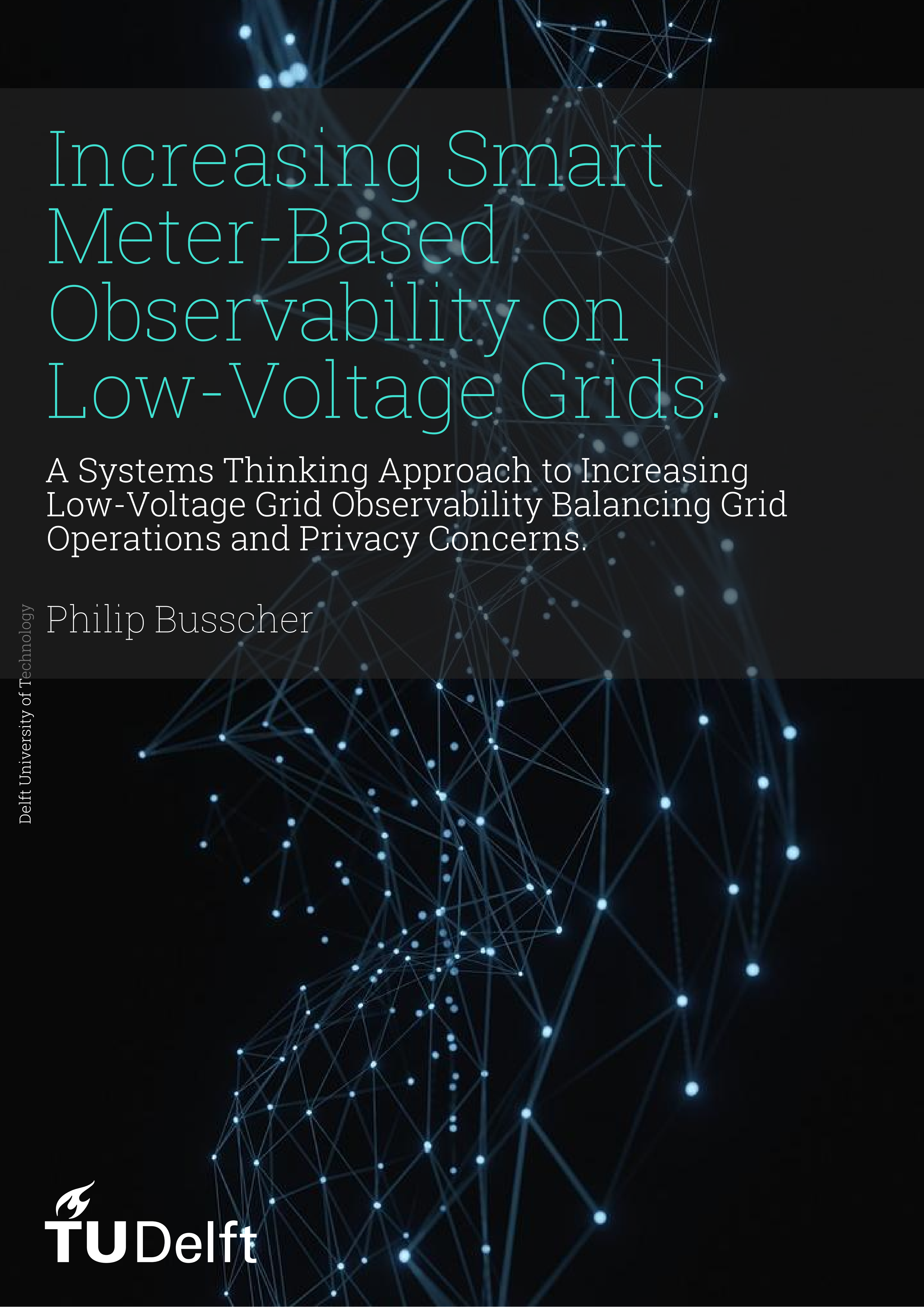

Increasing Smart Meter-Based Observability on Low-Voltage Grids.

A Systems Thinking Approach to Increasing Low-Voltage Grid Observability Balancing Grid Operations and Privacy Concerns.

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by

Philip Busscher

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This master thesis aims to apply a socio-technical perspective on the congestion problems that we currently encounter on the Dutch low-voltage grids. It does so by addressing the technical, institutional, and social aspects related to the low-voltage energy system. I hope that by applying a holistic and systems engineering approach, I have been able to bring a new perspective on how problems in the low-voltage grid can be defined and resolved.

In the first lecture of my BSc at TPM, we were taught that each TPM course serves as a tool for understanding the technical systems that surround us and shape our society. We were also told that, in the end, these tools collectively form a kind of Swiss army knife, equipping us to tackle and manage any complex situation. As I completed more courses over the years, I noticed my Swiss army knife becoming more versatile, allowing me to apply it to an increasingly wider range of situations. Some courses focused on adding new tools to the Swiss army knife, while others taught us how to combine specific sets of tools. However, during this thesis, I realised that every tool in my Swiss army knife proved useful.

TPM has taught me a lot about how to perceive complex problems, relations, solutions and complex socio-technical systems. But even more importantly, it has completely changed my perspective on how I view and take in the world. I am incredibly grateful to have studied at TPM, and I will forever cherish the collaborations with my fellow students and carry the valuable lessons from the outstanding professors with me.

Writing this thesis would not have been possible without my Graduation Committee. Therefore, I would like to thank Zofia, for your valuable and concise feedback and clear directions. Also, I would like to thank Werner for taking a leap of faith and allowing me to conduct my research at Alliander. I really enjoyed my time at Alliander's research lab and collaborating with such amazing scientists. Then, I would sincerely like to thank Roel. Thank you for the inspiring lessons on socio-technical systems and conversations that we had both during the courses and throughout my thesis. You have taught me to continually ask ”why,” even after understanding a system's technical aspects. Moreover, you have inspired me to consistently evaluate the implications of technical systems on other systems and, most importantly, on people and society. Finally, I would like to express my gratitude to Eva. Thank you for your positivity, all the brainstorming sessions we had, and for always being there to answer my questions and assist me when I was lost. At the start of my thesis, you advised me to enjoy the thesis process a bit, and I certainly did!

This thesis will be my final endeavour as a TU Delft student. However, I hope to continue learning, as I am far from finished. I will continue to view challenges through my TPM lens and carry forward the valuable lessons I learned during my time at the TPM faculty of the TU Delft. My time in Delft has been a lot of great fun with a lot of new friends and a lot of early mornings at the TU Delft Library. It has truly been a special experience which I will always cherish. Lastly, I would like to thank my family and friends for their unconditional support and for sharing all the special moments I had in Delft. Writing this thesis has been a fulfilling experience, and I hope you will enjoy reading it!

Philip Busscher
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Summary

The electrification of housing and industry increases electricity demand. Furthermore, integrating Distributed Energy Resources (DER) leads to more electricity being fed back into the low-voltage (LV) grid. Both developments increase the needed capacity for electricity distribution over the LV grid. However, since the current LV grid system was not initially designed for such high demand and bidirectional electricity flow, the existing LV grid infrastructure can no longer cope with the needed electricity capacity, causing LV grid congestion. Grid congestion on the low-voltage (LV) grid can lead to stagnation in new housing construction and hinder the development of businesses and industries, thereby impacting economic development.

To manage grid congestion, DSOs must monitor the LV grid state to perform appropriate interventions. However, due to electrification and the integration of DERs, monitoring and predicting the LV grid state using the established methods are no longer sufficient to manage grid congestion properly. To perform more effective congestion management, DSOs' capabilities for monitoring and predicting the LV grid's state must be enhanced first. Therefore, DSOs need more observability on the LV grid. Observability is defined as measurement data measured by measuring equipment or smart meters providing feedback on the LV grid state.

Smart meters installed in homes and commercial buildings can provide the measurement data needed to increase the observability that DSOs require to improve their monitoring capabilities. Although DSOs in the Netherlands own the smart meter infrastructure, established institutions, like AVG, make it difficult for DSOs to access smart meter data since it is perceived as personal data. Efforts have been made to reduce this complexity by introducing a code of conduct, the Gedragscode Slim Netbeheer (GSN), to enable DSOs to use smart meter data. However, the need for increased observability remains. This means that the GSN does not facilitate the required observability on the LV grid, and therefore, it does not meet the values and interests of the DSOs.

The related work states that in the energy sector, institutions should emerge from changing stakeholders' values. The introduction of smart meters introduced privacy-related values to the LV grid system. In response, the GSN was introduced to safeguard the consumer's values. This research assigns consumers with an installed smart meter the definition of 'data owner'. However, from the DSO's perspective, the GSN does not facilitate enough increase of observability on the LV grid, and therefore, it does not yet fulfil the values of the DSOs. While the related work states that institutions should emerge from changing values, it remains unclear why the values of the DSOs have not yet been incorporated into the GSN. This research aims to provide an understanding of why the DSO's values and interests of the DSOs are not satisfied in the GSN and what obstructs them from increasing observability by applying a Systems Thinking approach. This approach incorporates the technical aspects, institutions, values and interests of the stakeholders within the LV grid system to understand the complex system's behaviour and to identify the interrelations between the system's components.

First, literature research was conducted to gain insights into the workings of the LV grid system. These insights were used to identify which areas of the LV grid system should be explored to enhance observability. Second, interviews were conducted to explore the identified areas from the literature research and gain a deeper understanding of the technical- and institutional landscape and social interactions. Therefore, the chosen respondents play a significant role in managing congestion or enforcing the privacy regulation. An extensive analysis of the AVG, Elektriciteitswet 1998 and other energy-related legislation was conducted to explore the insights from the interviews concerning the institutional landscape. To understand the desired performance of the LV grid system concerning smart meter data access by DSOs, the values and interests of the stakeholders were collected during the literature research and the interviews. These values and interests are, for this research, considered as the system criteria as they provide insights into the preferred system performance. Also, the decision-making process can be deduced from the stakeholder's values and interests. The insights from the literature research, interviews and desk research were analysed using the Systems Thinking approach and combined in a mental model using a Causal Relation Diagram (CLD). The CLD enables the visualisation of causal relations, conflicts between institutions, technical components, values and interests. The CLD allows for analysis of the impact of the stakeholders' interests and plausible solutions that can be implemented to increase observability. The insights generated using the CLD were validated and evaluated with the Dutch data protection authority, Autoriteit Persoonsgegevens (AP), and the authority for consumers and markets, the Autoriteit Consument en Markt (ACM).

Based on the results of this research, it can be derived that the obstructions relate to the trade-off between increasing observability and preserving privacy. The first barrier to increasing observability comes from the fact that data owners and DSOs have different values and interests concerning the trade-off between increasing observability and preserving privacy. The second barrier comes from the established institutions that apply to the identified problem on the LV grid system. These institutions are the Elektriciteitswet 1998 and the Algemene Verordeningswet (AVG). The legal duties of the DSOs are outlined in the Elektriciteitswet 1998. These responsibilities include maintaining, operating, and developing the LV grids to ensure a reliable and efficient energy provision for consumers. As smart meter data is perceived as personal data, DSOs must have a legal basis for processing smart meter data according to the AVG, which can be obtained from the Elektriciteitswet 1998. However, the Elektriciteitswet 1998 does not explicitly describe to what extent smart meter data may be accessed by DSOs. This creates an institutional grey area in which DSOs find it challenging to assess whether they are permitted to use smart meter data to increase their low-voltage grid observability. A code of conduct, named Gedragscode Slim Netbeheer (GSN), was introduced to provide a uniform interpretation of the established institutions. The GSN was designed to enable access to smart meter data by approving specific use cases when DSOs may freely access specific smart meter data. However, the approved use cases exclusively permit smart meter data access to resolve grid issues reactively. It does not provide room for smart meter data access to prevent LV grid congestion proactively. This could lead to outages, often forcing DSOs to use smart meter data to resolve these issues. Consequently, both DSOs and energy consumers face a lose-lose scenario, where consumer privacy is compromised due to the necessity of accessing smart meter data. Yet, these infringements do not lead to improved congestion management. The cause for this lose-lose situation can be attributed to strict AVG interpretation and to the interpretation of the legal duties of the DSOs as outlined in the Elektriciteitswet 1998. Strict AVG interpretations force Alliander to use high aggregation levels and anonymisation, which improves privacy but reduces data granularity of smart meter data and, therefore, loses its effectiveness. To build a future-proof LV grid, DSOs need more access to more granular smart meter data for more LV grid observability to improve their monitoring abilities. This way, grid congestion management can be improved, and congestion-related outages can be prevented. This way, the reliability of energy provision can be improved, and the lose-lose situation can be altered to a win-win situation.

Alliander can increase smart meter-based observability by pursuing several solution directions to overcome the identified barriers. A priority solution is the re-interpretation of the established solutions. By interpreting the DSOs' legal duties more broadly, they can more frequently establish a legal basis for processing smart meter data, which is necessary under the AVG. Also, a more flexible interpretation of the AVG would enable DSOs to use lower levels of data aggregation to increase granularity and observability. Moreover, to overcome the diverging values and interests of data owners and DSOs, their values and interests must be broad together and aligned. Both the re-interpretation and converging of the stakeholder values and interests must be done by employing broad sector deliberations with AP, MFFBAS, ACM, DSOs, data owners and privacy advocacy organisations. These key stakeholders must unite and use the MFFBAS forum to rediscuss how the established institutions should be interpreted. New agreements must enable more smart meter-based observability and should be established in the GSN. Moreover, the forum should improve stakeholder engagement for piloting with data owners to test new observability-increasing technologies and policies. For instance, encryption methods like homomorphic encryption are solutions that have the potential to increase both observability and privacy. However, this method has not yet been extensively tested within Alliander. Therefore, by increasing stakeholder engagement using the MFFBAS forum, consent-based pilots must be enabled to contribute to developing certain encryption technologies. Ultimately, the re-interpretation of established institutions and the adoption of encryption methods should increase smart meter-based observability.

Contents

Nomenclature

As definitions and jargon can be different among distribution system operators the applied abbreviations, definitions and concepts can be found in this section.

Translation of definitions

English definition	Dutch translation
LV feeder	Afgaand veld laagspanningsnet
Medium-voltage substation	Onderstation
MV feeder	Middenspanningsroute

Abbreviations

English abbreviation	Definition
BESS	Battery Energy Storage Systems
CLD	Causal Loop Diagram
DER	Distributed Energy Resources
DSO	Distribution System Operator
EV	Electric vehicle
HEMS	Home Energy Management System
HV	High-voltage
LV	Low-voltage
MV	Medium-voltage
PET	Privacy Enhancing Technologies
RTI	Real-Time Interface
SE	State Estimation
SSI	Semi-Structured Interview
TSO	Transmission System Operator

Dutch abbreviation	Dutch translation	Definition
AVG	Algemene Verordening Gegevensbescherming	General Data Protection Regulation (GDPR)
CBC	Capaciteitsbeperkend Contract	Capacity Limiting Contract
GSN	Gedragscode Slim Netbeheer	Code of Conduct for smart meter data use
MSR	Middenspanningsruimte	Transformer substation
ODA	Overige Dienst Aanbieders	Third-party service suppliers

1 Introduction

1.1. Problem introduction

Grid congestion is becoming a major problem for low-voltage (LV) grids in the Netherlands (Giesbertz, 2024b)(Ministerie van Economische Zaken en Klimaat, 2024). Grid congestion is caused by the growing demand for electricity driven by the electrification of mobility, households, and industries (Kaat, 2023), as well as the increasing integration of Distributed Energy Resources (DER) (Barone & Buonomano, 2023). Grid congestion in the Netherlands significantly impacts economic growth, sustainability, and housing development. Capacity constraints on the electricity grid hinder business expansion and the integration of renewable energy, causing an annual economic loss of €10-35 billion. This also delays sustainability efforts, adding €1-1.5 billion in costs, and stalls housing projects, with an estimated loss of €0.1-2.5 billion per year. Overall, grid congestion slows the energy transition and creates widespread societal and economic challenges (Venema et al., 2024). Distribution System Operators (DSO) are legally responsible for managing grid congestion to guarantee reliable energy provision to the consumers in their service area (E.C. Joint Research Centre., 2021). Congestion can be managed effectively by grid reinforcement or digitalising congestion management solutions. To resolve congestion by reinforcing the grid, DSOs will need to exert 25% more effort than their current resources allow to meet the expected electricity demand for 2033. However, due to limited materials and trained personnel, it is unlikely that they will be able to increase their productivity in time (Westerveld, 2024). Since congestion problems are urgent, DSOs must not only focus on reinforcing the grid but also seek smart solutions to cope with the increasing need for grid capacity. Given the limited capacity available on the LV grid, it is crucial to optimise the use of existing LV grid infrastructure by implementing digital solutions for grid congestion management (Giesbertz, 2024a)(Ministerie van Economische Zaken en Klimaat, 2024). However, digitalisation requires extensive use of data providing feedback on the state of the LV grid, also known as observability. This data can be obtained either from measurement equipment embedded in the grid infrastructure or from smart meters installed in homes and commercial buildings. The installation of measuring equipment requires time, and it provides less observability than the use of smart meters. Moreover, smart meter infrastructure is already installed in most customers' homes and commercial buildings (Ministerie van Economische Zaken en Klimaat, 2024). However, smart meter data is classified as personal data under Algemene verordening gegevensbescherming (AVG), and its disclosure carries significant privacy implications. As a result, DSOs cannot freely access this data, which hinders their ability to improve congestion management on the grid (Netbeheer Nederland, 2024a). However, under the Elektriciteitswet 1998, DSOs have a legal obligation to ensure reliable energy provision, which includes managing grid congestion to guarantee that customers receive a stable electricity supply (Elektriciteitswet, 1998). These conflicting legislations make it complex for DSOs to determine whether they are legally permitted to access smart meter data to increase their LV grid observability. As a result, DSOs are reluctant to access smart meter data to enhance grid observability and improve grid management, which limits their ability to make optimal use of the available existing LV grid infrastructure. Because of the desire for more clarity and guidance regarding the complex legislation, Gedragscode Slim Netbeheer (GSN) was introduced. The GSN contains a set of use cases for which DSOs can freely access smart meter data. Moreover, the GSN outlines a process for approving new use cases, which are evaluated by independent bodies to ensure a consistent and standardized approval process. Once a use case is approved, DSOs can freely access smart meter data for that specific approved use case.

For grid operations departments of DSOs, the GSN is, in some aspects, an enabler of data since it allows for free smart meter data access for DSOs. However, the GSN restricts yet the most essential parameters for congestion management. Moreover, the approval process for new use cases is extensive and slow, making the GSN a limiting factor for grid operations as well. Alliander's customers include households and businesses. In the Netherlands, the DSOs own the smart meter infrastructure.

However, data generated by these meters is owned by the customers. Therefore, the customers are hereafter referred to as 'data owners'. Naturally, data owners prefer keeping their personal data private to avoid privacy infringements, and therefore, they value compliance with the AVG. At Alliander, AVG compliance is overseen by the Privacy Desk. This team ensures that all departments within the organization adhere to AVG, helping to prevent potential privacy infringement and safeguarding the privacy of the data owners. The Autoriteit Persoonsgegevens (AP) is the data protection authority. This body is responsible for overseeing and enforcing AVG, ensuring the rights of data owners are protected regarding the processing of their personal data. Moreover, the AP, in collaboration with data officers and the working group GSN, is responsible for approving new use cases (Netbeheer Nederland, 2024a). The Autoriteit Consument en Markt (ACM) is the regulatory authority responsible for ensuring that DSOs fulfil their public duties efficiently and reliably while preventing them from abusing their monopolistic position. Grid congestion reduces efficiency, and therefore, the ACM encourages DSOs to innovate and perform congestion management as long as this happens within the boundaries of the AVG (Netbeheer Nederland, 2024a).

1.2. Problem statement

Although the GSN was introduced to offer guidance and clarity, it has also brought new complexities. So far, use cases have primarily been approved because they address specific critical issues that demand urgent resolution. This approval process follows a reactive feedback mechanism, where new use cases are only considered after problems have already emerged. This reactional feedback mechanism hinders DSOs from proactively developing solutions to manage grid congestion. As a result, issues may be addressed too late, potentially leading to outages. Furthermore, since DSOs can access all smart meter data in emergencies, privacy is compromised regardless, creating a lose-lose scenario for both DSOs and data owners. In this lose-lose scenario, DSOs fail to fulfil their public duty of managing the grid efficiently, thereby falling short of the expectations set by the ACM. However, if early action is taken, congestion can be avoided, potentially preventing emergency situations and minimizing the need for last-minute access to personal data. This proactive approach would also better align with the AP's objectives by promoting privacy protection and minimizing personal data usage, ultimately benefiting the data owner by safeguarding their privacy and reducing the risk of unnecessary data exposure. This can be regarded as a win-win scenario where Alliander improves its service, and no unnecessary personal data is disclosed of the data owner.

To enable this proactive approach, Alliander needs to increase its observability on the LV grid. Increased observability could contribute to improving congestion management, preventing outages, and aligning with the expectations of the ACM. However, implementing proactive measures may require using data sources like smart meters in advance, which raises privacy concerns too and could potentially lead to conflicts with the AP. A complex trade-off exists between enhancing observability and safeguarding privacy. Further research is needed to determine how this lose-lose situation can be transformed into a win-win outcome. The next chapter will elaborate on the previous efforts to address this trade-off.

1.3. Related work

The desire for energy data and smart meter data is not entirely new. Prior research has primarily focused on developing technical privacy-enhancing solutions to enable the use of smart meter data and increase observability while ensuring consumer privacy. Wang et al. (2023) stress the importance of data of sharing energy data for sustainable energy systems. Therefore, they highlight that privacy-related issues should be addressed using numerous technical solutions like privacy privacy-enhancing techniques (PET). Moreover, Souri et al. (2014) specify that especially in the LV grid domain where energy consumers are connected to the grid, data security is the main concern. Therefore, they propose technical solutions like aggregation, anonymisation, encryption and differential privacy to be used to improve data security and ensure privacy. Also, within Alliander, there is a prevailing norm that issues should be addressed primarily from a technical perspective. This perspective is also taken when developing solutions to increase observability. However, despite the existence of privacy-enhancing technologies, smart meter data is not yet extensively used to increase LV grid observability. Milchram et al. (2018) state that although smart energy solutions like smart meters facilitate more sustainable energy systems, their societal acceptance is not solely determined by technical feasibility and privacy-enhancing capabilities. Instead, stakeholder values, like trust and privacy, strongly determine the societal acceptance and adoption of smart meter technologies. The transition to a new energy system involves changes in technological properties, like using smart meters to increase observability. However, technological innovation should always be accompanied by new institutions to achieve a system performance that is societally accepted (Kunneke, 2018). Milchram et al. (2019) state that in the energy sector, institutional change is driven by the evolving core values of stakeholders, like the shift from market efficiency to affordability and sustainability leading to new legislation regarding renewable energy.

However, in the Netherlands, shifting core values to more sustainability forced the transition to smart grids. The transition to smart grids requires the adoption of smart meters to use personal data for grid management. This technological innovation introduced new core values like privacy and data security. As a result, the values among the stakeholders within the LV grid system differ strongly. DSO's values drive the desire for increasing observability for efficient grid operations, which conflicts with data owner's values that strive for privacy. These conflicting values require new institutions to emerge to facilitate broad societal acceptance of smart meter adoption according to Milchram et al. (2019). However, for the Dutch smart meter case, it seems that there are still barriers that obstruct this institutional change since the use of smart meters by DSOs is not yet broadly accepted by society.

1.4. Academic knowledge gap and main research question

The related work demonstrates a strong interdependence between the technical landscape, institutions, and stakeholder values. Therefore, considering these three interconnected elements is crucial when transitioning to new technical systems, such as adopting smart meters for congestion management. However, the related work does not adopt a comprehensive approach incorporating all three elements to explain why Alliander faces challenges in implementing more observability in the LV grid. Building on the work of Milchram et al. (2019), it is necessary to understand stakeholders' core values to drive institutional change and successfully implement technological innovations like integrating smart meters for grid management. This research aims to identify the barriers preventing the adoption of smart meters to enhance observability and improve congestion management. Unlike previous work, this study does not primarily focus on technical solutions to enhance privacy. Instead, it takes a holistic approach that also examines the interdependencies between established institutions and stakeholder values. This provides a unique perspective on what is hindering Alliander from increasing observability in the LV grid. To operationalize this research, the main research question has been formulated as follows:

MRQ: What are the barriers to increasing smart meter-based observability on the low-voltage grid and how to overcome them?

1.5. Relevance to CoSEM program

This research is the final project for the master program of Complex Systems Engineering and Management (CoSEM) at the TU Delft. The CoSEM master's program emphasises multidisciplinary approaches, aiming to manage and design interventions within complex socio-technical systems and real-world decision-making challenges. This research aims to study low-voltage grid systems, which are complex systems because they consist of many interdependent components and heterogeneous stakeholders. It contains dynamic interactions between the components and stakeholders, like feedback loops between smart meters and DSOs. Moreover, due to the unpredictable nature of how the stakeholders interact with LV grids and the variability introduced by DERs putting electricity back on the grid, the LV grid system shows emergent behaviour. This research aligns with the CoSEM guidelines as it applies a systems engineering perspective. It aims to embrace the complexity by taking a holistic approach to studying the complex LV grid system and proposing interventions to alter its emergent behaviour. It does so by taking into account the technical, institutional and social aspects of the system that shape its behaviour.

