart from all of this, the grid operator is already extremely busy, and this adds to their workload. The intervention of the government is not necessarily the solution for this.

If you were to prioritize the waiting list, what indicators would you use? How would you measure the societal added value of allocating electricity?
Currently, there are a few hundred customers on the waiting list in Amsterdam. The municipality should not prioritize on its own because it has its own vested interests. It would be better if a higher level, such as the province, were to do it. For example, this could be done based on whether customers have sustainability plans.

What societal issues do you want to know to formulate policies?

1. Amount of electricity shortage
2. Impact on housing construction
3. Influence on public facilities such as schools and sports centers
4. Number of electric kilometers not charged by electric vehicles
5. Impact on CO2 targets
6. Costs of interim solutions such as generators

C.2. Distribution System Operator

- Date: February 22th 2023 09:30 - 10:00
- Place: Liander, Basisweg
- Interviewer: Julie van den Brink
- Expertise 2: area director Amsterdam for Liander

Could you explain a bit about your function and activities at Liander?
As area director in Amsterdam, I bridge the gap between the technical heart of Liander and the stakeholders such as the municipality of Amsterdam and the Port of Amsterdam. It is a more technical version of the classical relationship manager. My activities are of two-fold: I communicate the plans of Liander to the stakeholders and I collect information from stakeholders which is relevant for the electricity grid and thus Liander. In Amsterdam I focus on three themes: collaboration with the Port of Amsterdam to find smart solutions working together with all GV consumers in that area to solve congestion problems, the future of the distribution grid at MV and LV level, and innovative solutions to enable flexibility and

more optimal use of the grid as part of the Taskforce.

Is it possible to impose a transport restriction to someone with a contracted GTV (read: is it allowed for a DSO to deliver less electricity than promised?)
No.

Liander works with color coding for transport scarcity (see Figure 4.1). Do the same rules of transport scarcity apply to red, orange, and yellow areas?
No, in a yellow-coded area, there is still limited capacity left thus new or expansion requests for electricity are complied to, if possible. If the request for capacity can't be met anymore, the color code changes to orange. In an orange-coded area, we are conducting research on whether congestion management can unlock additional capacity. If the answer is no, the color code is changed to red. A red-coded area is declared as congested, meaning that there is transport scarcity: no new GTVs can be signed nor can GTVs be expanded. Keep in mind that a GTV is only necessary for GV consumers. In an orange-coded area, provisional transport scarcity is declared. This situation remains if the area moves to red, but if research shows capacity can be maybe available, we will accept new or expanding requests if the capacity limits allow.

What is the current situation of congestion and the waiting list resulting from transport scarcity in Amsterdam?
This is very privacy-sensitive information. There are a few (±three) hundred requests pending. In Amsterdam, we currently only experience congestion due to the capacity limits of OSs, with less than a handful of special situations where there is congestion on the MV cables. Contradicting most other regions in the Netherlands, Amsterdam is only experiencing congestion in the direction of electricity demand. This means there is sufficient capacity for electricity supply, such as from solar panels. In general, OS congestion thus has no influence on the deployment of VRES, though there are minor exceptions caused by the network topology.

Is it possible for all KV connections to increase their electricity demand, such as for the installation of an EV charging station?
Liander reserves capacity in the OS station for KV consumers, based on several forecasts such as autonomous growth, heating technologies, and urban development plans. At this point, OS congestion has no effect on KVs in Amsterdam. We have different types of KV connections: a private connection is either 3*25A or 3*35A (max. 24kW). The smaller connection supports the normal household appliances, and solar panels, an electric vehicle or an electrical heat pump. The bigger connection is only necessary for homes with for instance a sauna and jacuzzi. A commercial connection is between 3*50A and 3*80A (max. 55 kW). A KV is thus either allowed to grow their electricity usage to 24kW or 55 kW, and can install an EV charging station within those limits. Growing outside of those limits means moving to a GV classification, which are subject to transport scarcity. This may change at a later stage when every house in the street has a charging station for their EV and an electric heat pump, resulting in congestion on the LV net. Nonetheless, not every physical connection to the LV net can handle the increased impact: whereas new housing is built with a 3*25 ampere connection, older houses are only connected with smaller connections. The latter is insufficient for EVs or heat pumps. Nevertheless, constructing LS infrastructure and connections to the grid is a relatively quick process compared to the MS grid.

Does congestion actually occur or is it always prevented by transport restrictions?
Physical congestion is very rare due to transport restrictions. Sporadically, cables/stations exceed their capacity. As a result, they do not immediately break down or the power does not fail immediately, but parts do heat up and therefore wear out faster than desired. Short overloading is therefore not immediately dangerous, long overloading is.

C.3. Energy systems research

- Date: February 22th 2023 10:30 - 11:15
- Place: online

- Interviewer: Julie van den Brink
- Expertise 3: energy systems researcher and senior consultant at CE Delft

Could you explain a bit about your activities at CE Delft?
We are a research institution researching the energy transition and sustainability, focusing on several sectors and conducting many studies for policy making support. We provide techno-economic analyses with a societal focus. We have conducted a lot of research into the electricity system in the Netherlands and the congestion problems.

I heard from my supervisor that you planned on doing an SCBA for congestion on the electricity grid, but this project has not started yet. Can you tell me a bit more about this?
The reason we have not conducted such research yet is that we do not have the capacity at CE Delft. There are many important, and fun, challenges to solve, and we simply have not yet found the time for this one yet. Currently, I am conducting five research projects at once, amongst others one for Liander and one for EZK. Nonetheless, in my opinion, and from what I hear from other parties, this question is super relevant. Therefore, I still plan on conducting it at a later stage. We know that congestion on the electricity grid has major societal impacts at various levels, but no one yet has been able to put a number to it. Measuring the impact of congestion on electricity *supply* is a bit more straightforward than demand: we can measure the impact on non-realized renewable energy resource projects. The biggest challenge is measuring the societal impact of *demand* congestion, as it is a complex combination of technology, economy, and society. We need to be able to substantiate what exactly is the problem to validate decision making. We preferably want to make the quantification standardized and automated calculations to make it scalable. Our idea was to conduct an SCBA, but for this, you need a lot of specialized knowledge and a lot of time (3 months to a year).

What advice do you have for my research project?
I would advise you to not start modeling the electricity system. You can use data either from the TSA 2.0 or 3.0. This will tell you when, where, and how much insufficient network capacity there will be (keep in mind: the TSA does not incorporate planned expansion). Following up, you must define what/who exactly cannot operate. This is tricky, since it is dependent on a closed waiting list. For this you will have to make assumptions or you could adopt a normal distribution to all categories requiring electricity: e.g. if an OS has a capacity of 100 MW, but in 2025 the electricity demand will grow to 150 MW, you could divide that 50 unmet peak load over housing and industry. This is tricky because if you take a standard percentage for housing for all OS areas, this may not agree with the plans of the municipality (there probably won't be a lot of urban development in the historic center). Another bottleneck is that you only know the peak load and the contribution of a sector at that moment. The grid load of homes varies between 0.2 and 2 kW per home. Therefore, it's difficult to calculate the absolute peak back to the number of homes if you don't know what the grid load per home was at that time.

Following up, you want to know what the societal impact of 10 MW unmet electricity is. You thus want to move from the metric MW to certain indicators. I would advise creating indicators per sector/category/segment. Take for instance the following five segments: housing, industry electrification, SME, electric mobility, and new industry. It is not very easy to define the indicators. Maybe you could select them with a multi-Criteria Analysis, researching their importance. The impact on housing and electric mobility is straightforward and can simply be expressed in quantities. An obvious indicator of societal impact is CO2 emission, but personally, I don't think this is the most interesting. I think that 80% of businesses will use a diesel aggregator, and the rest won't settle. The key challenge lies in quantifying the missed 'welfare' from new SMEs and industries. The second order impact on society is also very complex and challenging: what is the pain of someone having to stay with their parents? Preferably, you would want to do an extra last step, translating all indicators to one and the same unit, which is done in euros in an SCBA. This allows for a proper comparison of impacts. I think this is too extensive for your research since you do not have the capabilities (knowledge and experience), time, or data for it. Plus, an SCBA must comply with several official standards. Nonetheless, moving from MW to indicators is already very insightful, such as the number of houses impacted. In the end, you want to be able to say something about the outcomes of the indicators, for this, you could use criteria/thresholds.

A few things to take into careful consideration: are you planning to conduct your analyses on a neighborhood level or on OS areas? I would advise you to take the OS area. Furthermore, you need to think through how you want to contribute. Mapping the unmet MWs has already been done in the TSA, and the municipality already roughly knows where the most industry or housing is, etc. So, what new insights will you create? Another note I want to make I think there is a very high possibility that though Liander reserves and promises capacity, it may happen that TenneT HV infrastructure won't be able to deliver. As a result, entire building blocks or neighborhoods may be left without electricity. Lastly, you could also decide to skip the number of unmet MWs but take the "red OS" areas as a starting point. Following, you would have to check the plans and ambitions from the municipality for that area, and state they all simply cannot be operated. You could research the societal impact by cases of a few key categories, conducting it for one or a few OSs. You could quantify the congestion impact of a sector even based on a scale from 1 to 10.

C.4. Congestion fixer

- Date: March 24th 2023 14:30 - 15:15
- Place: online
- Interviewer: Julie van den Brink
- Expertise 4: assists cases struggling with congestion in Noord-Holland

What do you do exactly?
I work at APPM. I have previously worked at a DSO (Distribution System Operator) and for a long time at a measurement company in the energy infrastructure. For the past year and a half, I have been focusing on energy transition and sustainable mobility. Additionally, I am also involved in governance and organization, working on collaboration issues both between the national government and decentralized authorities, as well as regional cooperation. I have been working on a project for the province of Noord-Holland for the past 7 months, specializing in "smart energy solutions for congestion," also known as a "fixer." I assist entrepreneurs, municipalities, knowledge institutions, project developers, and others who are affected by congestion. They have been subject to transport restrictions, either preventing expansion or obtaining new contracts. Usually, they receive the technical connection but cannot use it due to the restriction. I have been appointed by the province's task force because they lacked a connection between knowledge and subsidy. Currently, I am working on multiple cases, including those from local entrepreneur desks. I try to work hands-on with these people to find solutions together.