1.6. Thesis Outline

The structure of this thesis is organized to address the research questions and objectives systematically. Chapter 2 introduces the chosen research approach, outlining the methodology that guides the study's design and execution. Following this, Chapter 3 provides a rationale for all research activities, explaining the methods applied for data collection and analysis. Chapter 4 presents the key findings from the literature review, forming a theoretical foundation for the study. Chapter 5 explores the technical landscape, addressing sub-question 1, while Chapter 6 examines the emerging values and interests, responding to sub-question 2. In Chapter 7, the institutional landscape is discussed to answer sub-question 3. Chapter 8 provides the theoretical motivation for the analysis, focusing on sub-question 5, followed by Chapter 9, which presents an analysis of the current system to answer sub-question 6. The study's broader implications are discussed in Chapter 10, and finally, the conclusions are drawn, and recommendations are provided in Chapter 11.

2 Research approach and subquestions

This chapter describes and argues for the applied research approach to address the academic knowledge gap and answer the main research question. First, a motivation for the applied research approach will be provided. Then, an elaboration follows how the research approach is applied in this research.

2.1. Motivation for applied research approach

To find concrete means to increase observability on the LV grids, an integral analysis of the current LV grid system is required. The LV grid system is a complex system, primarily due to the diverse interests of stakeholders and the unpredictable nature of energy demand. This unpredictability is further increased by DERs, which are heavily influenced by weather conditions. These factors make it challenging to manage the LV grid system effectively or to apply changes to the system that suit all stakeholders. Therefore, to find fitting means to increase observability on the LV grid that serves all stakeholders, an integral analysis is required that covers the socio-technical and institutional aspects of the system. To achieve this, relevant information must be collected from the DSOs operating the LV grid and consumers who are connected to the LV grid and have a smart meter installed. Also, to systematically structure the complex aspects of the LV grid system and study the obtained information from the stakeholders, a theory must be introduced. This theory should contribute to creating insight into the inner workings of the LV grid system and create new insights to increase observability. This research applies Design Science Research (DSR) to combine the relevant LV grid system characteristics with the appropriate theory to structure and study the system systematically.

2.2. Design Science Research

In DSR, practical issues are addressed by developing artefacts to improve existing systems (Hevner, 2007). Artefacts are human-made objects that assist individuals or organisations in overcoming real-world challenges. DSR seeks to produce knowledge that expands on the current scientific body of knowledge while using empirical data from local practices to tackle these practical issues. The knowledge generated through DSR should offer a scientific contribution to the academic community and practical benefits to local practices. The output of DSR includes both the developed solution and the valuable insights gained from how it is used in real-world situations. (Johannesson & Perjons, 2021). DSR consists of three intertwined cycles that combine the intervention's requirements and existing theory and methods into an artefact for an intervention. The three cycles are the Relevance cycle, the Rigor cycle and the Design cycle (Hevner, 2007).

2.2.1. Relevance cycle

To design observability on the LV grid, it is crucial to have a comprehensive understanding of the current system by identifying opportunities and problems. In-depth knowledge of the technical aspects is vital, but equally important is an understanding of stakeholder behaviour and the institutions that influence and shape that behaviour. Also, the acceptance criteria from stakeholders should be extracted to evaluate and measure system improvements. These aspects of the system are defined in DSR as the 'system requirements' that can be found in the system's Environment. The system requirements are collected through various research activities through the Relevance Cycle (Hevner, 2007).

In DSR, it is usual to define the system requirements by employing multiple relevance cycles. Therefore, this research consists of two iterations of relevance cycles to iteratively define the system's environment. During the first iteration, a literature review is conducted to gain a clear, high-level understanding of the LV grid system. The knowledge gained from this review provides partial answers to sub-questions 1, 2, and 3. However, due to the different nature of DSOs and the varying ways in which they experience LV grid challenges, the literature alone is insufficient to address these sub-questions fully. Therefore, a second iteration is needed. Besides understanding the LV grid system, from the literature research, a set of themes, values, and interests are inductively generated to perform an effective second iteration. A second iteration of the relevance cycle is essential to gain a deeper and integral understanding of the Environment of the LV grid system. This second iteration was done by doing an internship at Alliander, a highly technologically mature DSO that operates a large LV grid in the Netherlands. Alliander provided expertise on both the technical system and also contributed to finding the right contacts with extensive knowledge of privacy-related values and interests. These themes, values and interests identified in the literature research were used to guide the conversations with the respondents. The set of themes was consequently used to perform thematic deductive coding of the transcripts of the interviews with the respondents to find complete and sufficient answers to sub-question 1 and sub-question 3.

To grasp a technical understanding of how the current system works, the first sub-question was composed. This sub-question aims to reveal how the DSO currently implements more observability on the LV grids in its service area:

To know how observability can be increased, it is necessary to understand how observability is currently implemented in the current LV grid system. The technical aspects of the system should be studied to understand the physical infrastructure, including grid components, but also operational characteristics, like how smart meters are used for implementing observability, identifying the technical landscape and understanding the limitations of the current technical system. To grasp a technical understanding of how Alliander implements observability in its service area, the first sub-question was composed:

SQ1: How is observability designed to operate low-voltage grids in the Netherlands?

To understand the emergent behaviour of this complex system, one must understand what drives the stakeholders in their actions. Their values and interests can explain actor behaviour. The values and interests of the stakeholders might conflict, which can cause a certain undesired system behaviour. However, values and interests might also create opportunities. Once motivations behind stakeholder behaviour are known, one can better understand how to intervene in the existing system. Additionally, to improve an existing system, more research is required to gain insight into the stakeholders' desired expectations for the system's performance, including the stakeholder criteria that can be used to measure the improvement of the system performance (Hevner, 2007). This research aims to collect the values and interests of the stakeholders and use them not only to understand their decision-making but also as system criteria to measure the improvement of the system's performance. Values and interests can be applied as non-measurable criteria in evaluations or analyses by serving as qualitative benchmarks that guide behaviour, influence decisions, and shape outcomes of systems Milchram et al. (2019). Unlike measurable criteria, such as costs or performance metrics, values and interests are subjective and context-dependent, making them difficult to quantify. To extract the values and criteria of the stakeholders and to further specify the problem statement, the second sub-question was composed:

SQ2: What values and interests emerge when smart meter data is shared with DSOs to increase observability on the low-voltage grid?

Values and interests influence actor behaviour through intrinsic motivation, representing internal drivers such as personal beliefs, ethical principles, or long-term goals. In contrast, institutions shape actor behaviour through extrinsic mechanisms by establishing external rules, norms, and incentives that guide or constrain certain actions (Legault, 2016). Sometimes, institutions are also an outcome of emerging values and interests. For example, the GSN emerged from the desire of DSOs to get more access to smart meter data Respondent M. To further understand the actor behaviour in this system, the institutional landscape should be studied to specify the initial problem statement better and to understand the boundaries of the solution space. To address this knowledge gap, the third sub-question was composed:

SQ3: What institutions govern the implementation of increased observability on the low-voltage grid for DSOs?

To effectively code the interview transcripts, a set of themes must be deducted from the first iteration of the relevance cycle. Therefore, from the literature research, the most important topics are selected and used to structure the interviews. To address this process the following sub-question was formulated:

SQ4: What key themes, identified from the literature, can be applied for deductive thematic coding of the interview transcripts?

2.2.2. Rigor Cycle

To ensure that this research is grounded in existing knowledge and theory, it will consult the existing knowledge base to search for relevant theories and methods that can function as guidelines for structuring the system requirements of the current LV grid system. In DSR, the process of finding the appropriate theory is defined by the Rigor Cycle (Hevner, 2007). To gain an integral understanding of the LV grid system, the system requirements from the relevance cycle, which consist of the outputs of sub-questions 1, 2 and 3, are systematically structured by applying established theory from the existing knowledge base. Based on these system requirements, the appropriate theory is selected. The following sub-question defines this process:

SQ5: How can the various insights from the relevance cycle be combined using established theory for comprehensive and actionable analysis of the low-voltage grid system?

2.2.3. Design cycle

The Design cycle in DSR inputs the system requirements from the Relevance cycle into the chosen established theory from the Rigor cycle for designing an artefact. In this research, the artefact aims to model the interactions between various stakeholders, the institutions and components within the LV grid system. The Design cycle constantly iterates and is examined against the system requirements until a satisfactory artefact design is achieved (Hevner, 2007). The artefact's design is considered sufficient when it accurately models the emergent system behaviour as described in the literature and interviews. This research aims to apply Systems Thinking to design an artefact that provides an integral understanding of the inner workings of the current LV grid system and to create insight into possible solutions for increasing observability on the LV grid. The following sub-question defines this design process:

SQ6: What insights can be learned for increasing observability on the low-voltage grid by applying Systems Thinking to the Relevance Cycle's system requirements into an artefact?

2.3. Main takeaways

The focus of this research is primarily centred on the relevance cycle. This emphasis arises from the initial literature review, which revealed that the current system and problem could not be sufficiently defined to generate valuable insights into increasing observability. Therefore, the research prioritizes specifying the existing system using theory to gain a deeper understanding of the system's dynamics and the conflicting values and interests of the stakeholders.

Moreover, in DSR, it is required to perform field tests by testing the created artefacts in the real system's environment by doing field testing (Hevner, 2007). A notable limitation of this DSR research is the absence of field testing. Without this, the artefact has not been validated in a real-world setting, which limits the ability to assess its practical effectiveness and scalability fully. This gap reduces the external validity of the findings and leaves room for further research to evaluate its performance in applied environments. Although no extensive field testing was conducted in this research, a detailed plan is outlined in the validation and evaluation chapter for how the validation would have been carried out. This plan includes implementing the artefact in a real-world setting and collecting data to assess its practical effectiveness, scalability, and impact. Additionally, two smaller-scale validations will be performed to provide initial feedback on whether the artefact could be useful. These short validations will help gauge the artefact's relevance and offer insights into areas for further refinement before full-scale implementation.

Figure 2.1 operationalizes the sub-questions by positioning them in the visualisation of the DSR. This figure provides an extra overview on what DSR cycle is addressed by each sub-question.

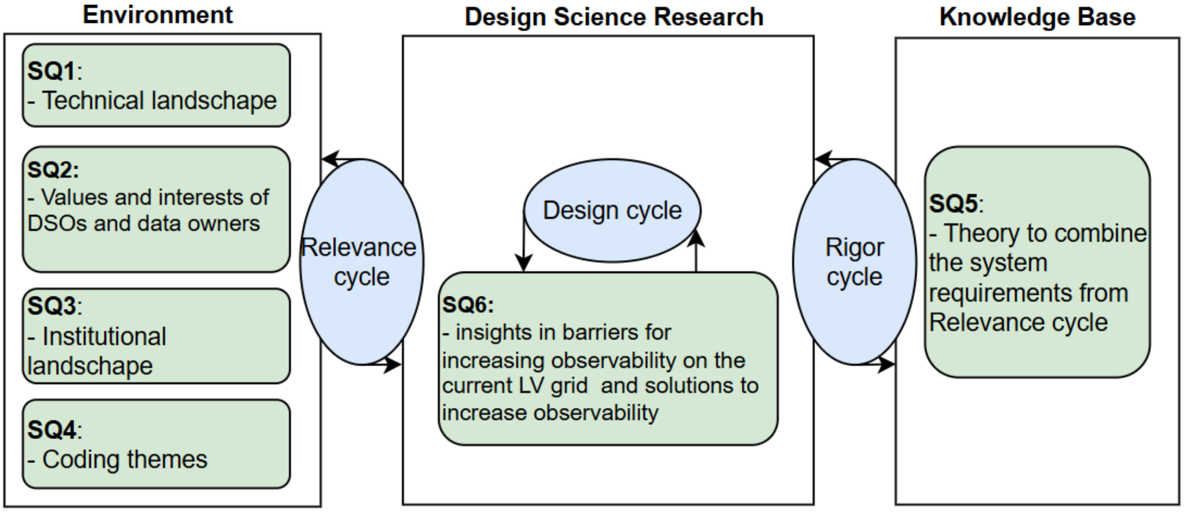

Figure 2.1: Design Science Research approach by Hevner, 2007 applied to operationalise the sub-questions.

3 Research activities

This section describes which research activities were conducted to obtain and process the required data to generate new insights. Each research activity is linked to one or more sub-questions. The research activities were selected to systematically contribute to answering the research questions and address the academic knowledge gap.

3.1. Activities for sub-question 1, sub-question 2

This chapter describes the efforts made to extract the system requirements, which are part of the Relevance cycle of DSR. The answers to sub-question 1 and sub-question 2 are developed through two iterations of the relevance cycle. The first iteration was a high-level literature research, and the second iteration was a series of semi-structured interviews (SSI). During the two iterations of addressing sub-questions 1 and 2, valuable insights were also gathered that contributed to answering sub-question 3. Nevertheless, the final answer to sub-question 3 will be derived primarily through desk research.

3.1.1. First iteration: Literature Research

In the first iteration, the established literature is consulted to develop a high-level, comprehensive understanding of the technical and institutional landscapes. It also provided an initial overview of the values and interests of the key stakeholders that were introduced in the introduction. Since the interviews were conducted with specialized experts from LV grid systems, this was an important step for conducting effective and efficient SSIs. The collected literature comprised academic literature, industry reports, governmental reports, websites, and internal company reports. The outcome of this cycle is a high-level socio-technical- and institutional understanding of the LV grid system. Also, since the second iteration of the relevance cycle consisted of SSIs, a set of main themes was extracted from the literature research to perform thematic deductive coding of the interview transcripts. This process is defined by sub-question 4.

3.1.2. Second iteration: semi-structured interviews

The second iteration consisted of semi-structured interviews with key stakeholders from the LV grid system. The goal of this iteration is to obtain information directly from the stakeholders to formulate a more in-depth understanding of the system based on their experience and knowledge. The data required to answer sub-question 1 and sub-question 2 is collected using semi-structured interviews. As explained earlier, this research aims to further specify the problem by gaining in-depth knowledge about the inner workings of the system. SSIs are an appropriate way to obtain data from primary sources (Varvasovszky & Brugha, 2000) involved in the system. Semi-structured interviews contain predetermined questions that serve as guidelines to ensure the conversation is time-efficient and consistent, which is desirable when doing interviews with various actors (Easwaramoorthy & Zarinpoush, 2024). The semi-structured interviews also leave room for discussion to provide more context and understanding of the applied institutional arrangements and technical components of the LV grid system (Easwaramoorthy & Zarinpoush, 2024). The interviews have a deductive character as the goal is to specify the understanding of the current system and the stakeholders, building further on the knowledge already obtained during the literature research (Williams & Moser, 2019).

SSI respondent selection criteria

An initial orientation on the topic of LV grid systems contributed to identifying the key stakeholders. During the internship, more insight was obtained into the many different departments within Alliander and other relevant stakeholders. A set of selection criteria is introduced to select the right respondents within and outside the DSOs for conducting the SSIs. Respondents should at least fulfil one criterion to be incorporated in the research. These selection criteria are:

- The respondent must have expertise in operating the LV grid.
- The respondent must have hands-on experience working in the operation of the LV grid.
- The respondent must have expertise in smart meter data use for grid operations.
- The respondent must have expertise in the energy data-sharing domain.
- The respondent must know and be able to speak out the perspectives of a Data Protection Authority.
- The respondent must be able to speak out for a privacy advocacy organisation.
- The respondent must be able to speak out for an organisation that regulates energy distribution and ensures that DSOs manage the grid reliably, affordably and safely.

Respondent selection

Based on the earlier described selection criteria, respondents from the following organisations were interviewed. The list of respondents can be found in Appendix A.

- Alliander, Asset and Product Management
- Alliander, Digitalisation
- Alliander, Privacy Desk
- Alliander, System Operations
- Alliander, Topology
- Allinader, Market Services
- Autoriteit Consument en Markt (ACM)
- Autoriteit Persoonsgegevens (AP)
- Logius
- MFFBAS
- NetbeheerNederland, Gedragscode Slim Netbeheer working group
- Privacy First
- Stedin

Coding for data analysis

To derive meaningful insights, the transcripts of the SSIs must be systematically processed and analysed. Therefore, coding was used as a qualitative data analysis method using the coding tool Atlas.ti. Coding allows for the breakdown of complex information into manageable, thematic categories (Williams & Moser, 2019). The SSIs were conducted to obtain data about the technical- and institutional landscape and to collect the values and interests of the stakeholders. By coding the transcripts, distinct themes and relations are identified, ensuring the technical- and institutional landscape and human elements are captured and analysed effectively (Williams & Moser, 2019).

Deductive coding is a theory-driven approach where predefined codes based on existing theories or hypotheses are applied to the data to test their validity while still allowing for discovering new themes if they emerge (Williams & Moser, 2019). As this research started with literature research, a basic understanding of the LV grid system and its stakeholders was obtained. The interviews contribute to building on this obtained knowledge so that the problem and system at hand can be further specified. Therefore, a deductive coding approach is applied to structure the transcripts made during the SSIs. The main themes, values and interests obtained from the literature research were applied as pre-defined codes to structure the data from the interview transcripts. The themes for these codes are obtained by answering sub-question 4. This way, the high-level preliminary problem statement can be further specified, and a more specific understanding of the system is obtained regarding how the LV grid is operated technically and what drives the behaviour of the stakeholders. Deductive coding allows the creation of new themes as the analysis progresses to expand the existing knowledge of the system. By creating new themes, the knowledge of the LV grid system and the problem will be further specified.

From the literature research, the main themes and first set of values and interests were identified, answering sub-question 4. These form the foundation for the deductive coding process. Subsequently, the transcripts were systematically reviewed, categorising relevant sections according to the predefined themes. This process involved a thorough, iterative analysis to ensure consistent application of the concepts across the data, facilitating a structured and coherent organisation of the transcripts for further analysis.

The sets of labels for coding contain themes related to the technical and institutional landscape. It also contains two sets of labels related to the values and interests. Quotations in the transcripts are assigned to a label when the respondent elaborates and explains the specific concepts represented by the theme, value or interest. The goal of labelling is to structure the topics discussed with the various respondents to gain a deeper understanding of the inner workings of the systems, the institutions that apply and the values and interests of the stakeholders.

Ethical considerations

In conducting this research, efforts were made to ensure that all ethical considerations were addressed and that the privacy and rights of participants were protected. This ensured transparency and credibility with the respondents throughout the interview process. The respondents were provided with detailed information regarding the purpose of the interviews before asking for consent from the respondents to conduct the interview. Participants were informed that their involvement in the interviews was entirely voluntary, and they had the right to withdraw at any time without providing a reason. Additionally, participants could opt not to answer specific questions if they wished. To ensure the confidentiality of the participants, several protective measures were implemented. Data, including recordings and transcripts, were stored securely on the TU Delft server, accessible only to the research team at TU Delft. This minimised the risk of data breaches or unauthorised access. Participants' identities were anonymised, ensuring no one was personally identified in the report. All personal data and recordings were scheduled for deletion within one month after the research concludes, around early December 2024. These steps reflect the commitment that was undertaken to maintaining participant confidentiality and data security in compliance with ethical standards.

3.1.3. Limitations of applied research activities

The research activities that were applied each have limitations that might have affected the outcomes of this research. Per research activities, the limitations are provided and how efforts were made to overcome the

Limitations of SSIs

Conducting SSIs and analysing the qualitative data is time-intensive, particularly because interview recordings must first be transcribed before coding can begin (Barriball & While, 1994). While transcription tools can assist, their output is often of poor quality, necessitating further manual corrections. This process, along with subsequent coding and analysis, demands significant time and effort. This research tried to reduce coding time by using the dedicated Atlas.ti software, which makes coding a more straightforward process. Also, SSIs are always prone to bias. Especially research in the field of LV grids covering multiple DSOS because, among DSOs, terminology can differ strongly. This can cause different respondents to interpret words or definitions differently based on their backgrounds, leading to inconsistencies in data (Barriball & While, 1994). For example, 'middenspanningsruimte' and 'transformatorhuisje' are two distinct Dutch words for the same concept: 'transformer substation'. However, the words are used interchangeably over various DSOs. As this can be confusing, during the interviews, special attention was dedicated to aligning these concepts to ensure equivalence in the meanings of the concepts (Barriball & While, 1994). Another limitation of conducting interviews can be caused by unintentionally framing certain questions to provoke certain results, creating an interviewer bias. Although SSIs allow for flexibility, this research to applied a consistent neutral set of questions throughout the research to limit interview bias (Barriball & While, 1994). Another limitation of interviews is that the sample size should match the variety of respondents. When doing research with a time cap, achieving data saturation can be an issue (Bekele & Ago, 2022).

Limitations of coding

A limitation of the qualitative nature of interviews is that after conducting them, the analysis depends on the researcher’s interpretation, making it a subjective process (Griffee, 2005). Coding provides a systematic approach to structuring the data, but it can’t fully remove all subjectivity as a researcher’s judgment, which can be influenced by their perspectives or theoretical biases. Especially theoretical bias, caused by the researcher’s pre-existing assumptions and expectations, can be introduced by deductive coding (Williams & Moser, 2019). This research aims to solve this issue by doing multiple iterations of coding, adjusting, and refining codes to catch and resolve inconsistencies in the coded data. A second coder can also resolve the interpretation bias (Krippendorff, 2004). However, this research is an individual effort, making this solution impossible.

3.2. Activities for answering for sub-question 3

This section describes what efforts were made to obtain information on the institutional aspects of the system requirements. Therefore, this section is also part of the Relevance cycle in DSR.

3.2.1. Desk research

To answer sub-question 3, Desk research was conducted. During the literature research and interviews, the established institutions were already discussed. However, further research is essential for obtaining a specific understanding of existing legislation. Desk research is a method that focuses on collecting and studying existing data from various sources like industry reports, governmental reports, websites, and internal company reports. It allows for researching various types of documents, making time effective (Broekhoff, 2011). During the interviews, respondents provided valuable documents related to the institutional landscape, including slide decks to present the GSN within the DSO with whom this research was conducted. Also, application forms for submitting new data-sharing use cases were shared, which offered critical insights into the process for requesting access to smart meter data. These documents reveal how the DSOs operationalise the institutions in place.

By studying the institutional landscape, it becomes apparent what shapes the behaviour of the stakeholders other than their values and interests. To understand why DSOs cannot freely access smart meter data, it is essential to study how the relevant institutions limit DSOs from accessing this data. To further clarify how the AVG impacts the sharing of smart meter data with DSOs, desk research is conducted to explore the limitations that might obstruct data exchange with DSOs under current AVG privacy regulations. Also, during the interviews, the relevance of the ’Elektriciteitswet 1998’ was highlighted by the respondents. The ’Elektriciteitswet 1998’ describes the laws related to the generation, transportation, and supply of electricity in the Netherlands. It outlines the key responsibilities and legal obligations of DSOs in the Netherlands. Therefore, valuable insights regarding the relationship between DSOs and their customers can be obtained concerning sharing smart meter data (Elektriciteitswet, 1998). Another important document discussed during the interviews was the Netcode. This document contains a more technical description of the responsibilities DSOs. It also provides additive regulations upon the Elektriciteitswet 1998 governing smart meter data access to DSOs.

3.2.2. Limitations of desk research

A limitation of Desk research is that the data can be outdated since secondary sources are used (Broekhoff, 2011). However, this desk research focuses on reports describing institutions that are valid while conducting this research. This ensures the information studied in the Desk research is reliable and credible.

3.3. Activities for answering for sub-question 4

To answer sub-question 4, the most relevant topics that were found during the literature research were selected as coding themes for the thematic deductive coding of the SSIs.

3.4. Research activity for sub-question 5

This section describes how the theory was selected to combine the system requirements. The answers to sub-questions 1, 2, and 3 define the technical, social, and institutional requirements of the system, which together constitute the overall system requirements. These system requirements are a product of the Relevance cycle. Sub-question 5 was introduced to consult the knowledge base for a suitable theory that supports the design of an artefact capable of structuring system requirements, thereby providing valuable insights into the inner workings of the current LV grid system. Choosing an established theory for dealing with the complex relations between the system's components and the stakeholders contributes to better structuring of the complex system at hand. The next section explains the steps to consult the existing knowledge base to select the appropriate theory to analyse the LV grid system.

3.4.1. System analysis theory selection process

To select an appropriate theory for combining the system requirements, a set of selection criteria was derived from the literature research and the interviews. Since the selection criteria are derived from the literature review and interviews, they are a product of the Relevance Cycle. The selection criteria and system requirements are used to evaluate the theory's suitability and effectiveness for structuring the complex properties of the LV grid system. The most appropriate theory is one that performs well on all criteria. The process of identifying the appropriate theory based on the selection criteria and system requirements is a key component of the Rigor Cycle in DSR.

3.5. Research activity for sub-question 6

To answer sub-question 6, the system requirements from sub-questions 1, 2 and 3, identified in the Relevance Cycle, are combined and structured according to the theory selected in sub-question 5. The answer to sub-question 1 provides insight into the technical components of the LV grid system, its limitations, and how these interact with the LV grid system. The values and interests identified in response to sub-question 2 offer valuable insights into stakeholder behaviour and decision-making, as they highlight stakeholders' preferences. Values and interests determine how stakeholders wish to interact with the LV grid system. Sub-question 3 aims to identify the institutional obstructions that govern smart meter access for DSOs. The institutions shape the stakeholders' interactions with the LV grid system. Also, understanding the institutional landscape is vital for ensuring compliance with these regulations. The insights from sub-questions 1, 2, and 3 must be combined to get a holistic understanding of the LV grid system. To combine and structure the insights from these sub-questions, a theory is selected by answering sub-question 5. During this process, the artefact is developed as part of the Design Cycle in DSR. In this research, the created artefact is a CLD that describes the structure, components, behaviour, and interactions within a system. Therefore, the created artefact belongs to the artefact type of 'system designs' (Offermann et al., 2010). The artefact is a mental model that represents the behaviour of the LV grid system derived from literature research and interviews. Additionally, potential solutions for increasing observability on the LV grid, identified during the interviews, will be incorporated into the artefact.

3.6. Research Flow Diagram

The research flow diagram is a visual representation of the research process. It outlines the sequence of inputs, research activities, outputs, and decisions made throughout a study, from problem identification and literature research to data collection, analysis, and conclusion.

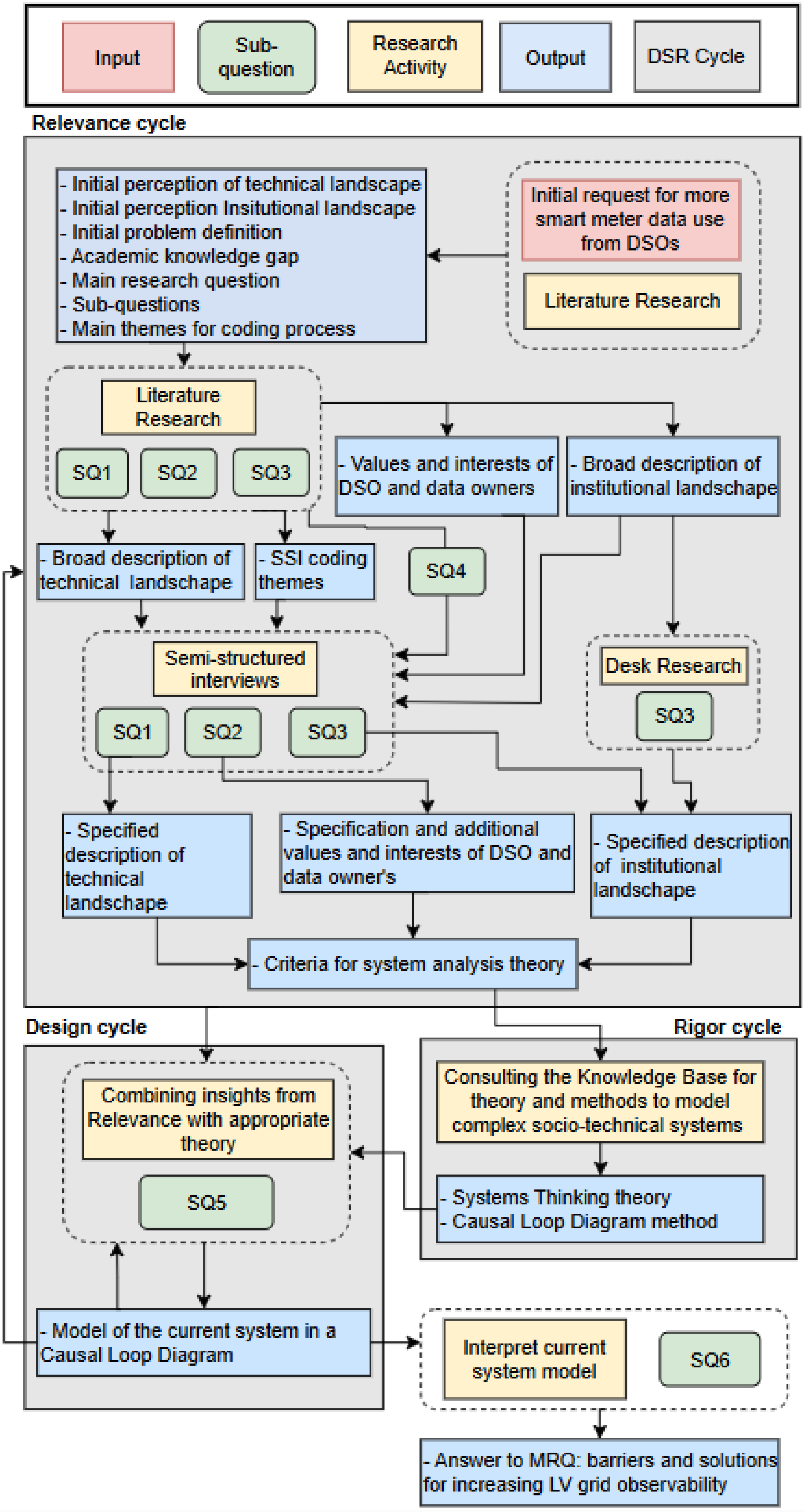

Figure 3.1: Research flow diagram.

4 Literature Research

A literature research is conducted to gain an initial high-level understanding of the technical characteristics of the LV grid system. Additionally, a brief overview of the existing institutions is provided, along with an outline of the key values and interests that play a role in the LV grid system. The literature research was conducted in preparation for the semi-structured interviews, as the respondents are highly specialized experts in the subject matter. Developing a high-level understanding of the system beforehand helps enhance the quality of the interviews and facilitates more informed discussions. Moreover, the main coding themes for thematic deductive coding are derived from the literature research. The preliminary conclusion to sub-question 3 is used to conduct targeted research into the relevant institutions. The literature review will provide initial insights into sub-questions 1, 2, 3, and 4. The complete answers to sub-questions 1, 2, and 3 will be provided in dedicated chapters.

4.1. Technical aspects of the LV grid system

4.1.1. Low-voltage power grid issues

The LV grid refers to the part of the electricity distribution network that delivers electricity from MSRs directly to end users, such as homes, businesses, and small industries. Transmission system operators manage the HV grid, while DSOs manage the LV and MV grid. Currently, the transmission grid infrastructure benefits from established expertise and advanced levels of automation. In contrast, the operators of the LV grid currently lack both (E.C. Joint Research Centre., 2021). In the Netherlands, according to the Elektriciteitswet 1998, DSOs have the responsibility to operate reliably, safely and affordably (Elektriciteitswet, 1998). They must maintain voltage levels on the LV grid at 230 Volt (Netcode Elektriciteit, 2023).

The recent trends cause three events that are problematic on the low-voltage grid: First, overvoltage occurs when the electricity supply exceeds what the grid can handle, often due to a surplus of solar power from DERs like PV panels. In areas with many solar panels, this can lead to inverters shutting off to prevent damage from high voltages, temporarily stopping the return of solar power to the grid (Ministerie van Economische Zaken en Klimaat, 2024). Many European countries struggle with overvoltage. However, integrating DERs into low-voltage power grids is crucial to the energy transition. DERs like PV panels put electricity back on the grid and, combined with the increased electricity demand, cause congestion (Eurelectric, 2023).
Second, undervoltage occurs when the electricity demand is too high, such as from heat pumps or electric vehicle charging points, resulting in voltage dropping below 207 volts. This can cause significant inconvenience, with flickering lights or even damage to equipment. When undervoltage is noticeable, the impact is typically severe (Ministerie van Economische Zaken en Klimaat, 2024). Third, congestion occurs when more electricity is demanded than the equipment can handle, causing components to overheat or damage. The increasing number of solar panels, charging stations, and heat pumps has significantly raised the transport needs on the low-voltage grid. Components automatically shut down to prevent severe overloading and potential damage, leaving connections without power until a technician can restore the grid (Ministerie van Economische Zaken en Klimaat, 2024).

4.1.2. Monitoring of LV Grid State

To make more effective use of the existing LV grid capacity, accurate monitoring of the LV grid state is necessary. Monitoring traditional electricity grids was straightforward because the flow of electricity was unidirectional. However, since the integration of Distributed Energy Resources (DERs), the electricity flow has become bidirectional. This increases the complexity of operating the LV grid, as system operators must account for new complex factors, such as weather conditions and the integration of electric vehicles (EVs), which significantly impact distributed energy production. To integrate these new assets into the grid, more accurate and real-time monitoring has become necessary (E.C. Joint Research Centre., 2021). Until now, the LV grid state was often monitored through approximations using simulation models (Ministerie van Economische Zaken en Klimaat, 2024). However, with the increasing use of DERs, EVs, and heat pumps, the grid state has become too unpredictable to rely on such approximations alone. This unpredictability complicates the accurate prediction of grid conditions, which is crucial for optimising the use of existing grid infrastructure (Karagiannopoulos et al., 2024; Ministerie van Economische Zaken en Klimaat, 2024).

State estimation (SE) is a powerful tool for the real-time monitoring of power grids. For the HV and MV grids, DSOs increasingly use SE to gain insight into the system's real-time state and determine which control interventions are necessary to address identified issues (Alassery, 2022). However, DSOs currently lack the capabilities to perform SE on the LV grid due to the inaccessibility of the required data (*Encyclopedia of electrical and electronic power engineering*, 2023).

To perform SE, data on grid state measurements and topology is necessary (*Encyclopedia of electrical and electronic power engineering*, 2023), but measurements from the grid infrastructure are limited, and smart meter data on power levels remains inaccessible to DSOs (Ministerie van Economische Zaken en Klimaat, 2024). Instead of relying on approximations, DSOs need grid state observability. For HV and MV grids, SE is increasingly used as more observability is available on these parts of the grid (Alassery, 2022). For the LV grid, SE remains a challenge due to limited data on grid measurements and restricted access to smart meter data(Karagiannopoulos et al., 2024).
This research defines observability as the controller's ability to determine the system's state. This concept emphasises the importance of the system providing feedback through sensors that can accurately measure the system's state in various parts of the system (Leveson, 2011). Throughout this research, data on measurements from grid infrastructure or smart meters that provide feedback on the system's state is regarded as observability.

4.1.3. Implementing observability in LV grids

DSOs can implement observability in two ways: by implementing sensors in the electricity grid (E.C. Joint Research Centre., 2021) and by extracting data from smart meters (Ministerie van Economische Zaken en Klimaat, 2024)(E.C. Joint Research Centre., 2021).

Smart meters are sensors installed in homes and businesses that measure various electricity-related values. They can track various parameters like electricity consumption in kilowatt-hours (kWh) and record how much electricity is produced and fed back into the grid. Additionally, smart meters measure the voltage of the electricity supply to ensure it stays within a safe and efficient range for household appliances. They also monitor the electricity supply frequency, typically in hertz (Hz), to ensure it remains stable (Depuru et al., 2011). In 2015, the Dutch government deployed smart meters to obtain real-time energy consumption from Dutch homes (Rijksoverheid, 2015). However, smart meter data is perceived as personal data (Persoonsgegevens, 2024), complicating the use of smart meter data for grid operation practices by DSOs.

4.1.4. Privacy risks of smart meter data

Sharing power level measurements from smart meters can have privacy implications for households and companies as it can reveal personal information like the number of people living in a house, people's presence in a house, people's daily schedules, installed household equipment and how people move through homes when people have smart home installations. Keeping this data secure against unwanted exposure, misuse, and breaches is crucial (Souri et al., 2014). Due to privacy considerations, the AVG also applies to all smart meter data, as it is perceived as personal data (Wang et al., 2023). Households indicate their concern about smart meters because they collect data that could reveal personal habits that might be shared without permission (Yuan et al., 2024). There is a pressing need for households to know about the potential use of smart meter data, how smart meter data is actually used, and what people agree with when they're adopting smart meters (de Godoy & Otrel-Cass, 2021). Collecting real-time smart meter data from households poses new privacy challenges, such as unwanted disclosure of personal routines or service usage (Madaan & Ahad, 2018). It increases data volumes, and gaining access to this data could compromise personal privacy and potentially enable malicious entities to gain insights into households' electricity use patterns, posing a security risk (Farhan et al., 2023). Although the use of real-time smart meter data could greatly benefit power grid operations and energy provision, there is a serious trade-off to be made concerning the privacy implications this could have for consumers (Mitra & Chakraborty, 2023). As privacy is a great but fragile good, numerous organisations advocate for the preservation and safe treatment of private and personal data.

4.1.5. Privacy-Enhancing Technologies

Smart meter data aggregation and anonymisation

There is an ongoing discussion between DSOs and privacy-protecting organisations about when smart meter data can be considered privacy-sensitive. To reduce the privacy intrusiveness of data, smart meter data can be aggregated. Aggregating smart meter data makes it less directly traceable to individual users, thereby enhancing privacy protection. Smart meter data can be aggregated over time and space. Data can be aggregated by space aggregation and time aggregation. Time aggregation involves summarising data over a specific period. It is commonly used to reduce the granularity of time-series data. This would mean that the frequency of sharing meter readings with DSOs is reduced for smart meters. Space aggregation involves summarising data over a specific spatial area by considering a collection of consumers and averaging out their energy consumption (Souri et al., 2014). However, as the level of data aggregation increases, privacy is enhanced, however, it reduces the usefulness of the data for grid congestion management (Knirsch et al., 2017). Anonymization removes personal identifiers from the data to make it harder to trace back to individual consumers (Souri et al., 2014).

Encryption methods

To protect households' smart meter data, encryption is a plausible solution (Souri et al., 2014). Data encryption enables data transmission and storage to protect it from unauthorized access. *Homomorphic Encryption* and *Secure Multiparty Computation* are particularly suitable due to their capacity for computation on encrypted data, allowing privacy-preserving calculations without decrypting the underlying data. *Homomorphic Encryption* is ideal for state estimation because it allows DSOs to perform mathematical operations on encrypted data Wang et al. (2023). Therefore, this feature enables the direct use of encrypted smart meter readings in state estimation calculations without revealing individual data points, thus ensuring data privacy. *Secure Multiparty Computation* enables the same features but makes it also possible to perform these calculations when multiple parties are involved, like multiple departments within a DSO. The challenge is making the data both usable and private, optimizing value while protecting privacy. However, loss of data granularity and detail by applying these technologies forms a data quality problem, making them not always applicable for every data sharing purpose in the energy sector (de Godoy & Otrel-Cass, 2021). Moreover, even when anonymization techniques are employed, the aggregated data from various sources can potentially re-identify individuals by recreating detailed user profiles. For example, by combining smart meter data with households' IoT data from other ecosystems (Madaan & Ahad, 2018).

4.2. Relevant institutions for the LV grid system

The AVG is the Dutch translation of the European Union's General Data Protection Regulation (GDPR), which has become the global standard for privacy protection policies. However, for the energy sector, creating privacy-preserving policies is challenging because the data needed to improve grid management also raises concerns about exposing consumers' private habits. Therefore, in the energy sector of Europe and North America, four privacy-protecting policies are emerging *Customer opt-out*, giving customers control over data collection; *Opt-in*, where consumers have control over whether their smart meter data is collected for any purpose; *Independent data storage*, allowing third parties to store smart meter data securely; and *Separate monitoring and enforcement agency*, establishing a government body to oversee privacy (Wang et al., 2023). Especially opt-in policies allow the consumer to have autonomy and control over their personal data use, which is not only a value consumers strive for, but also a legal right according to AVG (Persoonsgegevens, 2024).

However, policymakers in the Netherlands are starting to acknowledge that smart meter data might be essential for preparing the electricity grids for future developments. Therefore, the Autoriteit Persoonsgegevens approved nine use cases for which DSOs can freely use smart meter data. Since July 11 2023, Dutch DSOs have been allowed to extract data from smart meters that strictly relate to voltage levels. For nine specific use cases, permission was granted, and for every new desired use case, an approval process was designed in the Gedragscode Slim Netbeheer (GSN) (Netbeheer Nederland, 2024b). One use case is improving the localization of power outages. DSOs have a virtual visualization where malfunctioning connections are indicated with red lines and functioning connections with green lines. The data extracted from the smart meter is whether there is voltage on the connection or not (Netbeheer Nederland, 2024b). Due to the increased EV charging, electrical cooking and heat pumps, the grid experiences problems with voltage levels. To maintain the right voltage levels, three use cases are created to enable DSOs to read out voltage level data to prevent and solve voltage problems. When DSOs test new grid solutions, they can also extract voltage level data from smart meters to test the effect of particular solutions on voltage levels (Netbeheer Nederland, 2024b). When an outage lasts more than 4 hours, DSOs must compensate customers. Before the installation of smart meters, this was done manually. Since then, a use case was designed where smart meter data may be used to determine exactly how long an outage took. This is quicker, prevents human error, and ensures the customer is not over- or under-compensated (Netbeheer Nederland, 2024b). Another use case was introduced to determine whether customers have PV panels installed. PV panels. PV panels significantly impact the load on the network, and having insight allows for proactive grid management and planning. However, DSOs lack insight into smart meter data related to electricity consumption due to the restrictions and slow consideration process for new use cases. Also, voltage level data is insufficient for grid operations like congestion management (Ministerie van Economische Zaken en Klimaat, 2024).

DSOs especially need real-time data on energy consumption and distributed production. Releasing power level data will enable DSOs to apply grid congestion management measures that help reduce grid congestion (Athanasiadis et al., 2024). Power level data could help improve electricity demand prognoses by using energy consumption data as input data for load forecasting models. Also, power level measurements could be used by DSOs to make more informed decisions on power system planning. This entails predicting the trajectory of the system within a defined period, taking into account variables such as anticipated increases in demand, expansions in power generation capacity, and enhancements to transmission facilities (Athanasiadis et al., 2024). However, an explanatory memorandum to the law that facilitated the rollout of smart meters in 2010 provides an interpretation of the Elektriciteitswet 1998 that network operators cannot access energy consumption data from smart meters (Ministerie van Economische Zaken en Klimaat, 2024). However, this was just an interpretation, but it confused DSOs severely.

4.3. Emerging values and interests

Set C and D focus on themes related to the values and interests of the key stakeholders. Set C captures the values and interests held by DSOs, while set D addresses those of data owners. The purpose of identifying these values and interests during the interviews is not to quantify their frequency of occurrence. Rather, coding the themes will primarily help gain insight into what specific values and interests influence the stakeholders' decision-making processes.

Values	Description	Source
CV1 Reliable energy supply	DSOs have a fundamental responsibility to ensure a consistent and reliable energy supply to consumers.	(Elektriciteitswet, 1998)
CV2 Safe energy supply	DSOs must prevent incidents such as overvoltage, undervoltage, and grid congestion, which can result in damage to equipment and danger to consumers.	(Elektriciteitswet, 1998), (Ministerie van Economische Zaken en Klimaat, 2024)
CV3 Operational affordability	DSOs must ensure that energy remains accessible to all consumers. It represents the societal expectation that DSOs manage grid infrastructure and operations efficiently to prevent excessive costs.	(Elektriciteitswet, 1998), (Netbeheer Nederland, 2024a)

Table 4.1: List of values of DSOs from the literature research.

Interests	Description	Source
Ci1 Improved monitoring	To effectively prevent grid congestion, DSO must know the grid state at any time. Therefore, DSOs have an interest in improving monitoring capabilities.	(Ministerie van Economische Zaken en Klimaat, 2024), (Karagiannopoulos et al., 2024), (Alassery, 2022)
Ci2 Increased observability on the LV grid	DSOs need more observability to effectively monitor the grid state to cope with the increased electricity use and distributed energy production. This is crucial in preventing outages and ensuring grid reliability.	(Rijksoverheid, 2015), (Athanasiadis et al., 2024)
Ci3 Reduced grid congestion	To maintain grid stability and reliability, DSOs must effectively manage grid congestion.	(E.C. Joint Research Centre., 2021)
Ci4 Optimise the available capacity of the grid	To cope with increasing electricity demand in the short term, DSOs must increase transport capacity by optimising the available capacity on the existing grid infrastructure.	(Ministerie van Economische Zaken en Klimaat, 2024)

Table 4.2: List of interests of DSOs from the literature research.

Values	Description	Source
DV1 Privacy of personal data	Privacy is a fundamental value for data owners, as they seek to protect their personal information from unwanted exposure to personal habits, lifestyles, and routines.	(Yuan et al., 2024), (de Godoy & Otrel-Cass, 2021)
DV2 Security of personal data	Data security is crucial for data owners as it protects their personal information from unauthorised access, misuse, and potential threats and prevents security breaches that could harm the data owner’s privacy.	(Souri et al., 2014)
DV3 Reliable energy provision	Despite data owners highlighting the pressing need for private and secure handling of their personal data, they cannot function properly without energy provision.	(Mitra & Chakraborty, 2023)

Table 4.3: List of values of data owners from the literature research.

Interests	Description	Source
Di1 Control over personal data and differential consent	Data owners value controlling who accesses their personal data and how it is used. Particularly regarding the collection and sharing of their energy consumption data.	(Persoonsgegevens, 2024)
Di4 Privacy improving measures	To improve privacy and security of personal data, data owners strongly rely on measures like data aggregation and PETs to limit privacy-related risks caused by personal data use.	(Souri et al., 2014)

Table 4.4: List of interests of data owners from the literature research.

4.4. Conclusions from literature research

4.4.1. Preliminary conclusion sub-question 1

The literature research provides a definition to observability, which will be used throughout this research. This definition, provided by Leveson (2011), emphasizes that sensors provide observability by measuring and providing feedback on the state of specific components within the grid system. From the studied literature, it was learned that DSOs could use smart meter data to increase the observability of the LV grids. Smart meters can measure voltage levels, power levels and frequency levels. However, valuable parameters for grid congestion management, like power levels, are still mostly inaccessible to DSOs. From the studied literature, it cannot be deducted that using power levels of smart meter data is entirely forbidden. However, it does not specify under which exceptional circumstances power levels from smart meters may be read by DSOs. To obtain a better understanding of how observability is implemented using smart meters, special attention should be devoted to the exact situations in which Alliander is permitted to access the smart meter's power levels for performing congestion management. Also, the studied literature described that implementing sensors to perform grid measurements contributes to increasing observability. However, the studied literature does not elaborate on how Alliander performs grid measurements, as this can differ significantly per DSO. During the SSIs, special attention must be devoted to understanding how Alliander performs measurements in the grid infrastructure to implement observability without smart meters.

4.4.2. Preliminary conclusion sub-question 2

The studied literature provided in a first orientation on which values and interests are important to the involved stakeholders. The values and interests are described in 4 tables. Tables 4.1 and 4.2 contain the values and interests of the DSOs. Tables 4.3 and 4.4 contain the values and interests from the perspective of the data owners. However, these values and interests were derived from high-level literature rather than direct sources. As a result, they may not fully capture all the values and interests that stakeholders hold. Therefore, the SSIs should be used to extract a more comprehensive set of values and interests by exploring how stakeholders experience the situation on the LV grid and how they would ideally like it to be.

4.4.3. Preliminary conclusion sub-question 3

The literature shows that AVG is the dominant institution that governs whether DSOs may access smart meter data. However, from the literature, it could be deduced which elements of the AVG were most relevant to DSOs. During the SSIs, the most relevant elements of the AVG must be addressed to enable further desk research, allowing for a deeper understanding of how the AVG influences increasing observability.

Additionally, the 'Elektriciteitswet 1998' was identified in the literature as the legislation that assigns DSOs responsibility for the LV grid, therefore being a crucial institution. However, given the vast scope of this law, it was too extensive to determine which specific elements from the 'Elektriciteitswet 1998' have the most significant impact on increasing observability. Therefore, during the SSIs, the most important elements were discussed, which were then further examined during the desk research, focusing on those that impact the increase in observability.

The GSN is a rather new institution that enables increasing observability for a specific set of use cases. However, the approved use cases mostly enable DSOs to access voltage levels which are insufficient for congestion management. Also, in the literature, it could not be found how new use cases can be approved if this is desired by DSOs. Further insight is needed into the approval process for new use cases and the feasibility of use cases related to power levels. This must be discussed during the SSIs.

The literature also describes an explanatory memorandum providing an interpretation on the law that accessing power levels is restricted. Although this is merely an interpretation and not a binding law, it has still influenced DSOs’ perspectives on using smart meter data. During the SSIs, special attention should be devoted to how this interpretation continues to impact DSOs’ efforts to increase observability on the LV grid.

4.4.4. Conclusion sub-question 4

This section provides the concluding answer to sub-question 4:

SQ4: What key themes, identified from the literature, can be applied for deductive thematic coding of the interview transcripts?

A set of main themes is derived from the literature research to perform thematic deductive coding, answering sub-question 4. After conducting the literature research, this set was considered to cover the most important themes that should be elaborated on during the interviews. The themes are categorized into two distinct sets. One set of technical themes (A) and one set of institutional themes (B).