What kind of parties approach you?
The municipalities, for example, the municipality of Hoorn. They have a case in the harbor where inland cruise ships dock. This requires shore power. However, there was insufficient capacity to meet the current demand. As a result, they had to use diesel generators for several boats starting from April last year, leading to complaints from the surrounding area. This brings me into contact with people in the municipalities, such as the harbor master and someone who looks at the issue from an economic perspective. But they are not familiar with the technical aspects, so I try to mediate and explore alternative solutions. In this case, we looked at a battery solution based on the profiles. We also assessed the economic feasibility. It seems that it will probably be an economic decision not to allocate additional resources because it would cost more than it would generate. The other parties mainly consist of entrepreneurs, a dock company in the far north of North Holland, a manufacturer on the northern tip of North Holland, and two project developments in Amsterdam—one in Rembrandt Park and the other in Sloterdijk Zuid. I am also working on a new school and a new sports hall in Amsterdam Noord.

How do you provide congestion relief?
I'm not a wizard who can instantly solve congestion. I cannot install a connection or replace a substation. I do my best to help, but I can't make any promises. I can explore alternative solutions, but I am limited because I don't work at the DSO. In this case, Liander is involved. I cannot install a connection myself or replace a substation. But I have been able to solve some cases.

Are the cases you handle mostly from people who already genuinely need electricity, or is it mostly precautionary because they anticipate this problem? Has there been a significant im-

pact from congestion consequences already?
Yes, there is already an impact. There are developments that cannot start or are delayed because they cannot obtain the required transport capacity. There are companies that cannot expand because they don't receive additional transport capacity. I had a case where a company moved to a new location and saw that there was LC connection, but then was not appointed the transport capacity.

Is it possible to take over an LC contract from someone?
You can look up whether someone has a LC connection in a non-public connection register, but you can also physically see it. You can see it based on the fuse values, and you usually see it when there are power transformers. Taking over an LC grid connection is only possible if you are the legal owner and you move within the same feeding area. If you meet those conditions, it is possible, but there are always complexities involved. If you want to move your own GTV to a new addres, your current LC GTV at the old address must be terminated. If you don't notify the move, the LC GTV will simply expire and be reallocated to the waiting list. I'm not entirely sure if you can take over someone else's LC GTV, as I haven't come across that situation yet. I think it might be possible if you are a tenant, and the property owner has signed the LC grid connection contract. Then, as a new tenant, you can use that LC GTV. But once a new owner comes in, the contract with the DSO also expires.

What kind of solutions are you looking at?
We look at efficiency, so you can better utilize your own current GTV. We also consider battery solutions so that you can continue using your GTV. Additionally, there is self-generation, both sustainable and through generators. A diesel generator is really a last resort. Some companies sell combinations, such as a battery along with two gas generators, where they efficiently manage the battery and only activate the generators when necessary. We also explore alternative contract forms, often in combination with storage mechanisms.

But alternative contract forms like TCT can already be fully utilized in a congestion area, right?
Yes, that's correct. We look for any unused remaining capacity, but at a certain point, it becomes full. Once it's full, it's full.

How many cases have you handled in the past 7 months?
Around ten. I do this part-time. Each case requires a specific individual approach, and you're also dependent on other parties, which often leads to long processing times, especially when coordinating with the DSO. Sometimes it takes months. I started as a kind of pilot project to see what we can do and if it's effective. It has proven to be effective because people feel heard, and solutions often emerge just by giving attention to the cases. The plan is to expand the team, and eventually, there will be four fixers working for the province of North Holland. The intention was also to learn from these cases to develop a more generic approach on a larger scale.

What lessons have you learned so far?
1. It's very helpful to view the case from the perspective of the entrepreneur rather than just from the DSO's side. This has provided the DSO with new insights, and new solutions have been found. For example, the dock company. Liander discovered that the dock company had another location nearby with sufficient left-over capacity in their GTV, so they were able to provide that remaining capacity to the dock company's other location. 2. I've encountered several cases where the financial resources people have don't match the need to solve the problem. There must be sufficient demand and urgency to finance an alternative solution. Battery systems can quickly amount to hundreds of thousands of euros. There are subsidy opportunities, but it's still a significant investment.

Is congestion a reason to move?
Yes, if you were planning to move in 10 years anyway, it is interesting to expedite those plans. Or for example, to find another location in the city that is not congested, or even outside the city. I have a few cases considering this, but it's not a decision you make lightly, not for your customer base or your employees. You need to keep your employees close by. You can't just find new people easily. This may not be feasible for everyone; for example, a school cannot move, or a large entity like a

factory. Especially if you're in a specialized field, such as chemical analysts, you won't just move easily.

How do people decide on which solution to pursue?
People do want to choose a sustainable solution. Within a certain margin, of course, the financial aspect always plays a role; you need a viable business case. Sometimes you come across individuals who are very passionate about sustainability, and it matters less to them. A diesel generator feels bad for many people, especially with new developments that must, for example, meet a BENG standard. When you use a diesel generator whilst complying to those norms, that feels wrong. It is truly a last resort with a lot of reluctance.

To what extent is electricity crucial for operations?
You can't always say, "I'll wait." It may very well be that you depend on that growth (read: the growth that requires additional electricity) to continue to exist. Otherwise, you'll have to completely overhaul your operations and let people go. Consider your heating demand, combined with gas prices. If there is no alternative and gas heating is exorbitantly expensive, you have to find savings elsewhere. Some buildings need to meet certain requirements soon. If you don't comply, you risk fines. There is naturally a tension there. Take, for example, transportation companies that can't enter emission zones but can't obtain electricity for electrification of their busses and cars either.

What is the impact of congestion on job availability?
Well, imagine if there is no more construction happening, then you'll naturally miss out on a lot of jobs. And yet, we have an enormous housing construction task in the Netherlands.

What are the reasons for expansion? Is it mainly focused on sustainability?
Yes, the cases I see often involve electrification, such as the harbor in Hoorn. And, for example, a dock that used to operate on diesel but has been completely converted to run on electric winches.

What are some of the challenges and uncertainties associated with finding a solution for grid congestion, and what are the current developments and initiatives in this field?
Finding a solution for grid congestion is challenging. It takes a lot of time, numerous discussions, and a lot of explanation. And everyone is still pioneering in this field. Entrepreneurs don't know what to expect, market players are still figuring out what works best, and the grid operator doesn't have a fixed process for alternative solutions yet. There is still a lot of movement in this realm. Changes from the ACM (Authority for Consumers and Markets) are forthcoming. There is so much uncertainty, including legally. That's why progress often feels slow and difficult. However, I do see a lot of movement, including initiatives from the government.

C.5. Segment: Industry

- Date: March 20th 2023 11:00 - 12:00
- Place: Weesperplein 8
- Interviewer: Julie van den Brink
- Expert 5: Program Manager for Sustainability of Industry at the Municipality of Amsterdam
- Expert 6: Project Leader for CO2 reduction, storage, and reuse of the industry segment at the Municipality of Amsterdam

What exactly do you do?
I (expert 5) am the Program Manager for Sustainability in the Port and Industry at the Municipality of Amsterdam, focusing on topics such as hydrogen, biomass, and governance issues. We are also part of the Shareholders Committee of the Port of Amsterdam, and we are the owners of the AEB (Waste-to-Energy Plant). I (expert 6) am the Project Leader for industry CO2 reduction, storage, and reuse. We engage in conversations with industrial partners about the energy transition and what is needed for it, either in our role as owners or as the administrative principal of the environmental agency. We assist and encourage the industry to become more sustainable. We oversee the permit processes and have some budget for conducting external analyses. Our roles primarily involve facilitating discussions, fostering connections, and creating shared interests. We cannot enforce or make demands; market

forces are at play here. To be able to push for change, we need national, European, or international regulations at the very least. Otherwise, we risk driving the industry away. Examples of such regulations include carbon pricing and ETS (Emission Trading System) rules. Now that they have to pay, their business case is no longer viable, which provides greater motivation for the transition.

General information on the sector
The industry sector in the Port of Amsterdam (PoA) region consists of approximately KVK 3.000 registered businesses, of which about 600 are large companies. These companies produce a variety of products, from chocolate to kerosene, and there is no specific industry in Amsterdam. It is hard to generalize the activities of an "industry party". Most of the businesses are located in the Amsterdam harbor area due to noise pollution and CO2 emissions. There are specific outlines for this which limits the area where industry is allowed to settle. The CO2 emissions of the industry in Amsterdam can be found at the CO2 Emissions Authority. But good to know that only 10 industry parties are responsible for 80% of the CO2 emission from the industry segment in the Port of Amsterdam. Generally, businesses in the industry sector establish themselves for 40 to 100 years, and approximately 70.000 people are employed in the PoA region. The industry/harbor is what makes Amsterdam unique. The industry business climate is currently being improved by initiatives such as the Port of Amsterdam. There is limited space left in the PoA region, and there is a discussion now on whether it is desirable to welcome any new non-sustainable industry.