ID	**Concept**
A1	Observability
A2	Smart meter
A3	Grid operations
A4	State estimation
A5	Privacy Enhancing Technology
A6	Grid monitoring
A7	LV Congestion Management
A8	Privacy-preserving policies

Table 4.5: Coding themes for structuring the technical landscape.

ID	**Concept**
B1	AVG
B2	Elektriciteitswet 1998
B3	Gedragscode Slim Netbeheer

Table 4.6: Coding themes for structuring the institutional landscape.

5 Technical landscape

5.1. Technical landscape

To enhance the observability of the LV grid, it is crucial to comprehend both the technical infrastructure of the grid itself and the operational processes carried out by the DSO system operations departments. This is necessary to explore opportunities and obstructions for implementing more observability.

5.1.1. DSO system operations departments

The System Operations department ensures that the grid remains operational by carrying out a range of activities to determine the load on cables and MSRs Respondent M. Once issues are identified or expected to happen, they assess the root cause and determine the appropriate interventions. These interventions are consequently assigned to the responsible team for execution (Respondent J). The more you want to use the available capacity on the grid, the more you need to automate certain processes (Respondent J). Therefore, digitalisation is essential (Respondent N). To improve the effective use of the existing capacity, Alliander wants to implement Grid As A Service (GAAS) on the LV grid to automate system operations. This service can monitor the grid state, predict the grid state ahead, detect problems, and assign the right intervention to the responsible teams automatically. After the intervention was performed, GAAS monitors its effectiveness. However, before implementing GAAS, Alliander needs to know the grid state in almost real-time (Respondent M), which is impossible using the established methods (Respondent J). The next section will elaborate further on the current ability to monitor the state of the LV grid.

5.1.2. MSR Monitoring and LV grid state determination

For what happens inside the LV grid, Alliander is yet mostly blind (Respondent I). However, for some components on the LV grid, the state can determined by using data from various sources to feed to simulation models. Currently, it is particularly urgent to prevent MSRs from overloading to prevent major outages (Respondent M). Four data sources for monitoring MSRs are outlined in this section. First, DSOs can access quarterly consumption data from clients and derive 15-minute energy usage patterns. These are used to create average consumption profiles of households. The sum of the consumption profiles per household can be used to estimate the load on a particular MSR. Despite this being rather inaccurate, it also does not consider any production of DERs (Respondent M). Second, large consumers, such as factories, are obliged to report their energy consumption data to their DSOs. Moreover, large consumers connected to the LV grid always have their own connecting cable to the MSR. The consumption data from large consumers, in combination with the sum of the estimated average household consumption data, can be used to make more precise estimations of the load on an MSR. (Ministerie van Economische Zaken en Klimaat, 2024). This allows Alliander's system operations to use an estimation component called C-ARM to combine the average household consumption profiles with energy consumption data of large consumers to grasp the load on a particular MSR (Respondent M). Third, DSOs use weather forecasting to consider electricity use by heat pumps and production by residential PV panels to grasp how much energy will be fed back into the LV grid (Respondent M). Fourth, in many instances, MV substations have measuring infrastructure installed because this is where Alliander's service area connects to the service area of Tennet (Respondent I). Usually, multiple MSRs are connected to an MV feeder. If measurements in the MV substations indicate higher loads than usual on a particular MV feeder, then one can assume that one or more of the MSRs connected to the MV feeder is potentially overloaded (Respondent M).

However, due to the increased implementation of distributed energy resources, power and voltage levels on the LV grid are more capricious than before. Also, the data from large energy consumers come with a two-day delay (Respondent M). This makes the earlier mentioned conventional methods to determine the LV grid's state insufficiently accurate, requiring precise grid measurements instead of simulated values (Respondent J). As Alliander needs to ensure that the existing capacity can be used more effectively, Alliander aims to adopt methods for state determination that integrate these accurate grid measurements instead of calculations (Respondent N).

The most accurate way to determine the power load and voltage levels on the various components of an electrical system in any section of the LV grid is state estimation (Respondent J, Respondent K). However, to perform accurate state estimation, Alliander's System Operations department requires more short time interval measurements of both power and voltage levels from multiple locations in the grid and high-quality topology data (Respondent J, Respondent I, Respondent O, Respondent M). The service area that Alliander manages lacks both (Respondent J, Respondent K. Initially, DSOs had little interest in installing measuring infrastructure in MSRs as grid congestion on the LV grid was not yet an issue before the electrification of society and integration of residential PV panels (Respondent I). To resolve the lack of measurement data from measuring infrastructure, Alliander's system operators are eager to extract smart meter data from clients that are connected to the LV grid, like households, companies and small industries (Respondent M). However, privacy regulations restrict system operators from accessing the smart meter power levels for performing congestion management and other services (Respondent C, Respondent J). Also, the topology data on the LV grid is of rather poor quality. This is explained by the fact that the LV grid in some sections of the LV is very old, and the construction has not always been documented well (Respondent O).

5.1.3. LV grid observability

Alliander has been pretty much blind on the LV grid as most of the MSRs were not equipped with measurement infrastructure (Respondent M). Observability for the LV grid can be implemented in two ways. The conventional way is to install measuring devices in the grid infrastructure, like in MSRs. Within Alliander, this functionality is called 'LS Meten' (Respondent M). The other way to increase observability is by extracting grid measurements from smart meters. The project to execute this process is called within Alliander 'Project Basmati' (Respondent M).

LS Meten

LS Meten is an effort to generate more LV grid measurement data for Alliander's service area. This data can be used to verify whether the load on the transformers in MSRs do not exceed the maximum capacity but also to create insights for the MV grid (Respondent N, Respondent I). The MSRs are equipped with measuring devices that measure and report to Alliander every 5 minutes the maximum, minimum and average values of power- and voltage levels of each outgoing cable (Respondent M, Respondent N). By adding up the load per cable, the total load on the adjustable transformer in the MSR can be calculated. Moreover, if the quality of the topology of the service area is high, then good insights can be gained where issues related to congestion or voltage levels on the LV grid could occur (Respondent M, Respondent N?). In neighbourhoods where PV panels and heat pumps are connected to the same LV grid, local energy exchange can occur directly between these systems. Since this exchange bypasses the MSRs, it remains unregistered by LS Meten. As a result, the observability of the LV grid is significantly limited, reducing the ability to monitor and optimise grid performance effectively (Respondent M). For MSRs that lack measuring equipment, the load is estimated using a load estimator and data synthesizers. This tool relies on available data from sources such as registered large consumers connected to the outgoing cables, allowing it to make an informed approximation of the load on the MSR (Respondent M). Alliander aims to provide every existing MSR with the measuring equipment by the end of 2077 (Respondent N). Alliander is not the only DSO installing measuring equipment. Other DSOs perform similar efforts to increase their observability. Moreover, most of Enexis' MSRs are equipped with measuring devices. Stedin has in Zeeland a 60 to 80 per cent coverage, and in the rest of Stedin's service area, about 4000 of the 17500 MSRs are covered (Respondent E). Alliander has yet 2200 of the 4000 MSRs covered, severely less than comparable Dutch DSOs (Respondent N).

Project Basmati

For Alliander, it takes too long to wait until their 4000 MSRs are equipped with LS Meten. The situation on their LV grids becomes more critical, and the urgency for observability increases (Respondent N). In fact, Alliander just wants access to the power use data of their client's smart meter data so they can apply this data to perform accurate state estimations on the LV grid (Respondent J). However, the direct use of these parameters is restricted by privacy law as this is regarded as personal data (Ministerie van Economische Zaken en Klimaat, 2024). In an effort to improve privacy, project Basmati was introduced (Respondent I). Project Basmati refers to Alliander's data collection service that extracts voltage- and power levels from smart meters every 15 minutes. To improve privacy, the data is aggregated over 5 smart meter users and accessible one day after measuring to the departments within Alliander that need the data for grid-related operations (Respondent M). The measurements gained with Basmati can be used to calculate the load on MSRs by summing up all power levels of the smart meter measurements. This way, Alliander can monitor MSRs without the installation of LS Meten (Respondent M). In contrast to LS Meten, Basmati provides insight into the LV grid as the measurements come from multiple locations in the grid. This is beneficial for detecting congestion or voltage issues inside the LV grid (Respondent N). For instance, during summer, a DSO may need to lower the voltage level on the LV grid using an adjustable distribution transformer due to the increased voltage caused by PV panels. Alliander, for example, must ensure that the voltage in households remains around 220V. Since voltage drops occur along the grid, the voltage in the MSR needs to be higher than that in households to compensate. Monitoring voltage levels in houses using smart meters is easier and more reliable than attempting to model these variations using LS Meten data (Respondent N). Also, unlike LS Meten, Basmati can be operational without installing new infrastructure, as it only requires smart meters, which are already in place. Unfortunately, Alliander has not received permission yet to read the power levels from smart meters. Therefore, Basmati is not yet operational (Respondent M). In order for basmati to work properly, it is essential to know which houses are connected to the LV feeder that connects the houses to the MSR. Currently, due to yet disappointing topology quality, this still forms a challenge (Respondent M). Also, Basmati can only read data from households' smart meters that approve data sharing with third-party service providers (ODA), like their energy suppliers. This is only approximately 50 per cent of all smart meters. To compensate for the missing values, Alliander applies a data synthesiser component that approximates the missing values (Respondent M). Once Basmati is approved by the AP, Alliander can start using the aggregated data to calculate the load on the MSRs using Basmati. Preferably, MSRs with LS Meten installed will be used to cross-validate the performance of Basmati as the exact load on these MSRs can be measured. This way, the synthesiser performance can be validated, and topology flaws can be detected more effectively (Respondent M).

Obliged reporting and Real-Time Interface (RTI)

Producers and consumers of more than 1MW of electricity are obliged to report their energy production and usage if they are connected to the MV or HV grid (Netcode Elektriciteit, 2023). For the LV grid, large consumers are only obliged to report their use patterns if their use patterns are hard to predict by their DSOs (Netcode Elektriciteit, 2023). However, by obligating the reporting of energy use and production, observability is increased for DSOs to do congestion management (Respondent I). For congested areas, Alliander only connects new customers with a capacity-limiting contract (CBC) and a real-time interface (RTI). Using the RTI, observability is even more increased, and energy use and production can be monitored. The CBC allows Alliander to use the RTI to reduce the consumption or production of energy in case congestion might occur (Respondent I). This not only makes the RTI an observability-increasing intervention but also a means to reduce congestion. To increase congestion-reducing capabilities, Alliander would like to implement the RTI for every large consumer or producer on the MV and HV grid (Respondent I).

In conclusion, both Basmati and LS meten are ways to monitor MSRs. Basmati does not require the installation of additional measuring devices but is more privacy-intrusive. Moreover, Basmati's performance has not yet been validated due to low-quality topology. In contrast, LS Meten is precise and not privacy-intrusive but requires the installation of measuring infrastructure. However, it is important to note that Alliander sees Basmati as support to monitor MSRs for the time being, as LS Meten is not yet installed in every MSR (Respondent M). Given the urgent need for grid observability, privacy-intrusive measures like Basmati may be temporarily necessary for Alliander to maintain affordable, reliable, and safe grid operations. This could justify the approval of certain use cases in the short term. However, once LS Meten is fully implemented, these use cases should be reassessed to ensure the protection of household privacy (Respondent K). Also, the quality and performance of Basmati can not be guaranteed before implementing it and sharing the energy consumption data first (Respondent M). This complicates the discussion of whether these kinds of measurements can be justified.

5.1.4. LV grid congestion management

Once the system operations department has detected issues, Alliander can apply various interventions depending on the root cause of the problem. It can be as easy as sending a technician to mend a cable or other components inside an MSR (Respondent J). For voltage-related issues, Alliander is already allowed to read smart meter data as described by use cases 2 and 3 by Netbeheer Nederland, 2024b. For example, when PV panels raise voltage levels during summer, Alliander can monitor the voltage levels by reading out smart meters and shifting down voltage levels in the Regelbare distributietransformator (Respondent N). Use case 6 by Netbeheer Nederland, 2024b consequently allows Alliander to read smart meter data again to verify whether such voltage-related interventions worked.

However, Alliander also faces power-related issues, such as grid congestion or overload on MSRs. Resolving power-related issues on the LV grid poses a challenge for Alliander due to the limited availability of real-time power data on the LV grid state (Respondent N). Power-related parameters are not allowed to be used by DSOs for grid operations (Ministerie van Economische Zaken en Klimaat, 2024). Nor has a use case been approved to allow power-related parameters to be used (Netbeheer Nederland, 2024b). This lack of observability hinders the ability to perform real-time interventions on the LV grid (Respondent N) or predict overloads on MSRs (Respondent M).

FlexLaden

To respond to congestion in the short term, Alliander's only solution for solving congestion is through the FlexLaden initiative (Respondent I). This allows for the temporary reduction of power output from charging stations. Currently, this is the only direct control mechanism available to Alliander on the LV grid for managing congestion and power data from smart meters could provide real-time insight into where these actions are required (Respondent N).

Grid reinforcement

Besides making more effective use of the capacity of the existing infrastructure, it is inevitable to reinforce various sections of the LV grids and components (Respondent N). As described earlier, LS Meten and Basmati can be used to calculate the load on cable sections and MSRs. This data is exceptionally useful for prioritizing which MSRs need to be reinforced on a section of the LV grid (Respondent M). Insights gained from Basmati can be used to locate overloaded cables within the LV network which could help even more in prioritizing reinforcement (Respondent M)

Unfortunately, power-related issues like congestion are still difficult to detect since Alliander is not yet allowed to read power measurements from smart meters to perform state estimation (Respondent J, Respondent M)(Ministerie van Economische Zaken en Klimaat, 2024). State estimation would contribute to monitoring power flows in the cable and component infrastructure to detect congestion (Respondent J). To enable this, AP should approve this use case.

Distributed LV grid congestion management

In general, for the LV grid, DSOs do not have the technical means to have a large immediate impact on congestion. Therefore, to build an electricity grid that is robust enough to deal with future energy consumption and distributed production, Alliander and other DSOs should also focus on congestion management in a distributed way (Respondent N). This means that consumers should help stabilise the grid by adjusting their energy consumption patterns. DSOs can initiate this by collaborating with energy suppliers and introducing financial incentives and market mechanisms. Two kinds of market mechanisms are introduced here: First, a varying price per kWh over different time periods could resolve some of the congestion on the LV grid. For example, increasing the energy price between 16:00 and 20:00. Home BESSs and smart EV charging stations can factor in these varying prices to charge EVs in the most cost-effective way possible (Respondent N). Second, another problem for DSOs is when consumers draw large amounts of electricity from the grid over a short time period, as this causes peaks in demand, which is hard to manage as a DSO. To resolve this, DSOs can introduce varying capacity-bound tariffs. A capacity-bound tariff increases the price per kWh when a higher capacity per time unit is drawn from the grid (Respondent N).
To arrange a set of proper market mechanisms that benefit the management of congestion, cooperation between energy suppliers and DSOs is essential because energy suppliers determine price levels

per kWh, and DSOs know in which time periods congestion might occur. By cooperating effectively, increases in price per kWh can be synchronised with the congested periods. However, to arrange this, DSOs must have consent from consumers (Respondent N.).

In conclusion, the interventions available to DSOs for addressing power-related issues often demand substantial time and investment in grid reinforcement. Additionally, they may involve close collaboration with energy suppliers to implement market mechanisms or are restricted to large consumers, such as the RTI. Improving the opportunities for distributed LV congestion management would reduce the necessity for smart meter data. Therefore, this would be a good solution to focus on in case smart meter data remains inaccessible.

However, creating LV grid observability does not exclusively serve the needs for operating the LV grid and monitoring MSRs. LV grid observability can be of significant use for operating the MV grid as well because the observability implemented by LS Meten and Basmati also provides more insight into the load on the MV grid (Respondent N, Respondent I). The next section will further elaborate on this.

5.1.5. LV observability for MV grid management

As outlined in earlier sections, observability through LS Meten provides precise measurements of the load on MSRs (Respondent N, Respondent I), and Basmati can accurately estimate the load on MRSs (Respondent M). The hierarchy of the electricity grid operates as follows: To calculate the load on MSRs, one can either aggregate the loads from all smart meter measurements using Basmati or directly measure the load on MSRs via LS Meten. This approach enables monitoring of the LV grid. Similarly, by moving one level up in the electricity chain, summing the loads from all MSRs allows for calculating the load on substations which already have measuring infrastructure (Respondent I). This facilitates the monitoring of the MV grid as this creates insights in where congestion can occur (Respondent N, Respondent I). Monitoring the MV grid is useful for Alliander as Alliander has effective means to address grid congestion on this part of the grid (Respondent I). Four means are outlined here:
First, Alliander can establish bilateral contracts with energy-producing stakeholders, allowing them to request a reduction in energy production one day ahead (more than 24 hours in advance) when anticipating grid capacity issues due to solar and wind park production. Second, Alliander can balance the grid by re-dispatching in the intra-day domain (12 hours to 30 minutes in advance). Alliander must request a stakeholder to reduce its energy consumption and request another stakeholder to increase its consumption to balance the grid. Third, Allianer can switch power flows in the substations to re-direct power flows. Fourth, Alliander can install a Real-Time Interface (RTI) at large consumers connected to the MV grid for monitoring. Moreover, in some cases, a capacity limitation contract is established, allowing Alliander to actively reduce the electricity consumption of the involved stakeholders (Respondent I).

In conclusion, creating observability on the LV level does not only serve system operations on the LV grid. It also serves to effectively operate the MV grid, covering a large service area. However, to gain insight into the MV grid, measurement data is needed from every MSR. Since LS Meten has not been installed yet at every MSR, Basmati can provide a good substitute (Respondent N).

5.1.6. Privacy-Enhancing Technologies (PET)

The method currently employed at the system operations department of Alliander to improve privacy is anonymizing and aggregating right after receiving the data. Following this, the original source data is deleted and is never stored persistently if there is no legal basis for storing the data. All subsequent processing activities are conducted exclusively using the anonymised values or synthesised values based on the aggregated data, eliminating any direct link to individual consumers. From the literature, various other PETs were collected that might be relevant to the Dutch energy sector, like *Homomorphic Encryption* and *Secure Multiparty Computation*. The literature considered these methods to be suitable for performing encrypted calculations on smart meter data. When using PETs initial collection of smart meter data is required, whereafter it can be encrypted and stored for performing calculations. However, in the Netherlands, DSOs require a legal basis to collect and store smart meter data. Currently, DSOs in the Netherlands lack the legal grounds to collect smart meter data in most cases (Respondent E). Since sensitive smart meter data generally cannot be collected or stored, encryption-based solutions for increasing data availability for observability are not feasible. Nonetheless, encryption could present valuable opportunities for performing state estimations in a privacy-secure manner (Respondent J).

5.1.7. Conclusion sub-question 1

This section concludes on how observability is currently designed in the Netherlands. Therefore, this section contains the concluding answer to sub-question 1:

SQ1: How is observability designed to operate low-voltage grids in the Netherlands?

The literature research defined observability as the ability of sensors to measure and provide feedback on grid components. Also, DSOs can potentially use smart meter data to improve the observability of LV grids, measuring parameters like voltage and power levels. However, access to key parameters from smart meters, such as power levels for congestion management, remains limited, and the institutions do not clarify under what exceptional circumstances DSOs may access this data to increase observability besides the GSN. SSIs were needed to clarify how Alliander uses smart meters and other grid measurements to increase observability, as the methods may vary by DSO.

From the SSI's an extensive description of the technical landscape was extracted. During these interviews, it was extracted that Alliander implements observability on the LV grid in two ways. First, observability in the LV grids in Alliander's service area is implemented through LS Meten, which aims to increase grid measurement data. Measuring devices in MSRs report power and voltage levels every 5 minutes, providing insights into transformer load and potential congestion. A key benefit of LS Meten is that it operates without using personal data, meaning AVG is not applicable, ensuring that Alliander can freely access it. However, LS Meten only provides observability on MSRs. Therefore, the observability within the LV grid remains limited as local energy exchanges bypassing MSRs cannot be monitored, such as cable infrastructure between houses. The rollout of LS Meten is slow, and many MSRs remain unequipped. Therefore, software-based tools like load estimators and data synthesizers are used where LS Meten measurement equipment is still absent to track the load on MSRs. Also, Alliander still has limited LS Meten coverage and lags behind compared to other DSOs like Enexis and Stedin. Therefore, Alliander puts much effort into designing products to implement observability via smart meters.

The second way to increase Alliander's observability is Project Basmati. Project Basmati was introduced to use aggregated smart meter data for more detailed monitoring of LV grids. Basmati collects power and voltage data from smart meters every 15 minutes, aggregating over five smart meters to protect privacy. Basmati provides insights into the grid state without requiring new infrastructure. In contrast to LS Meten, Basmati offers increased observability within the LV grid by providing more granular data, enabling more detailed monitoring of the grid's state. Although Basmati offers the potential to improve grid observability, particularly for detecting issues like congestion or voltage fluctuations, it is not yet fully operational. Basmati is smart meter-based and, therefore, makes use of personal data, making it subject to AVG. Therefore, a dedicated use case should be introduced to operationalise Basmati. Also, Basmati faces technical challenges, such as incomplete topology data, which is required to know smart meters are connected to which LS feeder.

The SSIs provided a more in-depth analysis of the means that Alliander specifically uses to implement observability. More details were obtained on the inner workings of the observability-increasing means, and an overview of their advantages and disadvantages was provided.

6 Emerging values and interests

Increasing observability using smart meter data and knowing the stakeholders' values and interests is essential. Concerning smart meter data access by DSOs, DSOs and data owners often have conflicting values and interests. For Alliander to increase observability on the LV grid, considering these conflicting values and interests can play a key role in deciding which solutions are most appropriate for increasing observability. Another reason for gathering values and interests is that they offer insight into the desired system performance, which in turn can provide insight into the decision-making processes of the stakeholders and the inner workings of the system. Moreover, values and interests can be used as qualitative criteria to evaluate the system performance after applying alterations (Milchram et al., 2019).

This research differentiates between two perspectives. The most relevant values and interests from the perspective of the DSOs will be elaborated. DSOs aim to leverage smart meter data for grid congestion and design innovative solutions to improve LV grid resilience and perform more efficient system operations. This will reflect in their values and interests. Also, the values and interests of the data owners will be elaborated on. In contrast to DSOs, data owners prioritise privacy and protection of personal data, expressing concerns over how their personal data is used and shared. The values and interests are thematically coded using the same set of codes from the literature research. This way, the values and interests are categorised per topic. Note that not every theme was assigned a set of values or interests during this process. Per value and interest, the perspectives of the DSOs and data owners are elaborated. This way, an overview of perspectives is created.

6.1. Emerging values

6.1.1. A3 Grid operations

This section contains all values that emerged from the SSIs that relate to LV grid operations:

Reliable energy supply and provision

The value of a reliable energy supply and provision lies in its ability to ensure consistent access to electricity. For Alliander reliable energy provision is both a fundamental value and responsibility because it is central to its role in the energy sector and energy transition. For energy consumers and smart meter data owners, a reliable provision is essential for economic stability, public safety, and overall quality of life. It powers homes and businesses, enabling comfort, productivity, and economic activity. Disruptions in energy supply can lead to significant inconvenience, financial loss, and even danger, making reliability a priority for consumers who depend on stable energy access.

This value is shared by both DSOs and data owners because data because failing to ensure reliable energy provision can lead to penalties from the ACM, holding DSOs accountable for not meeting this critical responsibility.

Safe energy supply

Safe energy supply refers to providing electricity over the LV grid infrastructure that minimizes the risk of harming people, property, or the environment. Striving for this value, the grid must be operated without creating hazardous situations like undervoltage, overvoltage and congestion that require sudden interventions. For Alliander, this is another fundamental value and responsibility, as it is their responsibility to keep the electricity grid safe for households and businesses. Moreover, this responsibility is established in the Elektriciteitswet 1998. As undervoltage and overvoltage can damage household appliances and machines, a safe energy supply is also of great value for consumers and smart meter data owners.

Ensure a safe grid and use the grid safely for both parties in line with a safe energy supply. However, in emergency situations, sudden grid interventions sometimes require DSOs to access smart meter data, which conflicts with the value of ’Privacy of personal data’.

Operational affordability

Operational affordability refers to managing and maintaining the distribution grids cost-effectively, ensuring that the costs of energy distribution remain reasonable. Maintaining grid operations that are affordable is, for Alliander, an important value, as the Elektriciteitsnet 1998 implicitly mentions that grid operations must be efficient. Interventions like grid reinforcement require much time and human- and financial resources that the taxpayer and, therefore, the consumer and smart meter data owner eventually pay. Therefore, this is of important value to DSOs and data owners.

Alliander emphasizes that affordability can be enhanced by implementing innovations like smart meters for congestion management. For instance, the current practice of applying a 20% safety margin on the LV grid could be optimized. With increased observability provided by smart meters, these safety margins could be safely reduced, leading to significant cost savings by reducing the need for expensive grid reinforcement. However, reducing costs in this way conflicts with the value of ’Privacy of personal data’.