Energy needs of the sector
The energy consumption and needs of an industry business in Amsterdam depend on its specific activities. Generally, such businesses require a significant amount of energy for production and distribution purposes. This includes electricity for powering machinery and equipment and lighting, as well as natural gas for heating and fueling production processes. Furthermore, cooling and refrigeration and transportation are important activities that require energy. They mostly rely on gas besides electricity because many processes require large amounts of energy at once, which is not possible with electricity. The mix of energy sources is very different per specific industry party. There is no information on how many LC connections there are in the PoA region, nor is there information on how much electricity they are currently consuming. We can definitely say that the supply of electricity to the industry is very important.

The industry segments either wants an expansion of their electricity contract to expand operations or for matters of sustainability, or a new contract to settle. Everyone knows that they need to transition and become more sustainable. The electrification of parts of your primary process is becoming more and more financially viable and one of the key ways of becoming sustainable. We know that almost all parties have electrification plans. That's why there is congestion in that area, as everyone is now requesting electricity quickly. Electricity, complemented with steam and hydrogen, is absolutely crucial for making the industry segment sustainable.

Effects of congestion
Almost everyone in the industry sector has experienced problems related to electricity supply or capacity in the past, and this has had an impact on their operations. We have already heard of new parties choosing a different location. A reliable and stable electricity supply is crucial for the operation of industry in general. Any reduction in electricity supply can result in reduced productivity, increased waste, and higher costs. Many industries have backup generators in place to ensure uninterrupted power supply during electricity outages or other disruptions. However, it is not likely that an industry party would use backup generators for structural electricity shortage. If an industry party did not have access to the electricity it needs, they might consider alternative solutions such as gas turbines or steam power. However, these solutions may not be practical, financially viable or even sufficient to meet the shortage. Furthermore, these last resorts relying on fossil fuels would not be used to fill the expansion demand driven by sustainability. It is more likely that the industry would deal with less electricity or find other ways to adjust their plans and activities accordingly. If an expansion cannot take place, it will probably have a negligible influence on new jobs, as one new piece of equipment does not create a lot of new jobs. However, for a new industry actor not to settle, it will have an impact.

If an industry party did not have access to the electricity it needs, they might consider alternative solutions such as gas turbines or steam power. However, these solutions may not be practical, financially viable or even sufficient to meet the shortage.

Electricity, complemented with steam and hydrogen, is absolutely crucial for making the industry segment sustainable.

C.6. Segment: Commercial business

- Date: March 21th 2023 11:00 - 12:00
- Place: online
- Interviewer: Julie van den Brink
- Expert 7: supports the business market with sustainability at the Municipality of Amsterdam

What are your tasks and responsibilities?
I have a dual role: first, I work on promoting the offerings of our team "Sustainable Business Market" which includes providing energy advice and facilitating financing through subsidies or low-interest loans. At the same time, I actively engage with businesses located in business parks, assisting them in their sustainability efforts and serving as a point of contact of the municipality of Amsterdam for their sustainability transformations. This can involve topics such as transitioning away from natural gas, installing solar panels on rooftops, establishing electric vehicle charging infrastructure, or upgrading certain installations to more sustainable options. The businesses we assist primarily belong to the small and medium-sized enterprises (SMEs) sector since larger corporations and multinational chains usually have dedicated headquarters managing these matters. Our workload in this area is currently quite demanding. Overall, the assistance provided by the municipality is well-received by entrepreneurs, as sustainability initiatives can often be complex, involving various regulations, options, and technical complexities.

General information on the sector
The commercial market encompasses the entire business sector, excluding the industrial sector. This includes offices, restaurants, retail stores, and shared office spaces. The official definition of SMEs refers to businesses with up to 250 employees and a certain revenue threshold. Essentially, it comprises medium-sized companies that are not part of a massive chain, such as an automotive garage, for example. The SMEs are spread throughout the city. SMEs play a crucial role in shaping Amsterdam's business climate, making it highly attractive for entrepreneurs and investors.

Energy needs of the sector
The energy consumption of SMEs presents an interesting landscape, with variations depending on the location and type of business. In the city center of Amsterdam, which encompasses areas like the Nine Streets, Vijzelgracht, and Damrak, many small retailers, hospitality establishments, and offices operate in small, historic canal houses. These businesses generally have smaller energy profiles and do not fall under the category of large consumption (LC). However, when we venture outside the city center, towards areas like North, Southeast, and West, we come across businesses with larger energy connections, where LC profiles are more prevalent. CO2 emissions from the commercial market segment in Amsterdam are significant, accounting for approximately 28% of the city's total emissions. This emphasizes the importance of implementing sustainable initiatives to reduce carbon footprints. Although electricity plays a role in the energy mix of SMEs, natural gas remains a predominant energy source. In older and monumental buildings, transitioning away from gas can be challenging due to legislative constraints or economic considerations. Moreover, becoming gas-free is a substantial undertaking for many buildings. As a result, the energy mix for SMEs typically includes both electricity and gas.

The energy needs of SMEs can vary significantly depending on their specific activities. This includes requirements for heating, lighting, mobility, and production. Different types of SMEs have distinct energy consumption patterns. For instance, a clothing store would utilize electricity and gas for lighting, heating, and cooling purposes. On the other hand, a restaurant's energy consumption would depend on factors such as its size, including the usage of energy for refrigeration, freezing systems, gas ovens, and stoves. Meanwhile, a printing company relies on machinery that requires a startup time of around half an hour and needs to be used for at least one and a half hours, typically running on electricity. It's worth noting that approximately 80% of buildings in Amsterdam still rely on gas for heating, and many restaurants continue to use gas for cooking, although induction cooking is gaining popularity.

SMEs typically request power capacity expansion for natural growth, sustainability initiatives, or as a preventive measure. When companies anticipate reaching their maximum capacity due to steady growth, they apply for expansion in advance. For instance, a company may request an expansion to accommodate the installation of fast chargers or chargers for freight transport. While a single charging station can often be accommodated within existing capacity, multiple stations require expansion.

Electricity is needed in various aspects of sustainability for SMEs. This includes transitioning from gas to electric appliances such as ovens and stoves, adopting heat pumps, installing charging stations, and implementing energy-saving and efficiency measures. Sustainability often requires significant investments. The question is, can companies afford it? There always needs to be a business case behind it. It has to be economically viable to pursue sustainability measures. Subsidies play an important role in providing that initial push, as well as fiscal benefits. For example, businesses can deduct a portion of their sustainable investments from their revenue. The business market accounts for 28% of CO2 emissions, with a significant 21% attributed to electricity consumption. Switching from gas to electricity does not automatically guarantee zero emissions, as it depends on how the electricity is generated. However, there is a gradual transition towards greener electricity sources.

Effects of congestion
Congestion is a significant issue in commercial business areas such as Sloterdijk 1, 2, 3, and 4, as well as De Heining. While not all businesses have experienced congestion, some are already facing capacity constraints and anticipate potential problems if they intend to grow or expand. In my conversations, I haven't encountered entrepreneurs who are desperate or at their capacity limit. While everyone is mindful of the situation, the current focus is primarily on energy-saving measures. However, it is expected that this mindset will change in the future. In cases of congestion, entrepreneurs can report their situation to the congestion hotline operated by the municipality. Collaborating with the Distribution System Operator (DSO), they work towards finding solutions. This may involve adjusting production schedules, coordinating with neighboring businesses or the local community, or implementing other measures to alleviate congestion. Although congestion can be a genuine problem, I haven't come across cases where businesses leave solely due to congestion. However, it can influence entrepreneurs' decisions regarding the location of their businesses, as congested areas may pose challenges. Moving to other areas may also be difficult due to limited available space in Amsterdam.

Ensuring a stable and reliable electricity supply is of great importance to SMEs. However, their ability to cope with reduced electricity availability for an extended period can vary. Flexibility can be achieved through coordinated efforts by SMEs themselves, allowing them to adjust their operations during peak times and manage their energy consumption. While stability is valued, adaptability is also crucial for this segment. Backup solutions like diesel generators are not commonly utilized among SMEs. Although there have been informal mentions of such backups, they are not considered a desirable or widespread practice. The availability of sufficient space for such backup systems poses a challenge as well.

Establishing a business in Amsterdam can be challenging for this segment due to grid congestion. It is essential to have a stable and reliable electricity supply to operate efficiently. The attractiveness of the city as a business location may be impacted if grid congestion issues persist.There is likely a correlation between expanding an electricity contract in the business market and job opportunities, although the strength of the correlation is uncertain. Expansion is more closely related to natural growth rather than sustainability initiatives. There is a clear relationship between expanding an electricity contract in the business market and CO2 emissions. The demand for electricity, grid congestion, and CO2 emissions are interconnected. If businesses aim to transition to electrification but lack the necessary capacity, they will continue with their current practices, resulting in persistent CO2 emissions. It is challenging to determine if expanding contracts leads to increased emissions from sources like diesel generators. I think it is unlikely, as there are no incentives or financial attractiveness for such alternatives due to the absence of subsidies and the high cost of diesel. In terms of developing neighborhoods, grid congestion can affect the livability of the area. While small shops and coffee houses may not require high-capacity connections, larger community facilities such as schools, hospitals, care institutions, community centers, music venues, and theaters may face challenges due to limited electricity capacity.

In the diverse landscape of small and medium-sized enterprises (SMEs), there is no one-size-fits-all approach. The longevity of a business in this segment depends on various factors, and relocation is not always a straightforward option. For example, imagine a traditional pub that has been operating on Herengracht since 1960 or a bakery that has built a loyal customer base over the years. These establishments are deeply rooted in their locations, and the thought of moving would mean losing a part of their identity and customer base. Businesses in this segment prefer to stay in a location that suits them well for as long as possible.