Non-discriminiation

Non-discrimination on the LV grid ensures equal access for all consumers, ensuring fairness and equal treatment. By mandating grid connections, the law prevents exclusion or preference toward certain groups. This value is legally mandated to all DSOs in the Netherlands and, therefore, within Alliander, an important value. Moreover, the ACM ensures compliance with this legal obligation and gives penalties in case this obligation is not fulfilled. Grid access is essential to all consumers and potential consumers for economic activities, daily needs, and energy supply.

Currently, non-discrimination is at risk as congestion leads to growing waiting lists for LV grid connections. Increasing observability through smart meter data could help reduce grid congestion, enable more available capacity on the LV grid, reduce waiting lists, and mitigate discrimination. However, this solution conflicts with concerns about the ’privacy of personal data.’

More operational efficiency

Operational efficiency for operations departments means optimising resources to manage the grid cost-effectively while maintaining reliable electricity service. Since system operations departments also strive for ’operational affordability’, managing the grid efficiently is of utmost importance. Automation of services and improved monitoring is essential, but this requires smart meter data. From the data owner’s perspective, ’operational efficiency’ is not a priority value since this comes at the cost of the privacy of data owners. Privacy officers within DSOs also conflict with with the systems operations departments on this value since they should enforce proper alignment with AVG.

’Operational efficiency’ is highly important for DSOs as it contributes to the affordability and reliability of the LV grid. However, it strongly conflicts with values like ’non-discrimination’, ’privacy of personal data’ and ’empathy and respect’.

6.1.2. A8 Privacy-preserving/enhancing policies

This section contains all values that emerged from the SSIs that relate to privacy-preserving policies:

Privacy of personal data

The value of privacy of personal data lies in protecting data owners’ control over their personal data. The collection and use by others should only be with the data owner’s consent or for legitimate purposes. Privacy of personal data safeguards data owners from misuse or intrusion by others and ensures personal security in the digital and physical space. The ’privacy of personal data’ is rather an obstruction to innovation than a value to the system operations departments within Alliander. System operations preferably need as much data as possible to develop smart solutions. This is in sheer contrast with Alliander’s privacy desk, which needs to ensure AVG compliance to protect Alliander’s customers and prevent penalties by the ACM. Sharing energy-related data might seem harmless at first. However, privacy advocates argue that even small infringements can lead to a slippery slope of increasing privacy violations, eventually spiralling out of control. To ensure we do not slip down that slope, even small privacy infringements must be carefully guarded against. Therefore, data owners strongly value the privacy of personal data.

Personal smart meter data can be used to improve the reliability and safety of LV grid systems. However, DSOs must be able to access the smart meter data, which conflicts with the value of 'Privacy of personal data'.

Security of personal data

The value of 'Security of personal data' refers to protecting energy consumption data collected by smart meters. In Alliander's daily system operations, the primary focus is on efficient grid management, making this value less of a top priority. However, to Alliander's privacy desk, this is of significant importance as it is responsible for ensuring compliance with regulations to avoid penalties from the ACM. To smart meter data owners, energy-related data does not reveal intimate details like political preferences. However, it can still provide sensitive information, such as patterns indicating when someone is home or what electronic devices are used. This makes it valuable to criminals for activities such as burglary or kidnapping. Additionally, since electricity grids are critical infrastructure, the data is also a target for cyber and physical attacks. Therefore, ensuring the security of personal data involves implementing privacy-by-design approaches to prevent unauthorized access or data breaches, which could lead to sabotage or other harmful consequences.

The value of 'Security of personal data' mostly conflicts between the DSOs and data owners since the consequences of events like data breaches have mostly negative implications for data owners.

6.1.3. A9 Social

Empathy and respect

The value of empathy and respect requires DSOs to show understanding and respect to data owners making decisions about providing consent for smart meter data use. For many households and businesses, the rollout of the smart meter already felt like an obligation. Sharing personal data can be an experience that society must get used to first. Thereby, data owners must have the opportunity to make conscious, well-informed decisions about providing consent for the use of their smart meter data. Currently, data owners do not always feel respected when making that decision. However, system operators within Alliander do not always share this value with data owners, as they may not fully understand why data owners would withhold consent for access to smart meter data. DSOs may exert pressure on data owners through political discussions or by collaborating with energy suppliers to promote the use of smart applications to achieve consent in other ways.

DSOs are focused on the value of 'operational efficiency', making them blind to other stakeholder values like 'empathy and respect'. Also, the conflict within this value stems from the assumption that system operators within DSOs feel that households and businesses did not make a well-informed decision and do not fully understand why DSOs need smart meter data for grid operations. This creates opportunities for DSOs to put more effort into transparency and educating their customers.

Value	DSO perspective	Data owner perspective
Reliable energy supply and provision	Ensuring continuous access to electricity; essential for energy transition and sector responsibility	Powers homes and businesses, ensuring economic stability, public safety, and quality of life
Safe energy supply	Ensuring grid safety to prevent undervoltage, overvoltage, or hazardous situations; legal responsibility	Prevents damage to appliances and ensures safe electricity supply
Operational affordability	Managing grid costs effectively to maintain affordable energy; emphasizes smart meter use for savings	Affordable energy services, but concerns arise when cost-saving measures infringe on privacy
Non-discrimination	Ensuring equal access to the grid without preference; legally mandated and monitored by the ACM	Equal access to energy for economic activities and daily needs; risk of exclusion due to congestion
More operational efficiency	Optimizing grid management with smart meter data to enhance efficiency and reduce costs	Viewed less favorably when it compromises privacy; concern about balancing efficiency and data privacy
Privacy of personal data	Obstacle to innovation in system operations, which require more data; important for privacy compliance	Strongly valued; data should be controlled by the owner, protecting against misuse or unauthorized access
Security of personal data	Less of a priority for system operations, but vital for privacy compliance and protecting against breaches	Critical to protect personal and sensitive energy consumption data from potential criminal use or attacks
Empathy and respect	Often overlooked by DSOs in pursuit of operational efficiency; requires transparency and education	Expect respect and empathy when deciding whether to share data, especially after feeling pressured by smart meters

Table 6.1: Comparison of DSO and Data Owner Perspectives on Key Values

6.2. Emerging Interests

This section contains the interests that emerged from the SSIs.

6.2.1. A1 Observability

Increased observability on the LV grid

All smart meter data and measurement data from LS Meten that provide feedback on the grid's state are of great interest to Alliander. Observability is the most practical way to improve monitoring and thus increase operational efficiency, reduce costs, and improve reliability. Smart meter data is especially useful for obtaining more granular data on the grid's state. Enhancing observability through LS Meten is favourable for data owners, as it avoids the need for DSOs to process personal data. Increasing observability using smart meters is, for data owners, less desirable as this requires them to provide DSOs access and processing of personal smart meter data.

While smart meter data is of higher value to DSOs, the use of smart meter data strongly conflicts with the value of 'privacy of personal data.' Therefore, the actual need for smart meter data for congestion management must be considered, and prior assessment is required when LS Meten would be sufficient.

6.2.2. A2 Smart meter

Reading smart meter data without consent

In case of emergency, when the state of an LV grid is predicted to become hazardous, DSOs may read smart meter data without consent based on legitimate interest. For DSOs, being allowed to do this is of great interest for solving instant issues on the grid. However, to data owners, reading smart meter data without consent is the least desirable.

Smart meter readings without consent should be avoided. They conflict with the value of 'privacy of personal data'. However, it is sometimes required for safety reasons. For DSOs it is better to avoid hazardous grid situations, however, this might require smart meter data in advance. This highlights a key trade-off between feedforward and feedback approaches to smart meter data sharing.

6.2.3. A3 Grid operations

Digitalisation and Automation of LV grid services

Digitalisation enables the use of grid measurement data for improved monitoring based on the LV grid. Automation allows for the automatic determination of grid interventions. The digitalisation and automation of LV grid services aim to contribute to more operational efficiency, reliability, and affordability of grid management. To DSOs, digitalisation and automation are key to dealing with the limited resources and grid capacity. Digitalisation comes hand in hand with more extensive data use, which might conflict with the 'privacy of personal data'.

However, digitalization and automation enhance the values of a 'reliable energy supply', and a 'safe energy supply,' as automation enables quicker and more efficient resolution of grid issues, like congestion.

6.2.4. A6 Grid monitoring

Improved monitoring

Both data owners and DSOs have a strong interest in the improvement of grid monitoring to improve the reliability, efficiency, and safety of the electricity network thereby reducing the costs of grid management. However, grid monitoring requires increasing observability via LS Meten or smart meters. Using smart meters is an instant way to improve monitoring abilities. However, this conflicts with the value of 'privacy of personal data'.

6.2.5. A7 LV congestion management

Reduced LV grid congestion

Grid congestion is undesirable for both Alliander and data owners. Alliander is responsible for managing the grid and preventing or reducing congestion. If they fail to do so they may receive penalties from the ACM. Congestion restricts data owners from electrification and could hinder a reliable and safe energy provision.

Alliander wants to use the data owner's smart meter data to reduce the risk for congestion, this contributes to a more reliable and safe energy provision. However, using smart meter data to reduce congestion might conflict with the 'privacy of personal data'. This makes reducing congestion very complex.

Effective reinforcement of LV grid infrastructure

LV grid reinforcement against congestion involves upgrading the grid's capacity to handle increasing electricity demand and the integration of DERs. For data owners, grid reinforcement is a privacy-preserving solution to congestion, as it does not inherently require the use of personal data to strengthen grid capacity. To Alliander, grid reinforcement is practical as it reduces the reliance on personal smart meter data and LS Meten data to monitor for grid congestion. However, performing effective grid reinforcements requires identifying which parts of the grid must reinforced first. This process, in turn, requires smart meter data in advance.

Using smart meter data for efficient grid reinforcement conflicts with the value of 'privacy of personal data' However, it benefits grid reliability and safety and ensures non-discriminatory access to electricity services.

Optimise the availability of existing capacity of the LV grid

Making optimal use of the available capacity of the grid infrastructure is an important means to reduce grid congestion. Especially since the resources to reinforce the LV grid are scarce. Therefore, DSOs prefer optimal use of the existing LV grid infrastructure as it does not require investing time and financial resources in grid reinforcement. However, optimising the availability of the existing capacity of the LV grid requires more observability. Therefore, this interest could conflict with the value of 'privacy of personal data' if DSOs us smart meter data for increasing observability. Where this value improves reliability, affordability and efficiency of grid operations, it conflicts strongly with 'privacy of personal data'.

6.2.6. A8 Privacy-preserving policies

Increased institutional clarity

Increased institutional clarity refers to whether the stakeholders have a clear idea of the context in which they can use the data. Currently, there is a grey institutional area for smart meter data use caused by overlapping institutions like AVG and the Elektriciteitswet. DSOs consider the existing institutional landscape too complex to work with properly as it causes confusion and reluctance to use smart meter data. DSOs have a great interest in clarity. Clarity is partially provided by the GSN use cases. However, the approval process for new use cases is considered overly complex and slow by DSOs. In contrast, the GSN was initiated to increase the free use of smart meter data, which is not beneficial for data owners considering the value of 'privacy of personal data'. However, institutional clarity contributes to better compliance with AVG, improving the adherence to the value of 'Security of personal data'.

Control over personal data and differential consent (Autonomy and control)

Autonomy and control over smart meter data refer to the rights of data owners to manage how their smart meter data is collected, accessed, and used. This includes the ability to provide differential consent for approved purposes, ensuring privacy and protection of personal data. To data owners, this is a fundamental interest striving for the value of 'privacy of personal data' as with this interest, data owners remain in charge of their personal data. For DSOs this interest works two ways. First, once consent for a specific context is achieved, it is a powerful way to obtain access to smart meter data. However, obtaining consent costs effort in creating transparency and awareness.

Autonomy and control contribute to the 'privacy of personal data'. Gaining differential consent could improve the reliability, affordability and efficiency of grid operations. However, differential consent takes effort to achieve and it can also reduce efficiency.

AVG compliance

AVG compliance refers to adhering to the regulations set by the AVG, which governs the collection, processing, and storage of personal data within the EU. Elements that are especially important are legitimate interests, data minimisation, purpose limitation and transparency in data use. AVG compliance is for data owners fundamental. Moreover, the AVG was established to protect data owners' values, such as 'privacy of personal data' and 'security of personal data'. Alliander's privacy office ensures that Alliander's grid operations department adheres to AVG. However, compliance with strict AVG comes at the cost of 'operational efficiency' for DSO's system operations departments and can, therefore, reduce the reliability of energy supply. Conversely, the AVG does leave room for data use utilizing legitimate interests. Therefore, this can also be seen as an enabler of data use.

Privacy-improving measures

Privacy-improving measures, such as anonymisation, data aggregation, time intervals and Privacy-Enhancing Technologies (PETs), help protect personal data from misuse or unauthorized access. For both DSOs and data owners' privacy, privacy-improving measures are beneficial as DSOs can use the data to manage congestion while data owners keep their privacy. However, when implementing such measures, personal data has to be collected first, making it immediately prone to data leaks or privacy infringement and thus less favourable for data owners.

Implementing privacy-improving measures can contribute to the value of more operational efficiency and, thus, affordability and reliability of the grid. This can enable optimisation of the availability of existing capacity of the LV grid. However, since privacy-improving measures still require data collection, it conflicts with the privacy and safety of personal data.

Approval new use cases

The approval of new GSN use cases for open smart meter access to DSOs enables DSOs to access aggregated smart meter data for specific contexts. For Alliander, every new use case is beneficial and contributes to more operational efficiency, leading to more reliability, safety, and affordability for grid management. However, for data owners, each new use case represents a small yet significant privacy infringement over which they lack control. This accumulation of new uses can gradually reduce their sense of ownership and control over their personal data.

The interest in approving new use cases often conflicts with 'autonomy and control,' as these use cases are standardized and universally applied, potentially limiting individual decision-making.

6.2.7. A9 Social

Pressure from DSOs and politics / Lobby for new use cases

There is growing political and DSO-driven lobbying for the expanded use of smart meters. For instance, the rollout of smart meters has already signalled a shift toward smart solutions becoming central to grid management. For Alliander, this lobby is beneficial as it contributes to shifting privacy standards for data owners, enabling more use cases and differential consent. However, this lobbying pressure may force data owners to make decisions about sharing their data that they might not have made voluntarily.

This interest for DSOs conflicts mainly with the 'autonomy and control' over the personal data of the data owners. However, it indirectly contributes to the value of more operational efficiency and, thus, affordability and reliability of the grid, enabling more availability on the existing LV grid infrastructure.

Privacy lobby

Organizations advocating for personal data privacy are actively working to protect consumer privacy in the context of DSOs' smart meter usage. For Alliander, this could pose challenges in enhancing grid observability through smart meters, as advocacy organizations often amplify the privacy concerns related to the use of smart meter data by DSOs. However, for data owners, this lobbying serves as a constant reminder to DSOs and other data-dependent organizations that the value of personal privacy is crucial.

The lobby for privacy from advocacy organisations contributes to the value of more 'privacy of personal data' and 'safety of personal data'. However, it might reduce operational efficiency and, thus, affordability and reliability of the grid as it can limit the data owners' preparedness to share smart meter data with DSOs.

Awareness and Education

Awareness and education involve informing data owners about their data rights, privacy risks, and for what purposes their smart meter data is used. For the context of smart meter, this could entail DSOs explicitly explaining the purposes of smart meter use and the privacy measures applied to enhance privacy. Awareness and education are of great importance to both DSOs and data owners. For data owners, it enables them to make well-informed decisions about data sharing. When data owners are fully informed, DSOs are more likely to respect and empathize with their decisions, knowing that these choices were made with a clear understanding of the trade-offs involved. Moreover, it is believed that if data owners are informed about how their smart meter data can contribute to reducing grid congestion, more of them will be inclined to grant DSOs access to their data, highlighting the collective benefits of improved grid management.

Awareness and education can enhance operational efficiency, leading to greater affordability, reliability, and improved availability on the existing LV grid infrastructure. Additionally, it promotes better privacy protection, as informed data owners can make more conscious decisions about what they consider to be privacy-intrusive when sharing their data.

Interest	DSO Perspective	Data Owner Perspective	Value Contribution	Value Conflicts
Increased observability on the LV grid	Important for improved grid monitoring and operational efficiency.	Concerned about privacy implications of increased data collection.	Operational efficiency, reliability	Privacy of personal data
Reading smart meter data without consent	Necessary for grid safety during emergencies.	Opposed unless it's an emergency; concerned about data misuse.	Safety of energy supply	Autonomy and control over personal data
Digitalization and Automation of LV grid services	Supports operational efficiency and reliable energy supply.	Concerned about data collection increasing due to automation.	Reliable energy supply	Privacy of personal data
Improved monitoring	Helps track grid status, reduce costs, and improve reliability.	Supportive if privacy is maintained, prefer anonymized data.	Grid safety, reliability	Privacy of personal data
Reduced grid congestion	Important for preventing disruptions and penalties; requires smart meter data to be effective.	Congestion restricts electrification and can hinder reliable, safe energy provision.	Reliable and safe energy provision	Privacy of personal data
Effective reinforcement of LV grid infrastructure	Necessary for reducing grid congestion and ensuring capacity.	Prefers grid reinforcement to avoid extensive data collection.	Grid reliability, safety	Privacy of personal data
Optimise the availability of existing capacity of the LV grid	Critical to reduce grid congestion and better utilize resources.	Concerned if it requires increased data collection.	Operational affordability	Privacy of personal data
Increased institutional clarity	Necessary to streamline operations and clarify data usage.	Helps understand data use and privacy implications.	Transparency, security of personal data	Operational efficiency
Control over personal data and differential consent (Autonomy and control)	DSOs struggle with timely access to data when consent is required.	Strongly values control and consent over personal data use.	Privacy of personal data, autonomy	Operational efficiency
AVG compliance	Limits data access flexibility and slows operations.	Essential for protecting personal data and ensuring proper usage.	Privacy of personal data, security of personal data	Operational efficiency
Privacy-improving measures (e.g., anonymisation, PETs)	Allows access to data while protecting privacy.	Supportive but cautious about the initial data collection process.	Privacy of personal data	Privacy of personal data
Approval of new use cases	Important for accessing data to improve grid operations.	Concerned about cumulative privacy infringements over time.	Operational efficiency, reliability	Privacy of personal data
Pressure from DSOs and politics / Lobby for new use cases	Supports expanding use cases for better grid management.	Concerned that lobbying may pressure decisions about data sharing.	Operational efficiency, affordability	Autonomy and control
Privacy lobby	Hinders data access for grid management.	Supports strong privacy protections and limits data access.	Privacy of personal data	Operational efficiency, affordability
Awareness and Education	Important for transparency and fostering data-sharing consent.	Helps make informed decisions about data sharing.	Empathy, respect	Operational efficiency

Table 6.2: Interests, value contributions, and conflicts from the perspectives of DSOs and data owners.

6.3. Conclusion sub-question 2

This section provides the concluding answer to sub-question 2:

SQ2: What values and interests emerge when smart meter data is shared with DSOs to increase observability on the low-voltage grid?

In conclusion, when smart meter data is shared with DSOs to increase observability for managing congestion on the LV grid, several key values and interests emerge. To DSOs, interests that contribute to values like operational efficiency, grid reliability, and safety are a priority. On the other hand, data owners focus on protecting their personal privacy and security, compliance with AVG, and wanting to be respected in data-sharing. The interplay between values and interests that support improved grid management and those that prioritize safeguarding privacy and security creates a complex trade-off among the stakeholder groups.

The analysis of the emerging values and interests reveals significant conflicts between DSOs and data owners, particularly between smart meter data use for grid operations and privacy. However, aligning interests were also identified, such as ’Awareness and education’ and ’Reduced grid congestion’. These synergies create opportunities for finding fitting solutions to increase observability.

The interest in ’Awareness and education’ plays a critical role in bridging the gap between smart meter data used for grid management and data privacy. This is because informed data owners are more likely to understand the benefits of data sharing in relation to their personal privacy. This can contribute to obtaining more differential consent for accessing smart meter data to manage congestion.

A careful trade-off between innovation in grid management and the protection of personal data is essential for building trust between data owners and DSOs and ensuring grid operations that can deal with the increasing congestion problem. Therefore, it is essential to better understand what factors govern this trade-off and how the balance of this trade-off can be altered to increase observability. In the subsequent system analysis, it is essential to clearly visualize this trade-off. Additionally, the impact of aligning interests should be examined to understand how they might influence the trade-off. The visualization of the system, illustrating both the conflicts and synergies, will be presented in Chapter 9.

7 Institutional landscape

7.1. Institutional landscape

This chapter provides an overview of the institutional landscape governing the use of smart meter data. Smart meters collect sensitive personal data, making it crucial to understand the regulations protecting this data. To understand how DSOs might increase the observability of the LV grid using smart meters, it is essential to know which institutions and legal structures apply.

7.1.1. Algemene verordening gegevensbescherming (AVG)

The AVG is a Dutch translation of the General Data Protection Regulation (GDPR) and is designed to protect individuals' privacy and personal data. It sets strict rules on how personal data should be collected, processed, stored, and shared by organisations. As outlined in the introduction, all data generated by smart meters is considered personal data, meaning that the AVG applies to smart meter data (Persoonsgegevens, 2024).

However, the AVG does not explicitly restrict the use of personal data. It sets the guidelines for the contexts in which personal data may be used, and it sets rules on how it should be used to minimise the risk of privacy intrusion. During the interviews, several elements from the AVG were explicitly mentioned to cause issues as they leave room for interpretation. However, room for interpretation also leaves room for solutions for smart meter data access. The relevant elements are outlined in this section:

Legal basis for processing and legitimate interests

According to 'Legal basis for processing', personal data may only be processed if the data processor has a legal basis for doing so. DSOs can fulfil this legal requirement by gaining direct consent from households and companies to access their smart meter data. Another way to obtain a legal basis for accessing smart meter data is when an individual has the legal obligation to perform a particular duty and, therefore, needs specific personal data. For example, according to the Elektriciteitswet 1998, DSOs are legally obligated to perform grid management. If smart meter data is required for efficient grid management, then smart meter use can be justified (Government of the Netherlands, 2021).

Alternatively, the DSO can access smart meter data if they have a legitimate interest. This means that processing is necessary for the interests of the DSO or a third party as long as these interests do not outweigh the rights and freedoms of the data subject. Another case when the processing of personal data is permitted is when processing is necessary to comply with a legal obligation to which the controller is subject (Government of the Netherlands, 2021).

The legal basis and legitimate interest do not necessarily restrict smart meter data use. However, it allows room for interpretation and discussion, making it difficult for DSOs to clearly define what is permitted and what is not (Respondent B, Respondent E). Moreover, the legitimate interest and legal obligation might complement elements from the 'Elektriciteitswet 1998', which will be discussed later in this chapter.

Purpose binding

Another important element from the AVG that is relevant for DSOs is purpose binding. This rule states that personal data may only be collected for specific, explicitly defined, and legitimate purposes. The data can not be further processed in any other way than the purpose that it was collected for (Government of the Netherlands, 2021). Purpose binding is for DSOs a way to make explicit to their customers that power level data from smart meters will be exclusively used for grid management (Respondent B).

Data minimisation

The data being processed must be limited to what is necessary for the purpose for which it was collected. This means no data should be collected or processed more than strictly necessary for a specific purpose (Government of the Netherlands, 2021). The amount of data necessary for a specific purpose is not defined by any rule. Consequently, this leads to a discussion between privacy officers and grid operators (Respondent A). Grid operators complain that this element in the AVG restricts them from reading more smart meter data to increase observability (Respondent J).

Transparency

Data processors are required to inform data owners about the processing of their personal data. This means they must clearly state which data is being collected, for what purposes, and to whom the data may be shared. Transparency is not only an obligation, it can also be applied as a means to obtain more consent (Respondent B).

Accountability

In case personal data is accessed and processed, the processor must be able to demonstrate compliance with the processing rules of the AVG. This means processors of data must document their processing activities to be able to show their accountability to the Autoriteit Persoonsgegevens (Government of the Netherlands, 2021). For urgent situations, DSOs already access and process smart meter data. For example, when an outage might occur and if reading smart meter data can help solve the problem. For these specific situations, DSOs ensure they have documented their decision-making process. This documentation serves as evidence in case the AP questions the lawfulness of the data access (Respondent B).

In conclusion, the AVG does not explicitly restrict DSOs from accessing smart meter data to increase their observability. However, it does not specifically describe when the legitimate interest is urgent enough for DSOs to access smart meter data. This creates room for interpretation, making it complicated for DSOs to assess in what cases accessing smart meter data is lawful. Also, the AVG is not the only institution that applies for smart meter data. Another important institution that applies to the entire electricity sector is the ’Elektriciteitswet 1998’ and the ’Energiewet’. Further examination is described in the next section.