- Date: March 22 2023 10:00 - 11:00
- Place: online
- Interviewer: Julie van den Brink
- Expert 8: supports the business market with sustainability at the Municipality of Amsterdam

What are your tasks and responsibilities?
I work as a project leader in the ”Sustainable Business Market” program, where we have a team of fixers that conduct energy scans and utilize the sustainability fund to assist entrepreneurs. Our goal is to help businesses transition towards sustainability through energy efficiency measures and implementing solar panels on rooftops. The program was initiated in response to the municipality's climate report, which revealed that the small and medium-sized enterprises (SMEs) contribute to nearly 30% of the city's CO2 emissions. My role involves managing multiple projects simultaneously, working with individual companies as well as a few restaurant businesses in the Zuidas area that are aiming to become gas-free. One of our ongoing projects is the ”Net Congestion Loket”, where we are for instance collaborating with a homeowners' association (VVE) in Hemhaven to install a collective solar power system on their roof. We are also developing an energy hub in Weesp.

General information on the sector
The commercial market encompasses various sectors, including retail, VVEs (company collective buildings), real estate owners, hospitality, bakeries, shops, office buildings, and manufacturing industries. The energy consumption patterns differ significantly between sectors. For example, offices typically have a smaller energy footprint with a few computers and servers, while manufacturing industries have a higher energy demand due to their specific production processes. Additionally, certain businesses require additional permits to operate, such as emission permits. The duration of a small business's presence in Amsterdam varies, with some staying for the long term and others leaving sooner. Factors such as grid congestion can influence a company's decision to relocate or expand elsewhere. However, generally speaking, entrepreneurs tend to establish their businesses with a long-term perspective.

Energy needs of the sector
Approximately 25% of the businesses I interact with are considered large consumers (LC), meaning they have higher energy demands. However, many SMEs can manage well with a standard connection of three times 80 amperes. Only when it comes to larger-scale hospitality businesses with induction cookers and heat pumps do we see the need for higher capacity connections. Through the congestion hotline, we assist people who already have LC contracts or those looking to transition from small connection (SC) to LC contracts. The energy consumption of the small and medium-sized enterprises (SMEs) varies depending on their specific activities. In the manufacturing industry, energy usage can be significant, while for offices, it is relatively minimal.

The cost of electricity and gas is relatively small compared to other expenses for larger businesses, so there may be less incentive for them to transition. However, the recent rise in gas prices has started to drive sustainability considerations even among those initially resistant to change. The CO2 emissions in this segment primarily come from electricity consumption, supplemented by natural gas usage. The percentage of electricity in the energy mix of SMEs varies widely depending on the sector. For example, for a bakery, it can be around 30%, while for larger-scale industries, it may constitute only a few percent of their total energy consumption. However, the recent increase in gas prices due to the Ukraine crisis has sparked interest even among businesses that were initially hesitant to transition towards sustainability.

Effects of congestion
A stable and constant power supply is crucial for SMEs, and any power outage can cause disruption and inconvenience. There are some companies that have backup systems for energy. For example, I recently visited a goods transport company that has a lead-acid battery system, although it has limitations in terms of charging and discharging capabilities. In certain cases, businesses use such backup systems to support sustainable energy generation, while others may find it interesting to have as an additional feature. If the electricity demand is not met, it can pose challenges, particularly for new construction projects, changes in operations, or business expansions. Some businesses receive a "no" from the grid operator, limiting their ability to invest and grow.

The solutions for businesses facing electricity demand issues are highly dependent on their specific circumstances. Some companies may consider installing solar panels if they haven't done so already, as this can provide a viable solution. Alternatively, businesses that already have a heat pump can utilize its ability to turn on and off at specific times, offering flexibility in managing their electricity usage and generation. By optimizing their energy efficiency, they can often accommodate an expansion within their existing transport capacity. However, if these options are no longer feasible, a different situation arises. Although I haven't personally encountered cases where businesses relocate due to such challenges, it is a topic that generates significant concern and discussion within the community. In some cases, when businesses transition from a standard connection (SC) to a large connection (LC), such as in the case of a restaurant requiring three times 100 amperes, it is advisable to work with the largest SC connection, which is three times 80 amperes.

The need for grid expansion in the SME sector arises from natural growth or the desire to transition towards more sustainable practices. It is worth noting that not all solutions for sustainability initiatives require electricity. In fact, sometimes finding alternatives to electricity can provide more possibilities for optimizing energy demand and supply. For instance, if a business invests in solar panels with a favorable payback period of six years and faces grid congestion issues, adding a battery system could be solution, but extends the payback period to 10 or 15 years. But, grid congestion will definitely be a bottleneck in the path towards sustainability. Nevertheless, there are efforts to assist businesses in electrification processes, such as supporting hospitality businesses in the Zuidas area to transition away from gas through options like ground-source heat pumps, solar thermal collectors, or geothermal energy, enabling the discontinuation of gas connections.

Regarding CO2 emissions from SMEs experiencing congestion, it is important to note that while the electricity supply still relies on conventional sources, there is a push for sustainability. In terms of environmental impact, electricity is generally preferable to gas. However, diesel generators are sometimes used as a temporary solution, often in combination with other elements such as batteries, within a smart system. Proper management and control can significantly reduce the need for the generators to operate, with the ultimate goal being their minimal usage or even non-operation. Nevertheless, in this segment, if the reliability of electricity supply is compromised, businesses may consider shifting to less sustainable alternatives.

Congestion has a significant impact on job opportunities in the small and medium-sized enterprises (SMEs). When businesses are unable to expand or obtain new connections, it directly affects their plans and can result in job losses. For instance, a twelve-story business complex could accommodate numerous employees who are now facing limitations due to congestion. The potential job losses can be observed when considering the construction of additional facilities that require a certain amount of electricity to operate. Although the exact number of employees affected is difficult to determine, it could range from 10 to 20 individuals in such cases. In terms of the business climate and the livability of neighborhoods, congestion can lead to businesses relocating to alternative areas within a city. For example, if a company insists on being located in Amsterdam but faces challenges in securing a connection, they may opt to establish themselves in the eastern part of the city instead of the western region. When it comes to creating complete and livable neighborhoods, the impact may vary. For instance, a supermarket or a parking facility with charging stations near a hospital can be considered essential in terms of functionality. However, these amenities may also be viewed as nice-to-have additions that enhance the overall experience for residents and visitors.

C.7. Segment: Urban Development

- Date: March 24th 2023 14:00 - 15:00
- Place: online
- Interviewer: Julie van den Brink
- Expert 9: advisor energy- and utility services, urban planner for the municipality

What are your tasks and responsibilities?
I am responsible for managing energy systems in the area's urban development projects. My main focus is on coordinating with utility companies on the installation of waste systems, heat storage systems, electricity networks, and other related systems. As a project leader for cable and pipeline installations, I oversee the Sloterdijk Centrum and 1 Zuid areas. This entails coordinating the connections for nearly completed buildings and considering the wider area's requirements, such as the deployment of medium-voltage networks. Long-term planning reveals the necessity for new substations in these areas. I am involved in the spatial integration and cabling aspects of these substations, which often face spatial constraints due to limited available space. I engage with stakeholders in the area, communicating and aligning with them to determine their electricity needs and when they require these connections. While formal coordination occurs with the Distribution System Operator (DSO), larger-scale development projects necessitate forward-thinking and long-term considerations.

Energy needs of the sector
Urban project development for housing and non-housing projects requires electricity for both the construction and operation phases. During the construction phase, electricity is needed to power heavy equipment and tools, lighting for workers, and temporary structures such as trailers and offices. The amount of energy required during the construction phase can vary depending on the size and complexity of the project, as well as the duration of the construction period. This need almost always exceed the 3*80ampere limit, making it an LC connection prone to transport scarcity. For every new project that is developed, a new contract has to be requested. Once the project is developed, electricity is needed for the operation of various systems and appliances. In housing projects, electricity is needed for lighting, heating and cooling systems, kitchen appliances, and electronic devices. In non-housing projects, electricity may be needed for lighting, HVAC systems, elevators, and other building systems.

The choice of energy source for a particular urban project will depend on several factors, including the location, climate, availability and cost of different energy sources, and the project's sustainability goals. In project development, there is a variety in sizes of connections: housing fall into the LC segment, as well as shops and small offices, but larger offices and energy-intensive supermarkets or school require a LC connection. Regarding the timing of electricity requests, developers typically submit their applications during the final design phase, which is a few months before construction begins. However, meeting the 18-week connection obligation set by Liander, the network operator, is often challenging due to material and labor shortages. Hence, we emphasize the importance of engaging in dialogue with the DSO from the preliminary design phase. In the past, developers aimed to delay the signing of contracts until all installations were finalized, ensuring accurate power assessments and avoiding unnecessary expenses.

Effects of congestion
In practice, congestion is a real issue for this segment. I see it in the areas I work in, it is causing large consumers in this segment to be put on waiting lists for their electricity needs. As a result, some project developments are currently at a standstill because they have not been assigned construction power requests and are unable to proceed. ”Construction power” (bouwstroom) is a significant requirement for project development, since construction instruments like tower cranes require high amounts of electricity. One specific project that is currently on hold is the renovation of an office complex. They

considered using diesel generators as an alternative, but it was not financially viable and not environmentally desirable. The decisive factor was the financial aspect. I am not the primary point of contact for developers, but I attend technical sessions where I provide clarification on behalf of the municipality. Some developers are well-informed and aware of the challenges posed by congestion, while others are caught off guard by the situation.

It depends on the type of project being undertaken whether those who have not yet applied for construction power are unable to proceed. For residential developments, power capacity is typically reserved for the operation of the houses, which can be used for temporary construction power. However, the example I mentioned earlier pertained to an office building. There was no transport capacity reserved nor available for the operation of the project, thus there was also no capacity for powering construction. In the realm of project development, finding solutions to address electricity constraints has become a pressing issue. Most project development are mixed-use projects that combine residential and non-residential elements. The residential component receives power allocation as it is reserved in advance. However, the larger non-residential developments face significant delays and uncertainty, depending on the Distribution System Operator's (DSO) ability to provide solutions. It's a waiting game. The distribution of mixed projects in the two areas I work in primarily consists of a combination of residential units with commercial spaces located at the ground level, sometimes including office spaces. The ratio of non-residential to residential elements varies, ranging from 10% to 30% depending on the specific location. There are also projects that are fully non-housing, such as developers renovating office spaces.

Developers facing challenges due to incomplete power allocation in a mixed-use project express concerns about potential financial losses. If, for example, 20% of the commercial space remains without electricity, they fear years of missed income. While there haven't been cases where the entire project was halted due to this issue in combined developments, it remains uncertain whether this trend will continue in the coming years. The current predicament has persisted for approximately two years, but many of these projects have been in progress for much longer. Contracts have been signed, and there are lease agreements in place. Receiving the news 'the commercial spaces won't be connected to power' just before construction begins creates a vastly different situation than when receiving it at the start with an empty plot of land. If developers were aware of the situation during the earlier stages and could consider the future circumstances, their choices might have been different. However, my experience primarily revolves around the former scenario, where a few hundred square meters of commercial space in a development consisting of several hundred residential units are affected. In other cases, it could involve a supermarket or a few floors of office space. Currently, we are involved in the planning of parcels at Sloterdijk 1 Zuid, where several floors of commercial space are included. We are initiating conversations about their expected power requirements and whether the situation will work out. Of course, it also depends on how they divide and organize these spaces. They try to split the spaces up and make smaller power requests (SC) to stay below the LC power threshold.

- Date: March 21th 2023 16:00 - 17:00
- Place: online
- Interviewer: Julie van den Brink
- Expert 10: sustainability advisor for area development for the municipality of Amsterdam

What are your tasks and responsibilities?
I am part of the R&D team, focusing on strategy and policy implementation, particularly in the field of sustainable area development. My role as an advisor entails working on projects like Havenstad, Sloterdijk West, Foodcenter Amsterdam, and Schinkelkwartier. In Havenstad, we have Sloterdijk Centrum and Sloterdijk 1, which are already further along in their development compared to the rest of the area, as they have already undergone land exploitation. Our goal is to ensure that the municipality's sustainability policies, created by the sustainability department, are effectively incorporated into these area development projects. We provide assistance to project teams working in the built environment and public spaces. These area development teams, commissioned by "Grond & Ontwikkeling," consist of a project manager, an urban planner, an urban designer, a mobility expert, a finance representative, and someone responsible for land lease. My involvement is based on their specific needs.

General information on the sector
When it comes to area development, there are four phases to consider. The first phase is the initiation phase, which involves exploratory work often done well in advance. The second phase is the project decision or feasibility phase, where studies like environmental impact assessments are conducted. The third phase is the design phase, where urban planning and zoning plans are created. Finally, in the fourth phase, the land exploitation phase begins, the execution. During this phase, land is allocated to the market or specific entities. For example, my work on the Sluisbuurt started in 2016, which was in the third phase. Only now, years later, we see about half of the planned buildings being constructed. Area development is a long-term process and involves the creation of an entire city.

Area development is not always about developing empty plots; it can also involve transformation and renovation. Classic examples of area development like IJburg and Zeeburgereiland started as vacant spaces, essentially sand dunes. However, projects such as Havenstad and Schinkel involve transforming existing parts of the city. This approach aligns with the future direction as we no longer have empty spaces available in Amsterdam. Instead, our focus is on growing within the existing boundaries, densifying the urban fabric, and creating more comprehensive and sustainable neighborhoods.

Energy needs of the sector
Bouwstroom is a temporary power supply that is requested for construction purposes. If the request for a temporary connection is not made on time or is rejected, construction cannot proceed. In transformation areas, there are existing power connections that can be used for construction, but a contract is still required.

Effects of congestion
Regarding congestion, it primarily becomes a concern in phase 4, when project teams are actively working on implementation. From that point, it can take an additional 5 to 7 years to complete the project. It is crucial to ensure that the necessary infrastructure is in place during this process. In certain parts of the city, there are already challenges with providing sufficient power supply to large consumers, which can have a significant impact on connecting entire residential areas. Insufficient power supply can greatly hinder area development.

If there is a lack of electricity, there is a real possibility that a construction project might be halted. This decision could be made by the project developer in phase 4, or even by the municipality before reaching that stage. Eventually, all matters in a municipality become a matter of governance. There comes a point when the project manager has to say, ”I cannot proceed with this project because of capacity constraints.” The client then approaches the alderman, conveying the need for action. It’s important to note that this discussion relates solely to the municipality’s project inventory, without considering market players. This issue is currently under discussion and can be likened to the challenges posed by nitrogen emissions. Without a proper plan to address these concerns, construction projects may come to a standstill.

The pace of the DSO will determine the possibilities for area development. It is preferable for city councilors and urban planners to have a complete neighborhood rather than just individual houses without amenities such as supermarkets. For instance, in IJburg, there were insufficient facilities for many years, causing inconvenience to residents who had no schools or shops. The same issue exists in Amstelkwartier, where there are inadequate amenities, including a lack of schools. It is crucial to ensure the development of a complete city. If there is not enough electricity to support everything, then it is better to not proceed.

In terms of alternative energy sources for construction power supply, it is unlikely that options other than electricity will be widely used. The aim is to achieve emission-free construction. However, if there is no electricity available, alternatives such as hydrogen could be considered. Nevertheless, using hydrogen results in significant energy losses, and it is not yet practical in this segment. The prolonged halt in housing construction would be more disruptive than occasionally using diesel generators, although this is a debatable point. If sea levels rise, there will be no land left for construction... Ultimately, it always comes down to cost considerations. If a developer already knows that they would need expensive alternatives for power supply for two years, they are unlikely to proceed with the project. Often, everything is already too expensive, and every euro is carefully scrutinized.

If the ground floor cannot be operated, they may still build the residential tower depending on the profit model. In normal situations, sometimes the ground floor remains unfilled, and that risk already exists. They may still construct the tower with an empty ground floor. However, if it involves complete neighborhoods and provision of amenities, a development project may not proceed.

Congestion may make Amsterdam less attractive for project developers, but other factors such as energy costs, material costs, and the overall cost of construction carry more weight. In Amsterdam, there are numerous requirements, such as the need for mid-priced rentals, which make it uninteresting and challenging to generate returns. Congestion is a problem for everyone, not just in Amsterdam. We should not be afraid that developers will choose to relocate to Rotterdam.

There is actually an excess of job opportunities in area development, and there is a shortage of skilled workers, both at the project management level and in the execution phase. This shortage applies not only to construction but also to the electrical infrastructure. If project developers do not invest, everything comes to a standstill, and there will be no work available.

- Date: March 22th 2023 14:00 - 15:00
- Place: online
- Interviewer: Julie van den Brink
- Expert 11: project manager area development Sloterdijk 1 Zuid for the municipality of Amsterdam

What are your tasks and responsibilities?
As the project manager for the municipality of Amsterdam, I oversee the area development of Sloterdijk 1 Zuid. This project involves the collaboration of approximately 40 individuals, and I am one of the project managers. The investment decision for this project was made in 2019. The aim is to create an affordable residential neighborhood with 4,700 homes catering to diverse target groups. The development includes commercial spaces on the ground floor as well as above it, along with essential amenities such as schools and supermarkets. We work in partnership with market parties responsible for the actual realization of the project. Due to the high density, it is not feasible to develop each plot individually, requiring project developers to collaborate.

Energy needs of the sector
When it comes to the process of requesting electricity for a project development like ours, there are a few key factors to consider. Firstly, we need both temporary construction power and permanent operational electricity. The exact timing of when this request is made is not entirely clear, as it likely depends on various factors. It is safe to assume that a substantial planning is necessary before applying to the Distribution System Operator (DSO) for the electricity connection.

Effects of congestion
The impact of congestion in this segment depends on several factors, such as the available capacity and the types of functions being built. It's important to note that not everything is constructed at once. We have a planning horizon of 15 years from the start of Phase 4. Currently, we have three projects in the pipeline aiming to commence construction in 2025. This places us on the verge of capacity constraints. Personally, I expect demand congestion to persist beyond 2027, which means that these projects will encounter these challenges. Transport capacity has been reserved for houses, but there may be a priority given by the ACM (Authority for Consumers & Markets) to social amenities. However, the rest of the development is subject to transport restrictions. It's essential to understand that such development cannot be viewed in isolation; it is a comprehensive whole. For instance, a residential complex consists of not only homes but also a school, supermarket, and several offices. Therefore, all these functions need to be built simultaneously and integrally. Reserving capacity for housing alone does not ensure the development of housing because you cannot build only a portion of it. Developers would then have a significant amount of vacant space that cannot be sold or leased to end users.

I have encountered congestion issues twice before. One instance was with the Mediacollege, where there was insufficient electricity for expansion. The municipality actively sought solutions by engaging with the community and inquiring if there were parties willing to relinquish some capacity. Fortunately, a solution was found, but it's not feasible for everyone. Another example involves an office building where the owner intended to renovate. All tenants had already vacated, but the owner faced challenges in obtaining sufficient building power capacity and electricity expansion for the office enlargement. As a result, the project came to a halt, waiting for infrastructure expansion. The owner can still use the existing building under the current contract, but the expansion plans are put on hold. Thus, there are parties already facing significant obstacles. These were market-driven initiatives, and in our project, we haven't reached the construction phase, so we haven't encountered these issues ourselves.

When relocating within the same power supply area, you can transfer your capacity. However, if you move outside of that area, it's not possible. This poses a major problem in area development because sometimes we have to request companies to relocate to facilitate our development plans. However, these companies are reluctant to move due to the high risk of not obtaining electricity at the new location. Currently, there hasn't been a proposed solution for this issue, and it hasn't received much attention yet.