7.1.2. Elektriciteitswet 1998

The Elektriciteitswet 1998 is a law that regulates the production, transport, and supply of electricity in the Netherlands. This law covers all the segments of the electricity sector, and it also specifies the roles and responsibilities of Dutch DSOs (Elektriciteitswet, 1998). According to Article 16 of the ’Elektriciteitswet 1998’, DSOs have the legal obligation to operate, maintain and develop the electricity grid to ensure that it remains safe, reliable and affordable (Elektriciteitswet, 1998)(Netbeheer Nederland, 2024a). Moreover, it specifies in Article 26 that DSOs are allowed to use data from measuring installations in houses to perform their public task as DSO. However, it does not specify whether these measurements may be performed by smart meters (Elektriciteitswet, 1998).

Although DSOs do not always have access to smart meter data, they are responsible for distributing smart meter data to third ’other service providers’ (ODA), which are often energy suppliers that offer additional services to their customers using smart meter data. DSOs are legally obliged to keep this data confidential to third parties unless the data owner provides differential consent to share this data with the ODAs.

In conclusion, the ’Elektriciteitswet 1998’ clearly states that DSOs have the legal obligation to keep the electricity grid operational. However, it does not explicitly restrict DSOs from accessing smart meter data in urgent cases because, for those cases, DSOs have a legal basis and legitimate interest. However, room for interpretation with respect to legitimate interest leads to ongoing discussion when DSOs can access smart meter data.

7.1.3. Netcode

The Netcode for electricity in the Netherlands, established by the ACM, sets the technical and operational rules for managing the electricity grid. It defines the responsibilities of DSOs and grid users, including connection conditions, metering requirements, and procedures for network capacity and safety. The code governs how electricity is transported, measured, and allocated, ensuring that the system operates efficiently, reliably, and in accordance with European standards Netcode Elektriciteit (2023). The Netcode outlines that grid operators can access smart meters for grid management, congestion management, innovation and emergencies. However, the AVG also applies, meaning that DSOs can only access smart meter data when there is their legal obligation or legitimate interest Netcode Elektriciteit (2023). This once again leaves room for interpretation regarding the conditions under which legitimate interest applies, meaning the Netcode does not provide clear guidance to DSOs on when they are permitted to access smart meter data.

7.1.4. Institutional grey area

Data is considered personal as long as it can be traced back to the data owner (Respondent A). The AVG permits accessing and processing personal data if there is a legitimate interest or legal obligation (Government of the Netherlands, 2021). The Elektriciteitswet 1998 and Netcode state that DSOs are legally required to operate, maintain, and develop the electricity grid to ensure its reliability and safety. It also specifies that DSOs may access and process measurement data for grid operation purposes in urgent situations (Elektriciteitswet, 1998). Therefore, DSOs have a legal basis for accessing personal data from smart meters if it is necessary to fulfil their legally mandated responsibilities. For DSOs, the intersection between the AVG, 'Elektriciteitswet 1998' and the Netcode create a large grey area. In many cases, it remains yet unclear for DSOs when they have the right to access smart meter data to increase their observability. This often leads to discussion between DSOs' Privacy Officers and the System Operations departments (Respondent J, Respondent A). To guide DSOs through the grey area, the GSN was introduced (Respondent E, Respondent B). The following section will further elaborate on the GSN.

7.1.5. Gedragscode Slim Netbeheer

Since all the institutions that are in place create a maze of rules, the GSN was founded to guide DSOs through the process of accessing smart meter data (Respondent E)

In 2019, Stedin conducted a pilot by reading smart meter data from 5000 houses in a small neighbourhood. Until then, DSOs in the Netherlands were completely blind on the LV grid. The shocking results showed the severe impact of residential PV panels on the LV grid. The results were reported to the Autoriteit Persoonsgegevens (AP) to verify whether reading smart meters, in this case, was legally permitted considering the Elektricitietswet. The AP concluded that Stedin had interpreted the AVG correctly by doing a thorough risk assessment and was, therefore, not violating the law (Respondent F). As Stedin proved the necessity for using personal data, a uniform code of conduct was initiated to enable all DSOs in the Netherlands to apply a uniform interpretation of AVG. This code of conduct was named the Gedragscode Slim Netbeheer (GSN) (Respondent F).

The GSN outlines how all DSOs in the Netherlands should handle the use of personal data responsibly when managing the energy grid. This code aims to ensure that personal data use complies with the AVG and to keep the public function of DSOs safe, reliable and affordable (Netbeheer Nederland, 2024a). The GSN is strictly meant for operating energy grids to make a balanced decision on whether the use of personal data is suitable for grid management within the legal framework of the AVG (Respondent F).
Before being allowed to access smart meter data, DSOs must propose a use case for every specific purpose. A use case should contain a consideration that describes that it is just to extract smart meter data for that specific case. This consideration should balance smart meter data's necessity (is it truly essential for grid management), subsidiarity (can the issue be resolved without using data from the smart meter) and proportionality (is only the data that is genuinely required to be collected and processed) against the potential risks of using that particular personal data (Netbeheer Nederland, 2024a).

Every new use case must go through an approval process and be assessed based on a standardised model to ensure every use case is approved in a uniform manner. During this process, the use case is assessed by various independent bodies and organizations to evaluate potential risks. These bodies are, among others, the GSN Working Group, Privacy Officers and Data Protection Officers. The AP and the ACM oversee the whole process and verify the compliance of use cases. Each use case must be reviewed to determine if the data being processed includes personal information and, if so, what associated risks may arise (Respondent A).

Once a use case is approved, it is valid for all DSOs in the Netherlands (Netbeheer Nederland, 2024a). The GSN functions as a guideline in a grey area as there is no clear-cut way to determine which data can and cannot be used, as it depends on the specific context of each situation. The most critical requirement for using specific data from smart meters is what the intended purpose for data usage is (Respondent A). By following the guidelines of the GSN and collaborating with privacy-preserving bodies like the AP and privacy officers, DSOs can establish agreements on which data can be used and in what form, such as through aggregation or anonymisation techniques (Respondent A).

Not all data generated by smart meters is inherently privacy-intrusive. For instance, a single energy usage reading reveals little about a customer's behaviour. However, frequent readings over short intervals can reveal detailed consumption patterns that may compromise privacy (Respondent A). Furthermore, with the increasing integration of digital systems, initially, non-privacy-intrusive data can become privacy-sensitive when combined with other datasets (Respondent G). Also, future use of specific data cannot always be accounted for as it is still uncertain to what extent future innovations can use data in a privacy-intrusive manner (Respondent A)(Respondent G). The GSN and its use cases are also a way to communicate the balancing process that was followed to consumers and future generations (Respondent A) and ensure that Dutch DSOs apply a uniform consideration process (Respondent E).

7.2. Conclusion subquestion 3

This section provides the concluding answer to sub-question 3:

SQ3: What institutions govern the implementation of increased observability on the low-voltage grid for DSOs?

Increasing observability on the LV grid by implementing more measuring equipment like LS Meten is yet mainly obstructed by limited resources to install LS Meten in all MSRs.

Implementing more observability on the LV grid through smart meters is not explicitly obstructed by institutional barriers. However, the overlap between the AVG and the Elektriciteitswet 1998 creates an institutional grey area where DSOs struggle to navigate. This challenge arises from the responsibilities assigned to DSOs for grid operation under the Elektriciteitswet 1998 and Netcode, combined with the interpretation of legitimate interest, data minimization, and purpose limitation under the AVG. The institutions do not forbid DSOs from using smart meter data. However, differing values and interests of the stakeholders and different interpretations of legitimate interest form the challenge for increasing observability using smart meters. Moreover, the legal duty of DSOs to manage the grid also conflicts with the AVG. This is mainly because grid management can be performed in various ways, but the ways that require personal smart meter data are often more efficient and cost-effective. This creates a vital discussion about to which extent efficiency and costs must come at the cost of privacy.

To address this institutional grey area, the GSN was introduced as a practical guideline for DSOs, enabling them to navigate the complex legal landscape of smart meter data access. Through use cases, the legitimate interest, legal base, subsidiarity, purpose limitation and proportionality of data access are assessed in collaboration with third parties. This ensures compliance with AVG while Alliander can fulfil its operational responsibilities.

Despite the introduction of the GSN, ongoing discussions between DSOs, privacy officers, and regulatory bodies like the AP and ACM remain. There is a significant mismatch between what DSOs and data owners consider legitimate interest, which has profound implications for finding the right balance in the trade-off between smart meter data access and privacy. Moreover, purpose binding and data minimisation are per case op to interpretation, leading to more stakeholder disagreement. To gain a deeper understanding of this trade-off, the institutional insights from this chapter will be integrated with the values and interests within the broader technological landscape in a holistic system analysis.

8 Theory for system analysis

8.1. Theory selection

The to-be-analysed LV grid system is a complex socio-technical system containing many different interacting components and stakeholders. The stakeholders and components are inherently related and influence each other, resulting in emergent system behaviour. For the LV grid, without the interrelation between the components and stakeholders, the system loses its functioning (Haraldsson, 2004). Therefore, to understand the current LV grid system thoroughly, the interrelations should be made clear. Therefore, the theory chosen to analyse the system should comply with the following criterion:

- *The theory must be able to explain complex causal relations between components within complex socio-technical systems.*

Some of the interrelations between actors and components in complex systems form feedback loops (Arnold & Wade, 2015), which is also true for the LV grid. For example, when a DSO observes that the voltage level falls below the desired level, the DSO adjusts the transformer to increase the voltage. Once this control action is completed, the DSO monitors whether the control action worked. Feedback loops are crucial for understanding the overall system because they can severely impact the system's behaviour (Arnold & Wade, 2015). In order to comply with these system characteristics, the theory should comply with the following criterion:

- *The theory must be able to describe causality and feedback loops.*

Systems are often embedded within larger systems. But also, systems are built out of multiple subsystems (Haraldsson, 2004). However, when analysing large complex systems, it is not always necessary to consider the entire system. Therefore, reducing complexity is essential, which can be achieved by focusing on certain subsystems (Arnold & Wade, 2015). For example, an LV grid can be seen as a system of components like transformers, cables, meters, and circuit breakers. Each of these components consists of its own subsystems. For example, a transformer consists of coils and meters. The sum of the functions and interaction between these components and feedback processes maintains the core function of the transformer: regulating voltage levels. These components interact to ensure the proper distribution of electricity to households and businesses. The LV grid, in turn, is part of a larger power distribution system. While consumers don't need to know how the different components of the LV grid work to use electricity, they understand its overall system behaviour: delivering electricity. However, if a power issue arises, like a blackout, the problem may lie within the grid's internal components, like a defective transformer, or external factors, like a storm affecting the infrastructure. When studying systems to identify causes for certain undesired behaviour, it is essential to apply a theory that can clearly define boundaries between systems consisting of different sub-systems:

- *The theory must be able to define clear system boundaries between subsystems when analysing the system. requirements.*

Since the SQ4 and SQ5 require a comprehensive analysis that creates insights to improve the current system state, it is essential to model the system conceptually. Modelling can help to reduce complexity further and simplify the understanding of the system. Especially mental models can help to explicitly map problems within a system and make them visible for clearly communicating them with others (Haraldsson, 2004). Therefore the theory to apply in this research should comply with the following criterion:

- *The theory must include methods to conceptualise complex socio-technical systems by building mental models.*

8.1.1. Combining system requirements by Systems Thinking approach

Based on the proposed criteria, the 'Systems thinking' approach was selected to combine all the system requirements obtained during the interviews. However, many definitions can be assigned to Systems thinking (Arnold & Wade, 2015); this research will follow the definition for Systems thinking of Haraldsson, 2004: Systems thinking is a holistic approach to understanding complex problems by recognising the interconnectedness of components within a system. It focuses on how stakeholders and components within a system influence each other through feedback loops instead of analysing them as individual components in isolation. This approach helps to identify patterns, structures, and relationships that may not be evident in linear thinking, enabling a more comprehensive understanding of how changes in one part of the system can affect the entire system.

Systems thinking takes defining the problem with the stakeholders as the initial step in the process (Haraldsson, 2004). This research took that first step by doing the SSIs with the stakeholders to extract how the system components relate. The stakeholders interacting with the system might only focus on the sub-systems they are interested in or responsible for, not considering their actions from a holistic perspective. Without this holistic view, addressing problems can lead to so-called 'end of pipe' solutions, which, rather, cure symptoms instead of fixing the root problem (Haraldsson, 2004). For example, in a perfect situation, DSOs would like to extract all smart meter data to improve the functioning of the sub-system they are responsible for: the LV grid. However, this 'quick fix' does not consider the cascading effects this can have on consumer privacy and safety. It also works vice versa: if households with smart meters want to keep all smart meter data inaccessible to DSOs, then DSOs can hardly improve their public service. Taking a Systems thinking approach to these examples, the causal relations between these two issues can be clarified, and causal loops determining the ultimate system behaviour can be identified.

8.1.2. Causal Loop Diagram

To conceptualise the problems within the complex LV grid system, Haraldsson, 2004 propose the CLD diagram. CLDs are a tool used in Systems thinking to map out the structure and feedback within a system. It helps in visualising the relationships between different components of a system and understanding how these components influence each other through feedback loops. In a CLD, the researcher draws arrows between the factors representing positive- and negative relations. A loop can be identified when a factor indirectly influences itself via an array of other factors. Loops can reinforce certain behaviours, amplifying change like growth or decline. Also, loops can balance behaviour, stabilising the system, like the example where DSOs adjust voltage levels with the transformer (Haraldsson, 2004).

The CLD will eventually be the artefact created during the Design cycle in DSR. It is applied to create insight into the inner workings of the LV grid. Moreover, as all the relevant factors are incorporated in the CLD, this research aims to identify the means to alter the system behaviour.

8.1.3. Limitations of System Thinking

When conceptualising the LV grid system, the CLD might get too complex to analyse effectively (Haraldsson, 2004). Therefore, the CLD is simplified by reduction, transformation, abstraction and homogenisation (Arnold & Wade, 2015). Also, only the relevant sub-systems are considered by clearly defining the system boundaries. For this system, that means that only the factors on the LV grid were taken into account that relate to congestion and capacity issues. However, there is always a risk of misinterpreting the factors (Richmond, 2001). To mitigate this risk, only experts in the field were interviewed to gather information on how the LV grid system actually works in the Netherlands. Another limit of CLDs is that they lack a time dimension, making it challenging to understand the timing and pace at which certain developments within the system will unfold (Richmond, 2001).

8.2. Conclusion sub-question 5

This section provides the concluding answer to sub-question 5:

SQ5: How can the various insights from the relevance cycle be combined using established theory for comprehensive and actionable analysis of the low-voltage grid system?

By conducting the Rigor cycle, the theory for analysing the system was found. The insights gathered from the relevance cycle can be effectively combined through the use of Systems Thinking, a holistic approach that allows for the analysis of complex socio-technical systems such as the LV grid. Systems Thinking helps to map out the interrelations between various components and stakeholders, focusing on feedback loops and emergent behaviours that shape the system's functionality. By conceptualising the system through tools like CLDs, the cause-and-effect relationships can be visualised, and potential intervention points for improving grid management can be identified. However, simplifying these models is crucial to avoid overwhelming complexity, and system boundaries must be clearly defined to focus on relevant subsystems such as congestion and capacity. Despite its limitations, Systems Thinking provides a comprehensive and actionable framework for analysing the LV grid, offering insights that can guide both technical and operational decisions.

The selected theory, Systems Thinking, is a guiding framework for combining the answers to sub-questions 1, 2, and 3 to answer sub-question 6.

9 Current system analysis

This chapter aims to provide a visualization of the current system. To achieve this, insights from subquestions 1, 2, 3, 4 and 5 are integrated to build a mental model that clarifies the LV grid system's behaviour, highlights the interdependencies between components, identifies key trade-offs, and explores solutions for increasing observability.

The technical insights of the LV grid system provide essential information for understanding the operational challenges and constraints within the grid. These insights are needed to describe the current system performance, identify obstructions to increasing observability, and understand how interventions can improve observability.

Institutional insights explain the rules, regulations, and organisations that govern the LV grid system. Incorporating the relevant institutional aspects into the system analysis is an essential step in understanding how institutional structures shape the system's performance. Moreover, an understanding of the institutions is required to determine appropriate solutions within the solution space.

The values and interests of the stakeholders reflect their priorities and concerns and explain how stakeholders desire to interact with the LV grid system. Collecting values and interests helps identify both conflicts and synergies between DSOs and data owners, which provides insight into stakeholders' decision-making. The current system analysis contributes to understanding how the conflicts between values and interests are mostly hindering efforts to increase observability on the LV grid. On the other hand, synergies between values can also be positioned using system analysis to find fitting solutions for increasing observability that all stakeholders accept.

9.1. Current system's Causal Loop Diagram

The CLD represents the mental model of the current LV grid system, providing a visual representation of how the system's inner workings are understood based on insights gained from interviews with various stakeholders. It illustrates the perceived relationships and feedback loops within the system. The interviews and desk research explored a wide range of aspects of the LV grid system. However, when designing the CLD, the focus was intentionally narrowed to highlight the trade-off between increasing observability and maintaining privacy while also pointing to a few potential solution pathways.

from the technical aspects, the essential elements from the LV grid system related to observability or congestion were incorporated into the CLD, such as the drivers for congestion. Also, possible technical directions for solutions are proposed, such as anonymisation, aggregation, and PETs.

The conflicts identified while examining the stakeholders' values and interests highlight the trade-off between smart meter observability for grid management and privacy. This CLD aims to put this trade-off into perspective by positioning the most relevant interests into the system analysis. To highlight this trade-off, the most important interests from Chapter 6 are also incorporated into the CLD. The synergy identified for 'Awareness and Education' provides directions for solutions and, therefore, must be integrated into the CLD. Other important interests were 'Institutional clarity' and 'Lobbying for new use cases'. The interest in AVG compliance was partitioned into the most important elements of the AVG, like 'purpose binding', 'data minimisation, and 'legitimate interest', and added to the CLD. The interest in 'privacy-improving measures' is represented by 'Anonymisation', Application of PETs, aggregation and time intervals within the CLD.

The institutions incorporated in the CLD are embedded in the interests of the permitted level of aggregation, permitted time intervals, legitimate interest, purpose limitation, data minimisation and anonymisation.

All the important elements were combined using a Systems Thinking approach in a CLD. Moreover, since this CLD focuses on the trade-off between obervability and privacy, this CLD only elaborates on observability that is implemented using smart meter data.

The CLD of the current situation reveals three distinct loops, each illustrating a different method through which DSOs can access smart meter data. The first two loops describe how DSOs can access this data without obtaining consent, while the third loop outlines how consent to increase the '# Smart meter data available to DSO' is affected by the social debate on privacy security. In this CLD, it must be highlighted that all available smart meter data described by '#Smart meter data available to DSO' is personal data and, therefore, forms a privacy risk, increasing 'Actual risk on privacy violation', as it is impossible to mitigate this risk to zero.

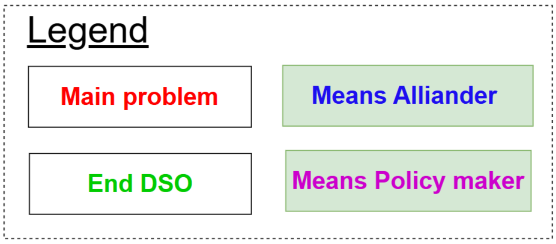

Figure 9.1: The CLD legend.

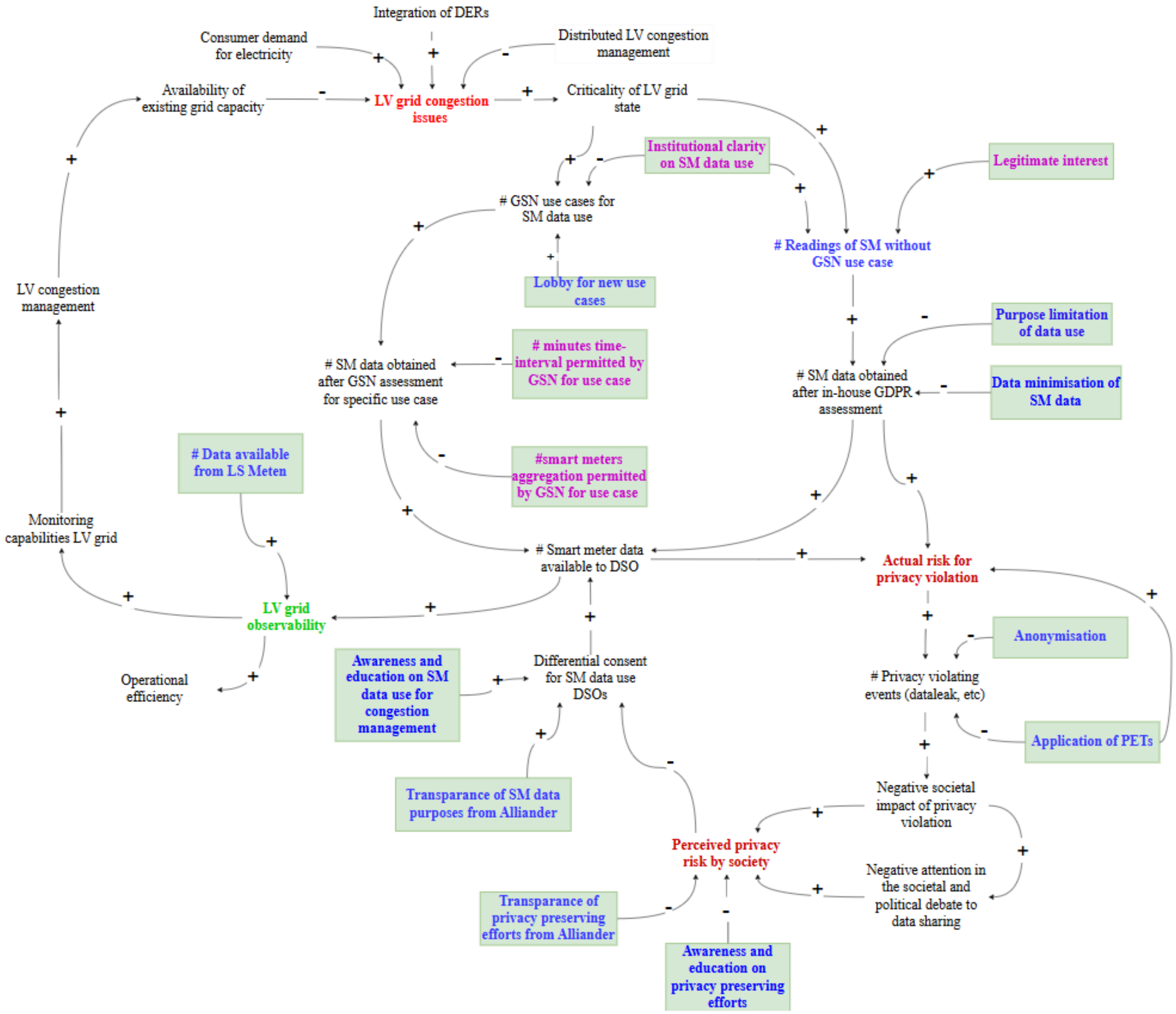

Figure 9.2: The current system's CLD.

9.2. Loop 1: 'GSN use case'

The first loop is called the ’GSN use case loop’, and it demonstrates how smart meter data can be accessed following the GSN use case approval process.

Loop description

- ’LV grid congestion issues’ lead to a more critical grid state where Alliander cannot guarantee the reliability and safety of the grid.
- Once the ’criticality of the LV grid state’ increases for a specific domain, such as voltage problems, DSOs can initiate a GSN approval process to compose a new use case, thereby increasing the ’#GSN use cases for SM data use.’
- As the number of use cases increases, the amount of data that can be used freely also increases with ’#SM data obtained after GSN assessment for a specific use case.’
- The data that can be freely accessed thanks to the use case adds to the total amount of data available to DSOs for increasing observability in the variable ’#Smart meter data available to DSO.’
- Consequently, ’LV grid observability’ leads to better ’Monitoring capabilities of the LV grid,’ improving ’LV congestion management’ and increasing the ’Availability of existing grid capacity,’ ultimately reducing congestion.

External factors explained

To start with, this loop clearly showcases that the initial cause for congestion on the LV grid is caused by increased ’Consumer demand for electricity’. This insight teaches us that all complexities in the system are initiated by a change in the behaviour of the energy consumer as it demands more electricity.

The use cases enable data use for DSOs that struggle with interpreting the grey area of the institutions that apply. The use cases are a product of the desire to clarify which data may be used. When there is little institutional clarity, the desire for well-defined use cases increases. Especially under the lobbying pressure of DSOs who explicitly stress the need to access certain smart meter data.

An important element in the GPDR and, thus, in the GSN is data minimisation. This element ensures that, eventually, the amount of data available to DSOs for grid operations is limited by aggregation and increasing the time interval. This has a severe impact on the amount of smart meter data that is eventually available to DSOs to increase observability.

Loop outcome: 'lose-lose situation'

The most important insight that can be deducted from this loop is that use cases are only initiated and approved on the condition that there is an increased ’Criticality of the LV grid state’. In terms of systems and control, one can speak of solving issues based on feedback, which essentially means that DSOs are enabled to solve issues once the issues have already occurred.