The financial investment decisions made by project developers are much earlier in the process, long before the electricity request is even considered. If developers foresee potential electricity-related issues, they may choose to delay their plans, possibly until the problem is resolved. This cautious approach helps mitigate the financial risk associated with having empty properties. In some cases, developers may even withdraw from the project at an earlier stage, before the final investment decision. It's important to note that the exploration phase of the project already requires significant investment.

The developers I have encountered are in the initial phase of development and are currently postponing the difficult decisions of how to respond to demand congestion. Consequently, I cannot make definitive statements regarding the choices they will ultimately make. However, I expect that there will come a point where difficult decisions need to be confronted. As for the timing of decisions determining whether a project can proceed, investors ideally want to gain clarity as early as possible in the development process. However, predicting this is challenging as it heavily depends on the particular developer involved. Some well-established entities may have sufficient financial resources to postpone such decisions for an extended period. On the other hand, smaller developers may not have the financial means to take substantial risks.

There is research being conducted to explore alternatives to construction power or regular electricity supply for operational purposes. One approach is to flatten the peaks of electricity consumption, which can lead to more efficient utilization of both the electrical grid and the project's own contract. Examples of such alternatives include the use of batteries or generators, smart contract sharing, and optimizing the utilization of residual heat. Implementing these solutions requires collaboration at the area level. Additionally, the feasibility of these alternatives depends on whether the project developer or the tenant covers the associated costs.

Now, regarding the preference between building individual houses or creating a complete city, I firmly believe in the importance of developing a comprehensive urban environment. This holds especially true for our project, as it is situated quite far from existing residential areas. Our aim is to establish a fully-fledged neighborhood that offers all essential amenities, including schools, supermarkets, and even a medical practice. While it may be the case that some facilities, such as schools, are not immediately available when the first houses are constructed, it is crucial to consider the long-term needs of the residents. Once children are enrolled in a school outside the neighborhood, it is inconvenient to relocate them. Similarly, having local shopping options is essential for the convenience and quality of life of the residents.

C.8. Segment: Public Services

- Date: May 19th 2023 09:00 - 10:00
- Place: online

- Interviewer: Julie van den Brink
- Expert 12: Team member of EVA and Taskforce, solving cases struggling with congestion in the Public Services segment

What are your tasks and responsibilities?
My expertise lies within program EVA. I've been working in this field [congestion and electricity services] for the past 4 years, focusing on resolving congestion issues. I do this by exploring alternatives and facilitating communication among stakeholders, primarily involving societal parties. Since I work for the municipality, we place significant emphasis on addressing their concerns.

One interesting case is the media college. In the service area of the substation that powers the media college, the municipality was also constructing a garage. The garage had requested a capacity of two megawatts, but they actually didn't need that much because it was all for future charging infrastructure that wasn't built yet. By chance, I knew the project manager of the garage, so I asked if they could return some of the capacity so we could use it for other projects on the waiting list. Liander, the energy network company, informed us that there was another party ahead of the media college on the waiting list. So we approached that party together with Liander and asked if they would be willing to transfer a portion of the released capacity to the college, and they agreed. One megawatt became available, with half allocated to the first party and the other half to the media college. That's how they managed to secure enough capacity for their opening.

Another example is the IJboulevard, where a bicycle garage was being built on the border of two supply areas, but its postcode fell within the congested area. I knew that cables from the other substation were running there, so I pointed it out to Liander, and they simply connected it to the other substation. It's all about knowing the details.

General information on the sector
The segment we are discussing mainly involves projects where the municipality of Amsterdam acts as the client. This includes the development of schools, healthcare facilities, community centers, and sports amenities. Within this segment, we also consider police and other security services, public transportation, public charging stations, municipal garage charging stations, critical infrastructure such as Waternet (pumping stations), and various provisions for bridges and public lighting. Regarding their location in the city, these projects are spread throughout Amsterdam.

As for the importance of this segment, we face several challenges both in Amsterdam and across the Netherlands. One of these challenges is the shortage of available housing for Amsterdam residents and the wider population. To address this, we need to construct more housing, which necessitates accompanying facilities. These publices services are essential for a densely populated city like Amsterdam. We observe significant demand and strain on such facilities, resulting in waiting lists for hospitals, schools, and other services. This creates societal unrest, and Amsterdam, like any growing city, faces its share of growing pains.

Energy needs of the sector This segment primarily uses energy for standard building-related facilities such as heating, cooling, lighting, computers, and alarms. There are also a few charging points here and there. In terms of energy consumption, it falls within the average range for buildings. It's not significantly different from other buildings, but we do see an increase due to electrification. We're transitioning to gas-free construction, utilizing technologies like heat pumps and electric cooking. In terms of energy usage patterns, it follows a typical work profile. It's often categorized similarly to offices by the grid operator. Offices, facilities, and educational institutions all have similar profiles. It's essentially a weekday, 9-to-5 or 8-to-6 pattern with peaks in winter due to the high demand for heat pumps and some peaks in summer for air conditioning. In terms of energy sources, new constructions no longer use gas, therefore they rely on on electricity.

Regarding energy classification, most relatively larger establishments fall under the high-consumption category. An exception would be a medical clinic with a waiting room and other rooms, that would fall just within the SC category. However, almost all buildings with their own heat pump and energy supply, such as primary schools and childcare facilities, fall under high-consumption. It adds up quickly. The only ones that truly fall under low-consumption are individual houses and small shops like shoe stores. It depends on the equipment in the building. To put it in perspective, a kettle and a microwave together already use around 2 kW, and the threshold is set at 55 kW, so consumption can quickly reach that level. Most schools currently require around 150 kW.

An electricity request is made for a new contract or an upgrade of an existing contract. Many of the upgrades currently being requested are a result of the energy transition. We are moving away from gas heating and cooking and transitioning to electricity, which requires more power. Previously, for example, a school could fall under the low-consumption category because they had gas heating. But now, they're switching to heat pumps and they need more capacity. Another situation is operation expansion, such as in the case of a hospital opening an additional wing. Often, you choose to make it more sustainable because it's a natural moment for it, like during major maintenance or renovations, those kinds of moments, so it is often intertwined. We're just starting to see the beginning of the sustainability wave, so to speak. So, it's only in the coming period that it will really take off. While there may be limited funds available, the focus is not solely on adding an extra sports hall but also on sustainability. The municipality is tasked with the sustainability of existing real estate.

The expansion size varies depending on the facility. For instance, the sports hall initially required 50 kW, but at the new location, considering their increased size, they needed approximately 140 kW, requiring an additional 70-80 kW of power. Typically, the increase is slightly less than double the power, depending on the scale. So, if a school currently operates at around 50-60 kW, you would need to account for approximately 100-120 kW in total. However, if you already have 200 kW, then you only need to add 60 kW, which is manageable. This calculation includes provisions for charging stations, heat pumps, and possibly other equipment. The size of the heat pump must be determined based on the building's dimensions, meaning larger buildings require larger heat pumps.

Responses to congestion

Finding solutions often requires creative thinking. Given the societal importance at stake, many parties are willing to cooperate to achieve the desired outcomes. It's not about entrepreneurs seeking higher profits but rather about the welfare of our city's facilities. Hence, things always work out somehow in this segment. This may also be attributed to the fact that there are fewer parties involved compared to commercial business segment. However, creative solutions have limits, especially if there is a widespread structural shortage for many parties. The construction market, for instance, has been severely affected by high prices, labor shortages, material scarcity, and environmental regulations. This has caused delays in this segment as well, therefore postponing an abundance of congestion cases. I do believe that things will improve in the coming years, which will likely make the challenges more apparent.

In this segment, there is always a solution from a technical perspective, although it may be more expensive or less sustainable. One could resort to using polluting generators to meet the electricity requirements, but the costs can quickly escalate. If no contract is given, the only solution is to work with generators. Storage would not be viable in that scenario, as you should be able to draw sufficient electricity from the grid to store. This is thus a good solution in combination with generators, or for expansion (2A). We often see the combination of storage and the utilization of a generator as a backup. You can rent a generator for the months you anticipate needing it. They are like portable units that you can bring and plug in. It's relatively straightforward. On the other hand, using generators is not our preferred option.In the case of the sports hall that requires 120 kW, we can meet their basic needs with a 55 kW SC connection (1A). Efficiency works well, but it is more applicable to larger buildings. For example, through proper insulation, you can reduce the need for heating and cooling, resulting in energy savings. By optimizing energy usage, you can make better use of your current contract.

What response is taken, depends on which phase the project is in. As the municipality, we allocate land to market parties for development purposes. We lease or sell the land to these market parties (in phase 4), and the conditions we set during the transfer include requirements for a certain number of houses, healthcare facilities, and schools. This is also a source of income for us because the land serves as a revenue stream. It's then up to the market parties to meet these requirements and develop the necessary elements outlined in the plan. If congestion is known in this area before phase 4, it's the municipality's decision whether or not to tender area/project. The costs for the alternatives are then borne by the municipality. Within the area development project, financial resources can then be allocated to provide alternative solutions. This must be addressed before phase 4, because that way it is budgeted for. In this segment, the municipality will likely cover the costs, and they assess this beforehand because it's somewhat clear for each area what the bridging period will be until congestion is resolved.

If the project reaches phase 4, the project developer is responsible, thus makes the choices. In some cases, congestion is declared only in phase 4. Developers and contractors working on a project may raise concerns because they are constructing their own project that may not have access to electricity or incurs extremely high costs. They might approach the municipality and say, "You provided us with a plot where we can't meet your requirements because we don't have access to electricity." In such situations, a joint assessment is needed to determine how to proceed. As a project developer, you have to develop the entire plot, you cannot choose to only built the SC categories of the project. They cannot choose to only built the dwelling and delay the other facilities, it is a cohesive entity. The residential properties themselves don't generate much profit for the developer. It's actually the amenities and facilities that hold the most value.

I think we're more inclined to think of postponing in this segment, than to change locations. You build on a specific location for a reason, with a certain philosophy behind it. Except for a university, where people come from outside Amsterdam to Amsterdam. Whether it's in the North or in Zuidoost, it doesn't really matter in that sense. But for all the other facilities, like a sports facility, if you planned it in the North, but there's no electricity, so you decide to plan it in Zuidoost. Well, that obviously doesn't make any sense. We have building standards per housing unit or number of residents. So it has to be in that location, so building somewhere else just doesn't apply to those projects.

When it comes to power upgrade, it depends on the purpose. If the upgrade is intended for the sustainability of the building, some may choose to delay it for about three years. It's a relatively easy solution to simply continue with the current approach and postpone implementing sustainable measures. This is acceptable since most sustainability goals are set for after 2030 or 2040. Therefore, there's still some leeway to wait a few more years before installing a heat pump or other similar upgrades. The urgency is somewhat reduced in such cases. However, if it's a necessary expansion of a wing, then the approach may differ, and alternative solutions would be considered. I believe around 80% of the respondents would opt to postpone sustainability measures, but in the case of functional expansion, alternatives will be explored.

Impacts of congestion

The societal impact of these consequences in this segment is significant. Regarding the expansion for the purpose of sustainability, it hampers our ability to achieve our goals of becoming more sustainable and greener in the coming years. Although we are still able to meet our targets for 2030, the pace of the progress will be slower. Those who delay the installation of heat pumps and the transition away from gas will continue emitting CO2 in the foreseeable future. I do not think there will be an impact on safety.

In terms of job opportunities, it might be relatively fewer compared to the commercial segment, especially when compared to the offices in the Zuidas area. However, hospitals, for example, employ a considerable number of highly skilled professionals. The economic value may vary, but there will likely be differences in terms of job counts. When it comes to the impact on job availability, the absence of teachers is noticeable but not excessively detrimental.

The most significant impact, in my opinion, is housing. As the municipality of Amsterdam, we have made it clear that we will not construct housing without providing the necessary facilities. If we are unable to build the necessary schools, it also halts the construction of houses, bringing the entire area development to a standstill. This, in turn, leads to housing shortages and prevents us from meeting the national policy objectives. Additionally, we also miss out on substantial land revenue generated by the construction of these homes. If the alternatives for demand congesion become too expensive, projects cannot proceed as developers will deem them too risky. For instance, the Sloterdijk 2 project is likely to be put on hold, greatly affecting housing development. It should be noted that we are currently working with the ACM to prioritize the parties on the waiting list of the public services segment. However, there is ofcourse also a limit to the capacity available to prioritize.

D
Input data

Substation data

Substation	Capacity [MVA]	Transformation [kV]
Basisweg	66	50/10
Bijlmer Noord	226	150/20/10
Bijlmer Zuid	99	150/10
Frederiksplein	66	50/10
Hoogte Kadijk	74	10
Ijpolder	20	50/10
Karperweg	88	50/10
Marnixstraat	88	50/10
Nieuwe meer	36	10
Noord Papaverweg	66	10
Rhijnspoor	66	50/10
Ruigoord	36	50/10
Schipluidenlaan	66	50/10
Slotermeer	50	50/10
Uilenburg	44	50/10
Venserweg	66	150/10
Vliegenbos	44	50/10
Watergraafsmeer	116	150/10
Westhaven	66	50/10
Westzaanstraat	66	50/10
Zorgvlied	176	150/20/10
Ijburg	80	150/20

Table D.1: List of medium-voltage substations in Amsterdam (end of 2022)

The expansion for the following ten substations are congruent with The Municipality of Amsterdam et al., 2022: Basisweg, Hemweg, IJpolder, Noord Papaverweg, Rhijnspoor, Schipluidenlaan, Slotermeer, Uilenburg, Venserweg, and Watergraafsmeer. The only inconsistency lays with Watergraafsmeer, which I indicate as an expansion instead of a new substation, since it will likely be as close as possible to the original substation. Furthermore, the Development Framework addresses the expansion of the substations Hoogte Kadijk, Vliegenbos, and Westzaanstraat, but this will happen after my time scope of 2030 (The Municipality of Amsterdam et al., 2022).

The input dataset includes the construction of nine new substations: Havenstad Zuid, Nieuwe Meer 2, Nieuwpoortstraat, Petroleumhaven, Sextantweg, Sloterdijk, Zeeburgereiland, Zuidoost 1, and

Zuidoost 2 (see Table D.2). The indicative dataset presents inconsistencies with the Development Framework since that outlines the construction of 17 new substations (The Municipality of Amsterdam et al., 2022). This inconsistency comes from the following cases: Watergraafsmeer is labelled as an expansion in the dat aset instead of a new substation, and the dataset includes the already completed substation in IJburg. A minor detail is that my dataset refers to Sloterdijk as Westpoort. The other six new substations mentioned in the Development Framework are scheduled to be built after 2030 (Overamstel, Osdorp, Zuidoost 3, Zuidoost 4, Cornelis Douwes and Buikslotermeer).

Substation	Capacity [MVA]	Operational in
Basisweg	106	2028
IJpolder	80	2026
Noord Papaverweg	119	2025
Rhijnspoor	106	2028
Schipluidenlaan	106	2027
Slotermeer	106	2029
Uilenburg	80	2023
Venserweg	106	2024
Vliegenbos	97	2025
Watergraafsmeer	170	2028
Havenstad	106	2028
Nieuwe Meer 2	80	2026
Nieuwpoortstraat	80	2026
Petroleumhaven	106	2028
Sextantweg	106	2025
Sloterdijk	106	2029
Zeeburgereiland	53	2030
Zuidoost 1	106	2028
Zuidoost 2	160	2028

Table D.2: List of medium-voltage substations to be expanded and newly constructed in Amsterdam

Case-study data

To calculate equations 4.2, 4.3 and 4.4, I have used the following parameters for the unknown variables:

Peak-load impact data

It is worth noting that the cluster definitions used by Liander differ slightly from the districts and neighborhoods used by the municipality. One should take into account the different scales of coloring used in the figure, which use an equal interval.

Variable	Value	Source
Average electricity consumption	602.313 $[kWh/year]$	Table D.4
Average gas consumption	49.187 $[m^3/year]$	Table D.4
Average workforce	31	Table D.5
CO_2 coefficient of gas	56,4 $[kg/GJ]$ == 1,6 $[kg/m^3]$	(RVO, 2020)
CO_2 coefficient of gas turbines	0,374 $[kg/kWh]$	(ACER, 2019)
Domino effect	2 %	Assumption
Electrification of gas consumption	30 %	Assumption
Expansion request	50%	Assumption
Gas turbine alternative	50 %	Assumption
Response 1C	100 %	Table 4.2
Response 2A	10 %	Table 4.2
Response 2C	85 %	Table 4.2
Sustainability reason	75 %	Assumption

Table D.3: Overview of input values used for the calculation of the societal impacts of the industry segment in Amsterdam

	Avg. electricity consumption $[kWh/year]$	Avg. gas consumption $[m^3/year]$
SBI B	-	-
SBI C	117.078	49.667
SBI D	1.066.889	-
SBI E	622.973	48.707
Industry segment	602.313	49.187

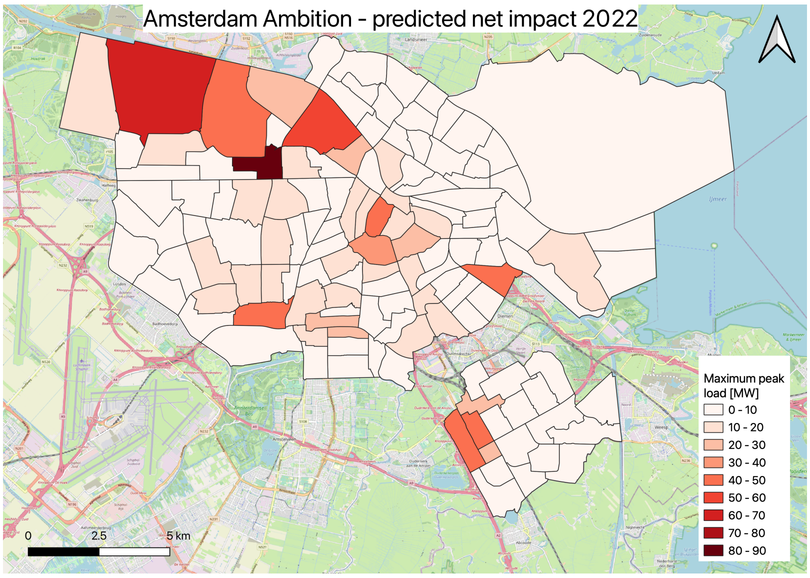
Table D.4: Average electricity and gas consumption per SBI segment in Amsterdam 2012-2021

	B	**C**	**D**	**E**
Establishments	22	2.694	57	86
Employees	297	14.526	3.753	3.380
Avg. workforce	14	5	66	39