When action is taken based on feedback, issues are often addressed too late or only after they have occurred. Furthermore, once the issue arises, smart meter data is accessed regardless, failing to prevent the problem while also infringing on personal data through a use case approval. This situation is considered a lose-lose situation: the DSOs failed to prevent the critical LV grid state, and the data owners lost autonomy and control over their personal data due to the use case increasing the ’Actual risk on privacy violation’.

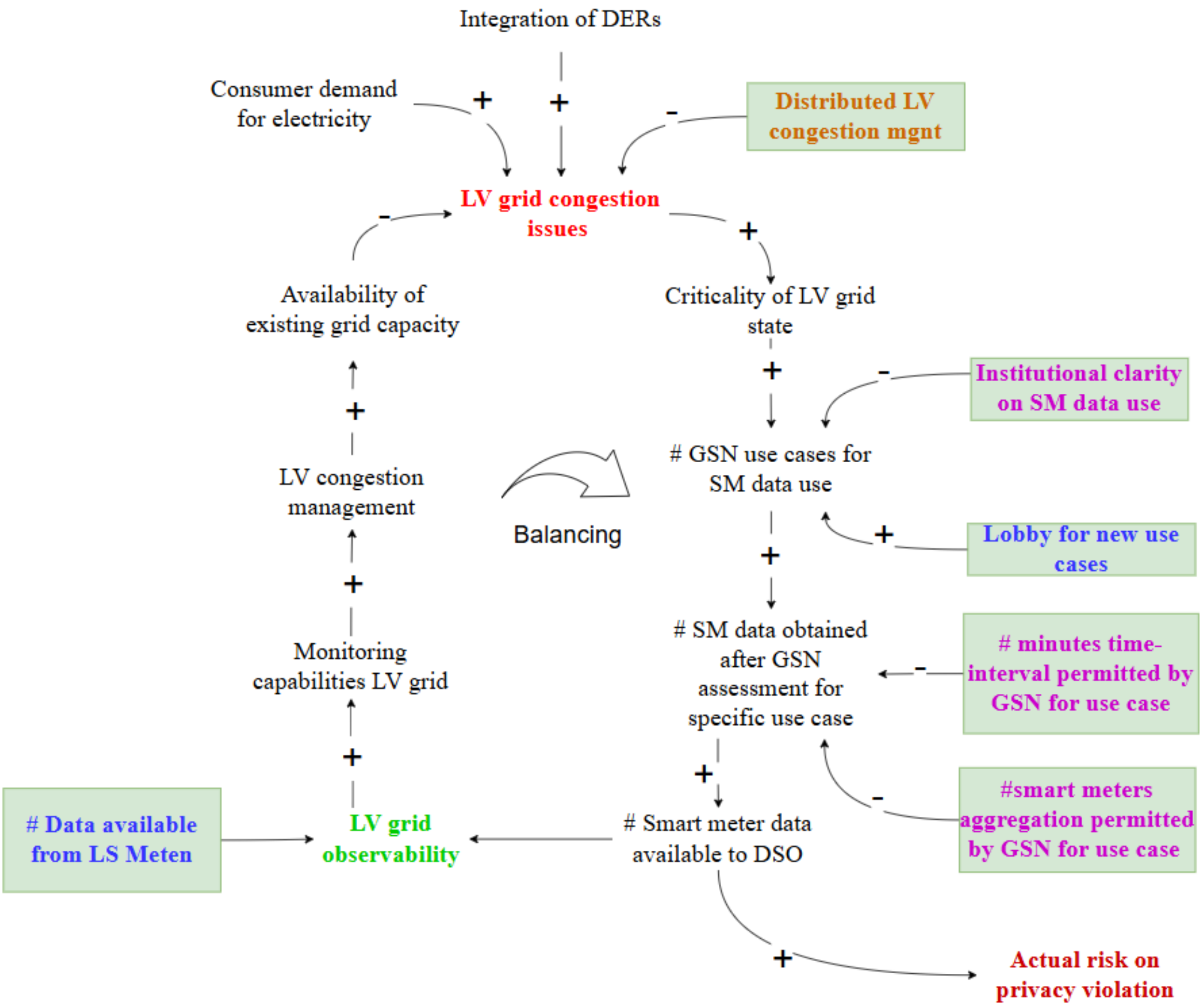

Figure 9.3: The 'GSN use case' loop

9.3. Loop 2 'smart meter access without GSN'

The second loop illustrates an alternative method for Alliander to access smart meter data without undergoing the GSN-supervised process. DSOs view the GSN process as slow and inefficient, particularly in emergency situations where a more immediate response is required. Additionally, since DSOs own the smart meters, they can physically access the data if they believe they have a legitimate interest in doing so.

Loop description

- When the 'Criticality of the LV grid' increases due to increased 'LV grid congestion issues', DSOs will inevitably need to perform smart meter readings without GSN use case.
- When smart meters are accessed more often the amount of data obtained without GSN with an in-house AVG assessment will increase.
- This will eventually lead to a larger amount of smart meter data that is available to DSOs to perform grid management with, leading to more LV grid observability.

External factors explained

The variable 'Institutional clarity on SM dat use' in this loop has a positive relationship with '#Readings of SM data without GSN use case'. This is because when DSOs have a clear understanding of the

regulations for accessing smart meter data, they no longer have to rely on the clarity provided by the GSN. As a result, they can more confidently assess whether accessing the data is permissible.
When DSOs believe they have a legitimate interest in accessing smart meter data without a specific use case, they must still comply with AVG regulations. Two key elements of the AVG that affect the amount of data available for grid management are data minimization and purpose limitation. However, these elements allow room for interpretation by the DSOs. Unlike the uniform assessment provided by the GSN, this flexibility increases the 'Actual risk of privacy infringement.' This is depicted in the CLD as a positive relationship between '#Readings of SM data without GSN use case' and 'Actual risk of privacy violation.'
Legitimate interest plays a significant yet ambiguous role in a DSO's decision to access smart meter data. Its context-dependent nature leaves room for interpretation by the DSO, creating a grey area. What one stakeholder considers a legitimate interest may not be viewed the same way by another. This makes legitimate interest both a powerful and complex factor in deciding whether to access smart meter data.

Loop outcome: lose-lose situation and increased risk on privacy violation

The outcome of this loop is more disadvantageous than that of the first loop. In addition to the continued presence of a feedback situation, where smart meter data is accessible only due to a legitimate interest in the case of a critical LV grid state, there is also a higher 'Actual risk of privacy violation.' This increased risk arises from the flexible interpretation of the AVG, which allows for a wide range of interpretations, possibly leading to less strict adherence to the AVG.

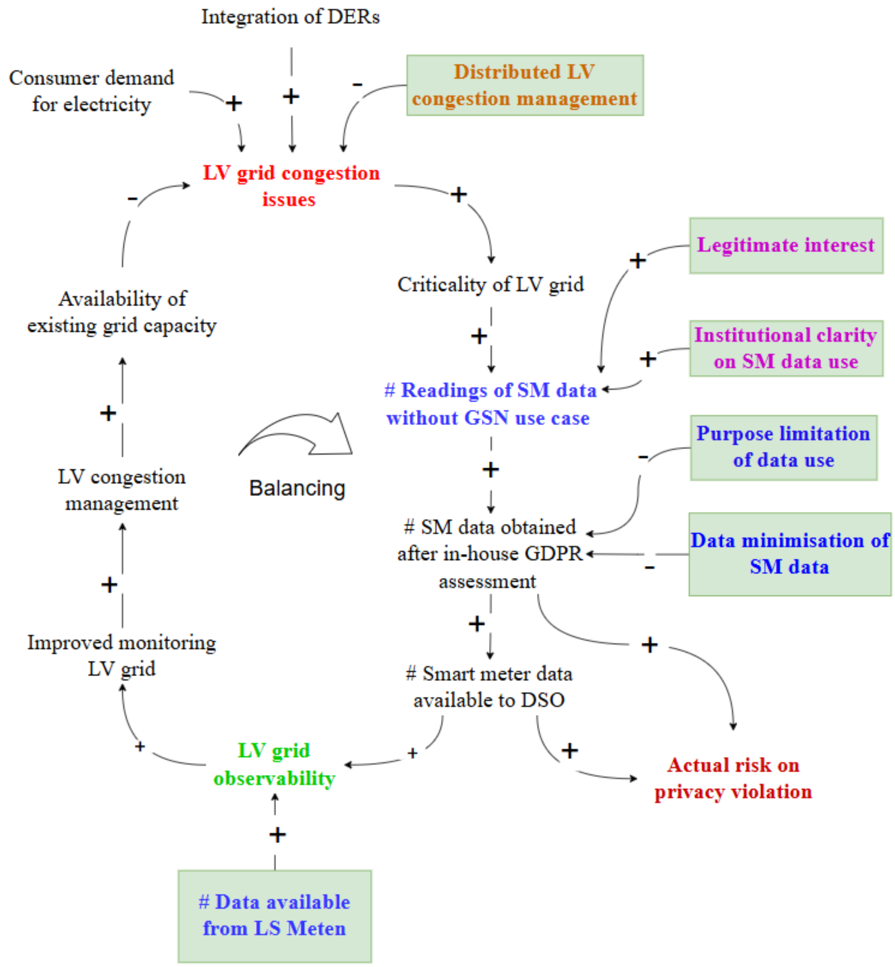

Figure 9.4: The 'smart meter access without GSN' loop

9.4. Loop 3: 'SM access with consent'

The third loop indicates that the ’# Smart meter data available to DSO’ can be directly increased through consumer consent, as represented by the variable ’Differential consent for SM data use DSOs.’ However, within this CLD, this variable is part of a balancing feedback loop. This means that continuous efforts are required to initiate and sustain changes in consumer consent, which is represented by ’Differential consent for SM data use DSOs’.

Loop description

- As the ’# Smart meter data available to DSO’ increases, the ’Actual risk on privacy violation’ will increase as it entails personal data and the risks for privacy violation cannot be mitigated to zero.
- If the ’Actual risk on privacy violation’ increases, there will inevitably come events that violate privacy, represented by ’# Privacy violating events’.
- privacy violating events have a severe impact on society represented by ’Societal impact of privacy violation’ which will lead to more ’Negative attention in the societal and political debate to data sharing’.
- Negative attention in the societal and political arena will increase the feeling of unsafety among data owners. Therefore, the ’Perceived privacy risk by society’ will increase which will have negative impact on the extent to which data owners will be prepared to provide differential consent for SM data use, represented by ’Differential consent for SM data use DSOs’.
- Consequently, this will lead to decreased ’# Smart meter data available to DSO’.

External factors explained

The external factors represented in the CLD are means that DSOs can apply to intervene in the balancing CLD. Therefore, this section will be elaborated in the conclusion of this report.

Loop outcome: 'differential consent'

The most important insight created by this loop is that an increase in available smart meter data (’# Smart meter data available to DSO’) for DSOs has negative feedback due to inevitable privacy risks. By showcasing this, it becomes clear that smart meter data and privacy risks are two elements that go hand in hand. There are means to mitigate the risks, but most of the means incorporate the reduction of data, which will come at the cost of the usefulness of smart meter data for increasing observability or other grid operation practices. PETs reduce privacy risk. However, once PETs are breached, personal data can still leak, making it a controversial solution.

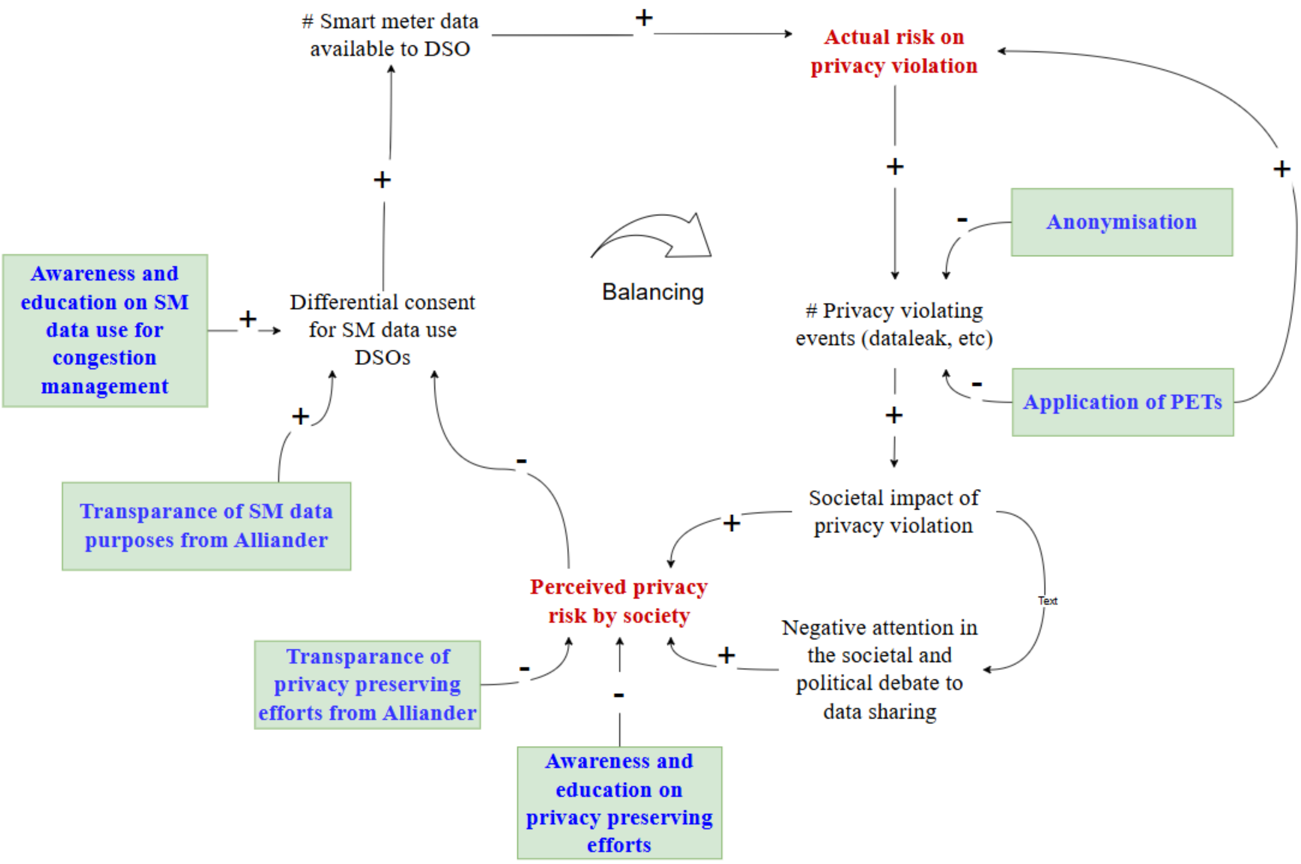

Figure 9.5: The 'smart meter access with consumer consent' loop

9.5. Conclusion sub-question 6

This section provides the concluding answer to sub-question 6:

SQ6: What insights can be learned for increasing observability on the low-voltage grid by applying Systems Thinking to the Relevance Cycle's system requirements into an artefact?

The CLD teaches several important insights about implementing observability on the LV grid using smart meter data. First, a conclusion on the outcome of the loops is presented, followed by a detailed explanation of the selected means that can influence the three loops. An important notion is that the identified means are sometimes closely related or an actionable version of the stakeholders' interests.

9.5.1. Insights from the CLD loops

The loops identified each create options for DSOs for increasing observability.

Loop 1 identified the current lose-lose situation that obstructs DSOs from obtaining smart meter data that enables Alliander to proactively detect and solve congestion. Meanwhile, data is infringed regardless of solving grid issues when the grid becomes too hazardous.

Loop 2 identified the lose-lose situations where DSOs access smart meter data without following the GSN use cases, increasing the risk of privacy-related issues since the DSOs themselves do privacy assessments.

Loop 3 shows that differential consent from data owners depends on the public debate, which heavily depends on how data owners perceive and experience privacy risk.

9.5.2. Interplay between CLD loops

The trade-off between smart meter observability and privacy, identified during the analysis of stakeholders' values and interests, becomes evident at the point in the CLD where the three loops intersect. It demonstrates that increasing the availability of smart meter data, which benefits DSOs, inevitably raises the 'actual risk of privacy violations,' which can be hazardous to data owners.

9.5.3. Available means for DSOs

Lobbying for new use cases

DSOs can indirectly enhance observability by lobbying for additional GSN use cases. This means directly impacts Loop 1 of the CLD. By applying pressure on the Werkgroep GSN Use Cases, as well as on Privacy Officers and Data Protection Officers, DSOs can emphasize their legitimate interest in accessing specific smart meter parameters, such as power levels, for congestion management. In response, the Werkgroep GSN Use Cases can then evaluate this interest and determine the appropriate levels of data aggregation and the required time intervals between measurements. This way, observability can be increased.

Accessing smart meter data without consent or GSN use case

DSOs can also choose to access smart meter data without consent or a GSN use case to increase observability, directly impacting Loop 2. However, DSOs remain obligated to comply with the AVG, so they must ensure legitimate interest, purpose limitation and data minimisation. This means must be applied under the strict supervision of Alliander's privacy officers.

Transparency, Education and awareness for consumer consent

Data owners' differential consent for using smart meter data remains a powerful tool for obtaining access to smart meter data and enhancing observability. This means makes a direct impact on Loop 3. The CLD suggests that transparency regarding the purposes and security of smart meter data can positively influence differential consent for its use. However, transparency alone does not guarantee that data owners fully understand the purposes of smart meter data usage or how their data is secured. Therefore, DSOs should also focus on educating data owners, helping them understand why DSOs need smart meter data and demonstrating the effectiveness of the measures taken to mitigate privacy risks. By not only ensuring transparent communication but also raising awareness and educating data owners about data purposes and safety measures, DSOs can increase differential consent for smart meter usage, thereby enhancing LV grid observability.

Application of PETs

Another means to alter the performance of Loop 3 is implementing more technical Privacy Enhancing Technologies. These technologies can reduce privacy-violating events, build more trust in the social debate and political arena, and reduce the perceived risk by society, leading to more differential consent and, thus, observability.

9.5.4. Available means for policy-makers

More flexible interpretation of legitimate interest

The AP is the authority that ultimately decides on the legitimacy of smart meter data use, including the appropriate levels of aggregation and time intervals. Legitimate interest is a significant factor in the GSN process, especially for DSOs accessing smart meter data without GSN or explicit consent. A more flexible interpretation of legitimate interest could allow DSOs more access to smart meter data, resulting in more observability.

Approving more GSN use cases

Increasing observability by increasing the number of GSN use cases directly impacts Loop 1 and increases the observability. This would require the GSN Working Group and data officers to approve more use cases concerning reading smart meter power levels, along with agreeing to shorter measurement time intervals and lower levels of data aggregation.

Providing institutional clarity

The grey area caused by the intersection of the relevant institutions makes it difficult for DSOs to assess when they truly have a legitimate interest in accessing smart meter data. Greater institutional clarity would enable DSOs to better assess whether they can access smart meter data when they perceive a critical grid issue, even if a specific use case has not been approved yet. This measure would primarily affect Loop 2, providing DSOs better grips for AVG assessments and reducing their reliance on GSN use case approvals. However, the GSN was designed to provide institutional clarity, so this solution would be redundant.

10 Validation and Evaluation

The solutions for increasing observability proposed in this research must be validated and evaluated with the key stakeholders to understand their viability and effectiveness. To validate whether a reinterpretation of the legitimate interest of the AVG is a viable option, there must be a validation with AP, the Dutch data protection authority. Also, the ACM will be involved during the validation of the result because the ACM oversees whether Alliander fulfils its public duty as DSO. The AP and ACM oversee and ensure compliance with the GSN use cases. Therefore, these stakeholders are crucial to verifying the results of this research. Due to time constraints, only the validation with AP and ACM were executed. Therefore, the results of the validation and evaluation of the AP and ACM are reported in this thesis. For Alliander and the GSN Working Group, only the description of the intended validation is provided.

10.1. Autoriteit Persoonsgegevens

The AP is the governing body responsible for overseeing compliance with the AVG. Therefore, validating with a privacy professional of the AP is crucial. The validation was done by presenting the outcomes of this research, but mainly the outcomes concerning legitimate interest. First, the setup of the validation and evaluation process is provided, and then the results containing the results provided by Respondent P are presented.

10.1.1. AP Validation and Evaluation Setup

During the validation and evaluation at the AP, the following means was addressed: *'More flexible interpretation of legitimate interest'*. This measure proposes a re-interpretation of the AVG, specifically for obtaining a legitimate interest for accessing smart meter data. While this is a controversial measure, it may be necessary given society's strong dependence on a well-functioning LV grid infrastructure. During the validation, it was essential to discuss whether an alternative interpretation of the AVG is even feasible. In particular, it must be validated whether the AVG can adapt to evolving technical and societal standards. This validation should be done in cooperation with an AP.

10.1.2. AP Validation and Evaluation results

Throughout the research, the assumption was made that the 'legitimate interest' was an important driver in obtaining access to smart meter data. However, during the validation, the AP pointed out that the *legitimate interest* is a rather rigid element in the AVG that does not allow for re-interpretation. Instead, grid operators must base their actions on a *legal basis* to gain access to smart meter data, as outlined in the Elektriciteitswet 1998, not on legitimate interest.

There are specific criteria for establishing legitimate interest. The legitimate interest must directly impact an entity's own interests. In the case of Alliander, accessing smart meter data serves the general public interest rather than a private interest. Therefore, Alliander cannot completely rely on legitimate interest to gain access to smart meter data. Moreover, the interest must be immediate and current. Therefore, using legitimate interest to access smart meter data to prevent potential future congestion is not applicable. According to Respondent P, the only legal grounds that Alliander can rely on are the legal basis for managing the grid provided by the GSN use cases, the Elektriciteitswet 1998 or obtaining differential consent from the data owners. Furthermore, it has been agreed in the GSN that legitimate interest cannot be used as the basis for DSOs to access smart meter data. Unfortunately, this important restriction was not discovered during the literature review, desk research, or interviews.

According to AVG, a legal basis is required to process personal data. This legal basis can be provided by the Elektriciteitswet 1998 only if the purpose for which the smart meter data will be used falls under the legal duties of the DSO described by the Elektriciteitswet 1998. It does not specify what kind of data may be used to manage the grid. If it is determined that preventive measures fall under the DSOs' legal duty and personal data is required to fulfil this duty, then it would be possible to obtain a legal basis to access certain smart meter data on that basis, provided that strict necessity is assessed and all other safeguards are met. This leaves room for interpretation regarding what society considers to fall under the legal duties of the grid operator. Lastly, concerning the interpretation of *data minimisation* and *purpose binding*, this is very context-specific and should be considered per case with privacy officers. However, a broader interpretation of what society deems falls under the DSO's legal duty would strengthen the legal basis for grid management, allowing DSOs to potentially argue for reduced data minimization and less strict purpose limitation.

In conclusion, the room for interpretation is not in the legitimate interest of the AVG but in the legal basis obtained from the Elektriciteitswet 1998. If DSOs want to obtain a legal basis for processing personal data, like smart meter data, then they need a stronger legal basis provided by the Elektriciteitswet 1998. This can be achieved by re-interpreting the Elektriciteitswet 1998 and rediscussing what tasks fall under the responsibility of the DSOs.

10.2. Autoriteit Consument en Markt

The ACM is a key stakeholder in this process because it ensures DSOs meet their legal obligations under the Elektriciteitswet 1998. Moreover, ACM plays a key role in approving GSN use cases. The results from the research will be validated and evaluated by discussing them with the ACM.

10.2.1. ACM Validation and Evaluation Setup

The approval of new GSN use cases is, among others, supervised by the ACM. Therefore, to verify whether the solution *Approving more GSN use cases* must be validated with the ACM. Moreover, the ACM is responsible for ensuring that DSOs appropriately apply the Elektriciteitswet 1998. After validating the findings with the AP and gaining insights into the reinterpretation of the DSOs' public duty, these new insights must also be validated with ACM.

10.2.2. ACM Validation and Evaluation results

According to Respondent P, it is important that DSOs can perform their legal duty to keep the LV grid safe, reliable and affordable as described by the Elektricitietswet 1998. When there is an application requiring smart meter data that aligns with the legal duties of the grid operator, the AVG should never be an obstacle to accessing that data. DSOs should not be hindered from fulfilling its public duty if there are no viable alternatives. For example, as long LS Meten is not fully enrolled, providing DSOs access to 15-minute smart meter power levels is important for Alliander because it must know the energy use and distributed production to manage congestion and ensure a reliable grid. By making a solid argument as to why Alliander needs that specific data, it can obtain a legal basis for processing smart meter data. in conclusion, if the DSOs think they can make a strong argument for accessing more smart meter data, then they should make a request for a use case. However, the AP finally decides whether there is a legal basis for processing personal data. So, a broader interpretation of whether DSOs have a legal basis for processing personal smart meter data must be discussed in a broader deliberation with the key stakeholders, including the AP. However, Respondent P suggests requesting more use cases that push the boundaries of the AVG to stimulate discussion about use cases that enable more smart meter data access.