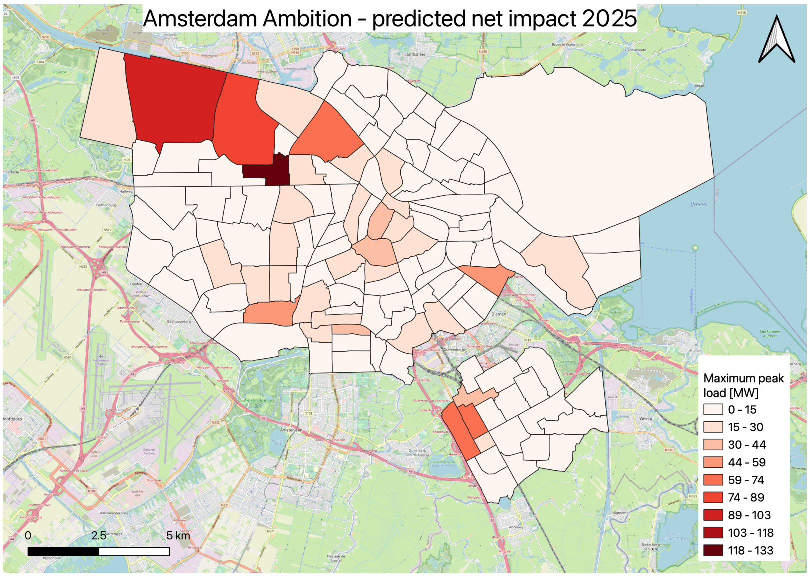
Table D.5: Average workforce of sections B-E in Amsterdam in 2021 (Municipality of Amsterdam, 2022b)

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
C - Establishments	2.270	2.455	2.445	2.560	2.700	2.785	2.905	3.055	3.150	3.155
D - Establishments	35	45	45	60	60	70	70	90	110	120
E - Establishments	85	100	95	105	110	110	110	130	135	140
C - Total electricity consumption [kWh/year]	348.882e3	343.007e3	378.011e3	-	300.344e3	287.210e3	313.200e3	304.882e3	284.896e3	294.239e3
D - Total electricity consumption [kWh/year]	56.705e3	69.310e3	70.100e3	-	-	78.221e3	-	66.262e3	53.524e3	49.177e3
E - Total electricity consumption [kWh/year]	65.296e3	76.189e3	73.071e3	75.759e3	78.219e3	57.745e3	54.938e3	-	60.859e3	55.960e3
C - Avg. electricity consumption [kWh/year]	153.692	139.717	154.605		111.238	103.127	107.814	99.797	90.443	93.261
D - Avg. electricity consumption [kWh/year]	1.620.142	1.540.222	1.557.777	-	-	1.117.442	-	736.244	486.581	409.808
E - Avg. electricity consumption [kWh/year]	768.188	761.890	769.168	721.514	711.081	524.954	499.436	-	450.807	399.714
C - Total gas consumption [m^3/year]	133.736e3	143.378e3	134.815e3	137.167e3	135.613e3	131.035e3	139.674e3	130.010e3	130.401e3	130.364e3
E - Total gas consumption [m^3/year]	6.666e3	6.729e3	-	6.294e3	6.511e3	4.421e3	4.596e3	4.711e3	4.018e3	3.576e3
C - Avg. gas consumption [m^3/year]	58.914	58.402	55.139	53.580	50.227	47.050	48.080	42.556	41.397	41.319
E - Avg. gas consumption [m^3/year]	78.423	67.290	-	59.942	59.190	40.190	41.781	36.238	29.762	25.542

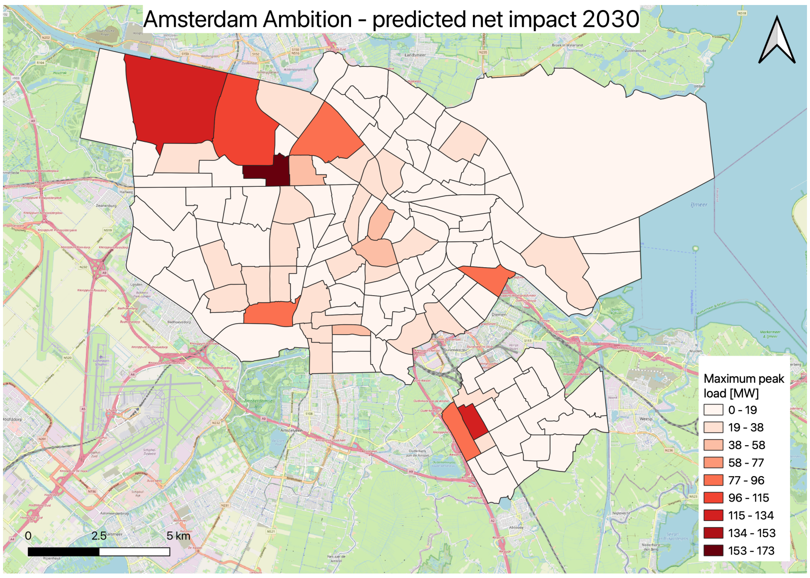
Table D.6: Overview of available data of the energy consumption in the B-E segment in Amsterdam 2012 - 2021 (Rijksoverheid, 2023)



(a) Maximum peak-load in MW in Amsterdam in 2022

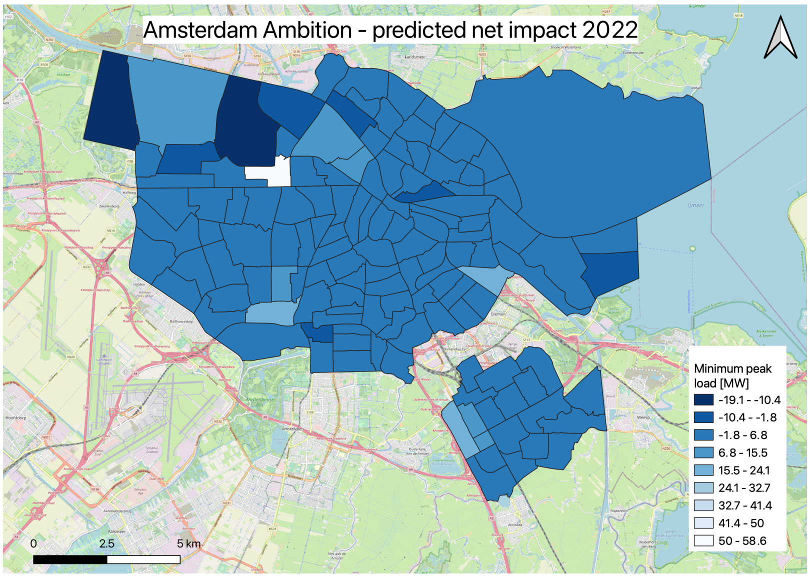


(b) Maximum peak-load in MW in Amsterdam in 2025

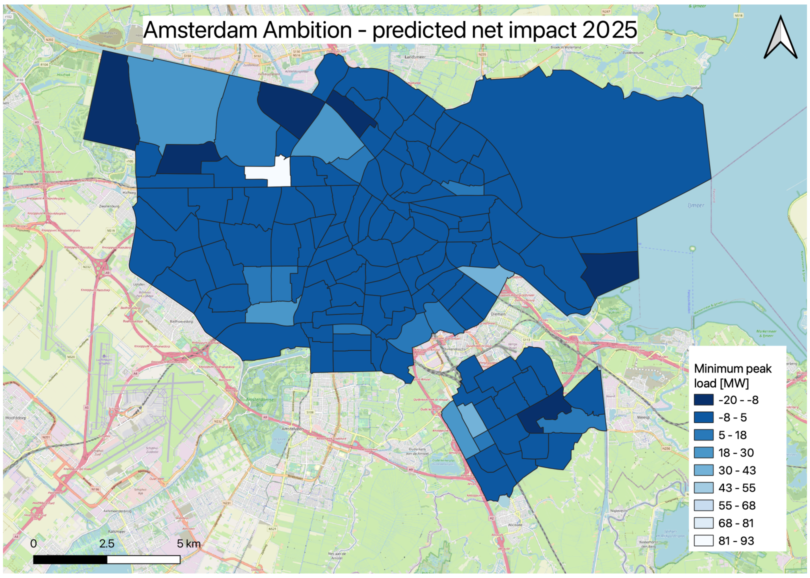


(c) Maximum peak-load in MW in Amsterdam in 2030

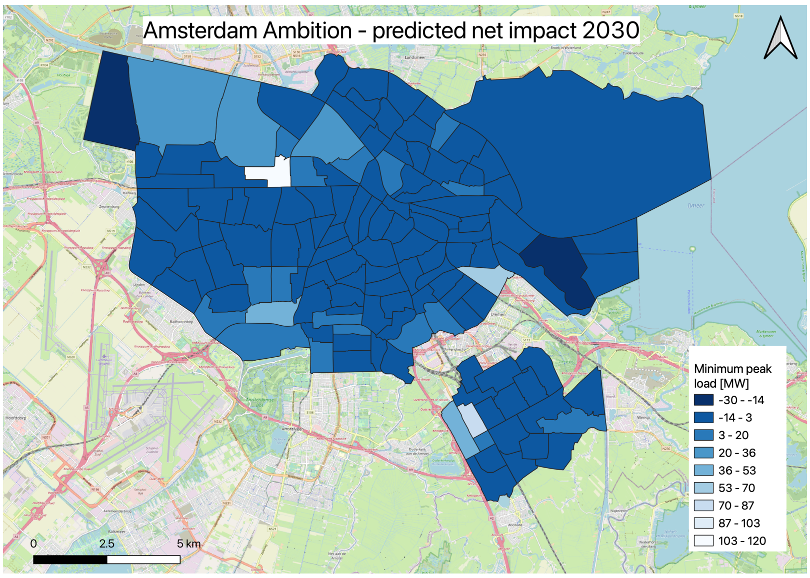
Figure D.1: Predicted maximum peak load in Amsterdam - Amsterdam Ambition scenario (Municipality of Amsterdam & Liander, 2021)



(a) Minimum peak-load in MW in Amsterdam in 2022



(b) Minimum peak-load in MW in Amsterdam in 2025



(c) Minimum peak-load in MW in Amsterdam in 2030

Figure D.2: Predicted minimum peak load in Amsterdam - Amsterdam Ambition scenario (Municipality of Amsterdam & Liander, 2021)