10.3. Alliander's privacy office

During the validation and evaluation at Alliander, the following means must be addressed: *'Lobbying for new use cases'*, *'Accessing smart meter data without consent or GSN use case'* and *'Transparency, Education and awareness for consumer consent'*. The validation and evaluation should involve collaboration with both the privacy desk and the system operations department at Alliander.

For validating *'Accessing smart meter data without consent or GSN use case'* and *'Lobbying for new use cases'*, including the privacy desk is essential because it ensures compliance with AVG. The privacy desk understands the risks and safeguards the handling of personal data. For means involving data access without explicit consent, their expertise is critical in assessing whether these means align with privacy requirements and their feasibility. On the other hand, Alliander's system operations department brings technical expertise and operational insights, understanding how these means would practically impact grid management and improve observability. System operations especially understand what use cases have priority in lobbying for improving grid management and solving congestion. Together, these departments provide a balanced evaluation, ensuring that the proposed means enable the appropriate use cases or smart meter data but are also legally compliant.

The validation and evaluation of the means *'Transparency, Education, and Awareness for Consumer Consent'* should involve the market services department at Alliander because this department has a direct connection to consumers and a thorough understanding of consumer behaviour. They can educate consumers on why and how their smart meter data may be used and help design messages that align with consumers' values to encourage differential consent. Alliander's privacy desk can also play a role in this process by providing education on the privacy implications of smart meter data.

10.4. Gedragscode Slime Netbeheer Working Group

To validate the means of *'Approving more GSN use cases'*, it is essential to assess with the GSN whether options exist to enhance productivity in the use case approval process. As the GSN is a relatively new organisation with the approval process still developing, unresolved inefficiencies may still be present. This validation process should examine whether there is potential for improving productivity in a way that aligns with the current standards and goals.

11 Discussion

During the discussion, the research results are interpreted and put into perspective regarding the problem. First, the main findings concerning the challenges to values, interests, and institutions are elaborated. Then, the shortcomings of the GSN use cases are explained. Then, the technical means that improve privacy are explained, and consequently, the institutional routes for increasing observability are elaborated. After providing institutional ways to increase observability, an extensive elaboration is provided on how the sector must organise its stakeholders to re-interpret the established institutions and how stakeholder engagement can be improved.

11.1. Immediate Challenges and Institutional Trade-offs

Increasing observability to manage congestion better is a wicked problem not solved by implementing a single intervention. The LV grid case involves overlapping institutions and interdependent stakeholders with differing values and interests. Therefore, most solutions introduce new challenges or leave some unresolved, making solving this problem a complex exercise.

Since the introduction of smart meters that generate personal data, new privacy-related values and interests were introduced to the LV grid system. The values and interests that emerge from the interaction between the stakeholders form a stringent trade-off between increasing observability and privacy preservation. This trade-off divides the data owners and Alliander in their perspective on whether smart meter data must be shared for congestion management.

In the LV grid system, divided by this strict trade-off, the established institutions do not provide enough guidance to reduce the complex relationship between the DSOs and data owners regarding smart meter data access. Moreover, they form an overlap, creating an institutional grey area, making it complex to assess in what context smart meter data access is permissible for DSOs. The Elektriciteitswet 1998 creates a legal basis for DSOs to perform efficient, reliable and affordable grid management. The AVG approves access to personal data for specific cases: when there is a legal basis for processing personal data or legitimate interest. However, the AVG also states that if alternative methods are available that do not require personal data use, these alternatives should be prioritised according to the AVG. From the perspective of DSOs, alternative methods for congestion management are no longer considered efficient, reliable, or cost-effective, rendering them unviable. Therefore, DSOs consider themselves to have a legal basis and legitimate interest in accessing smart meter data for congestion management practices. However, from the perspective of the data owner and AP, as long as alternative options are available, these must be applied. Privacy security is a priority, even if that means that DSOs must work less efficiently and less cost-effectively. The differences in perspectives on the institutional grey area concerning these institutions create tension and frustration between the grid operating departments, privacy officers and the AP. This complicates determining the contexts in which DSOs may access specific smart meter data parameters, including the appropriate level of aggregation and measurement time intervals.

11.2. GSN shortcomings

The GSN was introduced from the desire to increase smart meter-based observability for LV grid management and to provide guidance in the institutional grey area. It provides use cases and specific contexts for when certain smart meter parameters may be accessed, including the appropriate level of aggregation and time intervals.

From the literature research, the GSN seemed to be a fitting solution to help DSOs navigate through the institutional grey area. However, from the interviews, it can be derived that DSOs find the GSN to be a slow, cumbersome approval process for use cases. Moreover, it still lacks use cases that allow access to the smart meter's power-level data, which is required for congestion management. It exclusively contains use cases that enable smart meter data access to voltage levels to fix voltage-related issues, making the use cases useless for congestion management. Congestion management requires power-level data. Therefore, the GSN falls short of increasing smart meter-based observability for congestion management. Moreover, the yet-approved use cases exclusively provide access to smart meter data to resolve current LV grid issues.

An important example of this can be found in the LS Meten and Basmati cases. The issue of LV grid congestion initially manifests in the MSRs, as these are the critical nodes where the LV feeders converge with the MV feeders. To monitor these critical nodes in the Lv grid infrastructure for overloading, the LS Meten project is employed and installed, aiming to provide all MSRs with measuring equipment. However, for Alliander, the deployment of LS Meten cannot keep pace with the rapid progression of congestion. To address this, Alliander developed an alternative service to monitor the MSRs: a smart meter-based observability-increasing service known as the Basmati project. However, as Basmati relies on power-level data from smart meters, a GSN use case is required before deployment. This use case must enable the extraction of 15-minute interval power-level data aggregated across a minimum of 5 smart meters. Although this use case had not yet been approved during Basmati's development, Alliander proceeded with its development to showcase its effectiveness in congestion management and to demonstrate its capability to preserve consumer privacy. Now, this use case is close to being officially approved as a GSN use case.

From the Basmati example, two important lessons can be drawn. The first lesson drawn from this example illustrates that use cases tend to receive approval reactively, based on feedback after issues have occurred, rather than proactively to prevent such issues. This is an issue because this increases the risk of outages and might require DSOs to access smart meter data anyway to fix these outages. In other words, Alliander's congestion management failed, and privacy preservation failed, which is a lose-lose situation. Moreover, the Basmati use case has been approved to complement LS Meten for improved monitoring of the MSRs. However, as congestion issues shift from the MSRs deeper into the LV grid due to increased electrification, LS Meten will eventually become ineffective. At that stage, more granular smart meter data will be required to monitor LV grid congestion, necessitating the approval of new use cases with shorter time intervals or lower aggregation levels, and so on. This is an ongoing bug-fixing cycle, and Alliander cannot build solid solutions based on this feedback mechanism. This first lesson highlights the need for use cases that provide extensive access to smart meter data that enables grid innovations while preserving the data owner's privacy. Examples from the literature that can potentially contribute to this are homomorphic encryption and multi-party computation.

The second lesson is that when DSOs test and develop services that may impact privacy but improve grid and congestion management, they can help secure approval for new supporting use cases. For example, with the Basmati project, DSOs were able to demonstrate both its effectiveness and privacy-preserving features. This approach increased the likelihood that the GSN Working Group would ultimately approve a supporting use case. This mechanism should not be exclusively applied to Basmati but to any innovation that can bridge the gap between smart meter-based observability and privacy. This lesson highlights why Alliander must put effort into developing solutions that preserve privacy and enable smart meter data access. For instance, PETs like homomorphic encryption. Even though encryption is not used because it cannot be applied as an argument for data processing according to the AVG, when the LV grid becomes more hazardous, more drastic measures are required and will eventually be societally accepted.

11.3. Opportunities for PET-based Innovation in Observability

This research defines PETs as all technological innovations that prevent data from being traced back to specific individuals, thereby ensuring that personal identities remain protected. This section elaborates on the technical interventions that Alliander could perform to increase observability on the LV grid.

11.3.1. Anonymisation

When Alliander accesses smart meter data for any purpose, anonymization is applied wherever feasible. This is especially important for power-level data from smart meters as this can expose personal habits of energy use. However, anonymisation is not as easy as removing personally identifiable attributes from the data. After reducing personal attributes, like names, individuals can often still be traced back based on other attributes, like addresses. Moreover, even when all personal attributes are deleted from the data, data sets can be combined to trace back individuals. Also, anonymization can reduce the effectiveness of data for certain applications. For example, in congestion management, as congestion penetrates further into the LV grid, DSOs need precise location information to identify problem areas accurately. Anonymisation measures like removing location-specific attributes, such as street names or house numbers, increase privacy but can limit their ability to manage congestion effectively. The more the data is anonymised, the less effective the data set becomes for congestion management on the LV grid. Therefore, the effect of anonymisation on the trade-off is as follows: as anonymisation is applied more, privacy increases, but observability decreases because the data granularity decreases, losing essential information. Keeping more personal attributes in the data increases the chance for re-identification of individuals, which forms a great risk to data owners. Therefore, anonymisation is in solid interplay with the AVG. Following the AVG, the risks of applying anonymisation are mitigated. However, anonymisation can still be a great solution for obtaining access to smart meter data for purposes that do not require highly granular data, like congestion management on the MSR level. For the safe application of anonymisation and to mitigate and balance the risks, privacy officers must always guide its application. This way, one keeps a human in the loop to verify the proper application of anonymisation. To increase safety technically, anonymisation should always be implemented in parallel with other PETs, such as aggregation.

11.3.2. Aggregation

Aggregation is an effective PET that Alliander implements in Basmati or other cases when power levels of smart meter data must be accessed for emergency reasons. The required level of data aggregation for congestion management depends on the specific grid level at which congestion issues arise. As congestion issues arise at lower grid levels, finer data aggregation becomes necessary, increasing potential conflicts with the AVG due to the increased risk of re-identification. Aggregating the smart meter data by applying lower time intervals between the measurements can expose the personal habits of data owners, which also forms a risk. Therefore, to overcome these risks, the applied level of aggregation should always be discussed with the privacy officer. The permitted aggregation levels depend on the legal basis for data processing from the Elektriciteitswet 1998. Aggregation faces the same issue as anonymisation concerning the trade-off between observability and privacy; the higher the aggregation, the more privacy, but the less useful the data becomes for congestion management on the LV grid. Therefore, Alliander should anonymisation and aggregation in parallel for more secure data processing.

11.3.3. Encryption methods

In the literature research, Wang et al. (2023) described that encryption methods can significantly benefit sharing energy data. During the interviews, encryption was also praised for its effectiveness. However, currently, encryption methods are not used by Alliander, as encryption alone does not provide a decisive justification for the collection and processing of personal data under the AVG and Elektriciteitswet 1998. Moreover, under the current obligations for high aggregation and strict anonymisation, data encryption would be a redundant measure. However, implementing encryption could offer significant benefits to DSOs for grid management, as it would enable lower aggregation levels and shorter time intervals without risking individual traceability in the data.

A suitable encryption method from the literature is homomorphic encryption. This is a cryptographic technology that allows computations to be performed on encrypted smart meter data without decrypting it first. Smart meters must encrypt the data before sending it to the DSO. After the data is sent to DSOs, they can perform necessary computations directly on this encrypted data. This might include summing up energy usage across a neighbourhood, identifying peak load times, or estimating demand. Throughout its entire lifecycle within the DSO's systems, individual smart meter readings are never decrypted. Therefore, individual energy usage patterns and identities remain hidden, preserving data owners' privacy. However, encryption methods are not yet extensively used. This is because, currently, high levels of aggregation and anonymisation are applied following the GSN and AVG, making encryption redundant. Following these institutions, the fact that encryption is applied can not be an argument for obtaining access to personal data. This is because there is always a risk that unauthorised entities succeed in decrypting the data, leading to privacy and safety issues. However, encryption methods are becoming safer and more secure. Therefore, its potential must not be ignored. Moreover, applying homomorphic encryption increases privacy and, therefore, provides a solution to permitting lower levels of aggregation and anonymisation. This means that homomorphic encryption can enable safe processing of large volumes of data. This means that homomorphic encryption can both address increasing smart meter-based observability and increasing privacy. This starkly contrasts with anonymisation and aggregation, which can only prioritize either privacy or observability, but not simultaneously. This makes homomorphic encryption even more relevant and should, therefore, be further explored and developed. To increase privacy and trust when applying homomorphic encryption, Alliander could use homomorphic encryption in combination with a central data collection unit governed by an independent, trusted third party. This way, the security of the smart meter data can be centrally and uniformly governed. Moreover, by introducing an independent entity with no interest in using data owners' smart meter data, the data owner's trust can be increased.

First, smart meter data must be encrypted and sent to the central unit. Encryption can be done by compatible smart meters, or the central unit must encrypt the raw, unencrypted data after receiving it. The smart meter data can be stored in a secure, centralised database managed by a trusted third party or within the DSO's secure infrastructure. Since data remains encrypted, even the trusted third party hosting the data cannot access or process the data, aligning with AVG requirements. Meanwhile, DSOs can access the centralized data storage through a secure interface to perform computations for congestion management tasks on the encrypted data without needing to move or replicate it. Homomorphic encryption can also be combined with aggregation and anonymisation to enable increased granularity while keeping the secure aspects of aggregation and anonymisation.

Homomorphic encryption can be valuable to Alliander for using smart meter data for grid congestion management while preserving the data owners' privacy-related values and interests. Considering the urgent need for better congestion management, it is incomprehensible that high-potential solutions like homomorphic encryption remain underexplored. Especially since it is known that the boundaries for using personal smart meter data tend to stretch as grid congestion worsens, this is the right time to experiment with solutions that may seem drastic now but will soon be essential, such as encryption. Alliander must explore and experiment with PETs like homomorphic encryption to demonstrate their effectiveness to the GSN Working Group and AP. This way, new use cases can be lobbied for and developed. Therefore, this report will propose in the Recommendation how Alliander can empower this implementation of encryption-based methods.

11.4. Institutional mechanisms

Institutions should always accompany the application of new technology. This is also the case for PETs, which facilitate increasing smart meter-based observability. However, in this case, the established institutions governing privacy-enhancing technologies need a different interpretation to empower the PETs to work according to the system's requirements. This section elaborates on the shortcomings the established institutions, how the interpretation of the established institutions can be tweaked for increased smart meter- based observability and what can be expected of relevant future institutions.

11.4.1. Re-interpretation of existing legislation

To increase smart meter-based observability for congestion management, Alliander must ideally obtain permission to use power levels of smart meter data with lower aggregation levels and less anonymisation for more cases. This permission is pre-determined by the GSN or privacy officers and finds its basis in the Elektriciteitswet 1998 and AVG. The permission for access to smart meter data with a certain level of aggregation and anonymisation is based on three aspects: whether there is a legal basis for processing of personal data, purpose limitation and data minimisation.

First, per case, the GSN or privacy officers assess to what extent there is a legal basis for processing smart meter data based on Alliander's legal obligation to perform its legal duty, established in the Elektriciteitswet 1998. According to the AVG, this legal basis is required to access smart meter data. To increase smart meter-based observability, Alliander must obtain a legal basis for more use cases to access more smart meter data. This can be arranged through the Elektriciteitswet 1998 by broadening the interpretation of what falls under the legal duty of the DSO. For example, if Alliander first had a legal basis for accessing smart meter data to resolve instant grid issues. A new interpretation could be that Alliander can obtain a legal basis for accessing smart meter data, not for instant issues, but to develop services to resolve future grid issues. The stronger the legal basis for processing smart meter data, the stronger the legal arguments that Alliander has for lower levels of aggregation or less anonymisation. During the Validation and Evaluation with Respondent A of the AP, it was confirmed that assigning a broader interpretation of the legal basis is not impossible, provided that the other AVG safeguards are met and if it is strictly necessary. The extent to which it is necessary to process the data requires thorough deliberation with key sector stakeholders.

Second, once a legal basis for processing personal data is obtained using the Elektriciteitswet 1998, Alliander can access smart meter data. However, purpose limitation still limits the purposes for which Alliander may use smart meter data. If Alliander can use a data set for multiple purposes, then this can increase observability. For instance, under a broader scope, Alliander could use smart meter data not only for billing purposes but also for grid monitoring. Therefore, observability also depends on the scope of purpose limitation. If purpose limitation is interpreted more flexibly with broader scopes, then Alliander can increase observability on the LV grid.

The last limiting factor of the AVG is data minimisation, which limits the amount of smart meter data that Alliander may use for specific purposes. Data minimisation, among others, directly impacts the level of aggregation enforced by privacy officers. To increase smart meter-based observability, data minimisation could be interpreted less strictly, enabling more data available for congestion management. For example, when the time interval between data points is reduced, the total amount of data points is increased, increasing granularity and usefulness for congestion management.

In conclusion, increasing data granularity and observability by reducing the level of aggregation and less anonymisation is a matter of re-interpretation of the Elektriciteitswet 1998 and the AVG. Reevaluating established law is not something a single entity can achieve overnight, as it would undermine the rule of law, which is highly valued in the Netherlands.

Re-interpretation of established institutions to increase observability inevitably impacts privacy, posing disadvantages for data owners. However, neither the Elektriciteitswet nor the AVG explicitly addresses emerging PETs like encryption. These technologies offer the potential to increase observability while simultaneously preserving data privacy. However, its implementation may require a technical, institutional and organisational redesign. Nonetheless, Alliander must begin exploring these methods. While the Elektriciteitswet 1998 and the AVG lack provisions for encryption methods, the new Energiewet could provide room to incorporate these solutions. This will be discussed in the next sections.

11.4.2. The new Energiewet

The Elektriciteitswet 1998 will be entirely replaced by the new Energiewet in January 2025, which modernizes and updates regulations for the electricity and gas markets. However, this law was still under construction during this research, and therefore, to avoid confusion, its contents were not incorporated into this research. However, since this law is still under construction, it offers opportunities to propose adjustments based on insights from this research. Under the Elektriciteitswet 1998, DSOs can explicitly obtain a legal basis for processing personal smart meter data for urgent grid situations. Suppose it is impossible to obtain a broader interpretation of the DSO's legal duty under the Electricitietswet 1998; in that case, the legal duty of the DSO could be redefined more broadly in the new Energiewet. This way, DSOs could be granted a legal basis to obtain more smart meter-based observability for more cases and improve congestion management.

Another topic not embedded in the Elektriciteitswet 1998 or the AVG is the encryption of smart meter data. During the design of Elektriciteitswet 1998 in 1998, PET was not as far developed as it is now. It is, therefore, a true shortcoming for not coming back on these methods, while encryption has the potential to increase observability without directly impacting privacy. The new Energiewet could provide more guidance for encryption-related technologies by permitting DSOs to use these methods for congestion management.

11.4.3. The AI Act

Although Alliander has not yet implemented AI for congestion management, it is essential to explore its potential applications, as the emerging trend of AI is likely to bring along opportunities in congestion management. Therefore, proactively considering the AI Act is necessary when exploring opportunities for increasing congestion management. The new legislation provided by the AI Act can create new barriers that limit Alliander's adoption of high-potential technology. AI systems that influence critical infrastructure like energy grids will fall under the high-risk category in the AI Act, particularly because they impact essential services affecting public safety and energy security. This means congestion management systems using AI must comply with strict requirements from the AI Act regarding safety, reliability, and transparency. Moreover, AI systems for congestion management will most likely rely on smart meter data. The AI Act mandates high-risk category systems to perform strict data governance. This is to ensure the data feeding into AI algorithms is accurate, representative, and unbiased to avoid hazardous malfunctions or unfair behaviour of AI models. Working with smart meter data also increases the need for additional privacy and data protection. This is crucial given that congestion management using AI systems may also involve analyzing usage patterns at a granular level. However, this will inevitably hinder the adoption of AI-based congestion management methods, as they must also comply with AVG regulations. Methods like anonymisation, aggregation, and encryption can be empowered to facilitate data protection and improve the adoption of AI methods for congestion management. Moreover, the AI Act requires human oversight for high-risk AI applications, ensuring there is always an option for human intervention in critical decisions. For congestion management, this could mean that grid operators retain control over final decision-making, with the AI system operating as a recommendation or alert system rather than making autonomous decisions.

In conclusion, for Alliander, the AI Act introduces an additional regulatory layer that may pose further challenges to compliance. To address this, Alliander must proactively clarify which applications qualify as AI. This should happen not only within Alliander but also across the whole sector. This way, new emerging institutional grey areas can be prevented. These issues must be addressed in a broader discussion with the key stakeholders in the sector.

11.5. Broad deliberations for re-interpretation of institutions

The lobby for new GSN use cases was a solution found during this research. However, this solution exclusively reflects the interests of the DSOs. Therefore, one-sided lobbying might infringe on democratic principles. If the GSN is to be used to increase smart meter-based observability, then a more inclusive approach must be applied. As described earlier, the re-interpretation of well-established institutions must never happen overnight. It requires broad deliberation on existing laws to assess how they can contribute to increasing smart meter-based observability. These deliberations should allow all core stakeholders to weigh the potential benefits against privacy concerns, ensuring a balanced approach to institutional adaptation.

In re-evaluating the trade-off balance between increased observability and privacy, all key stakeholders, both those influencing and affected by this trade-off, should be actively involved in the deliberations. The AP must be involved as this entity ensures enforcement of the AVG. Together with a privacy advocacy organisation like Privacy First, the AP must protect the interests of the data owners during these deliberations. The ACM must ensure that DSOs fulfil their legal duty as described by the Elektriciteitswet 1998 and should also be involved during the broad deliberations. The GSN Working Group and Alliander's privacy officers are the entities that must operationalise a newly established balance in the trade-off between privacy and increased smart meter-based observability. Therefore, these entities must be involved in the deliberations about new interpretations of established institutions. Finally, the system operators of Alliander and other DSOs are crucial to involve because they can assess what advancements in congestion management can be made with increasing obtained observability. It is essential to involve system operators and privacy officers of both Alliander and other DSOs to incorporate a broad range of perspectives. The MFFBAS is an entity where energy data sharing is discussed and promoted. This organisation serves as a central forum that brings together key stakeholders in the energy sector who either possess data to share or need access to specific data. Currently, on the MFFBAS forum, only large commercial energy consumers and energy producers are connected to exchange energy-related data. However, because the MFFBAS is an established institute, its experience in hosting the discussion on sharing energy-related data can be of great use in facilitating the deliberations and finding a new balance in the trade-off between privacy and increased smart-meter-based observability. Outcomes of prior conflicts between actors on the MFFBAS forum can guide the discussion about sharing smart meter data with DSOs. Furthermore, MFFBAS possesses a data-sharing infrastructure that can function as an independent data storage unit for conducting pilots with promising emerging PETs, such as homomorphic encryption. Moreover, the MFFBAS can provide a platform for the key stakeholders to engage with data owners. This way, values and interests can be exchanged, and discussions about the interpretation of the established institutions can take place. Also, pilots for testing new technology or policies can be arranged using this platform.

The primary goal of uniting these key stakeholders is to address the pressing concern expressed by DSOs that, under the current institutional interpretations, they cannot make the grid resilient for future demands due to the bug-fixing nature of the approved use cases. One must not forget that the root cause of the LV grid congestion problems lies in the changing electricity use of the energy consumer. To keep up with this changed behaviour and ensure reliable energy provision, implementing solely new technologies does not suffice. The institutions that shape actor behaviour must be revised to achieve a system performance that satisfies all stakeholders. In prior sections, the lose-lose situation was explained under the current application of the established institutions. However, the proposed efforts must turn the system performance towards a win-win situation.

To achieve a win-win situation, the two opposing stakeholder groups, the DSOs and the data owners, must both find a ”win” in the new situation. To the data owner, personal privacy is at stake. However, due to the increased demand for electricity, not only privacy is at stake, but energy provision is also at stake. Moving forward, under the current interpretation of the established institutions, DSOs could maintain current privacy levels. However, in that case, energy reliability will decrease drastically as LV grid congestion evolves over time; this would be a great loss. However, this scenario can be prevented by exchanging a bit of privacy by letting DSOs access lower aggregated power-level data from smart meters. This way, outages can be prevented and sudden smart meter data extraction to resolve sudden issues can be prevented. Although a small amount of privacy is infringed in advance, outages can be prevented, and energy reliability can be maintained, this is a win for the data owners. A ”win” is achieved for the DSOs if they can keep a reliable, cost-effective and safe energy provision. This is their legal obligation described by the Elektriciteitswet 1998. If DSOs cannot adhere to this, the ACM will penalise them. Therefore, they need both technological and institutional developments to safeguard their public duty.

Achieving the ”win” for DSOs is relatively straightforward. They primarily need more access to smart meter data, specifically power levels. In contrast, securing the ”win” for data owners is more complex, as it involves a compromise: granting DSOs access to their smart meter data entails a concession on the part of the data owners. Therefore, a structured approach is required during the deliberations with the key stakeholders in MFFBAS.

The first and most urgent challenge to be addressed is verifying whether observability can be increased following the established institutions. This can be done by re-evaluating how the energy sector might alter the interpretation of the Elektriciteitswet 1998 to obtain a legal basis for data processing for more cases and the AVG to obtain access to more data. For the energy sector, the GSN Working Group aims to provide a uniform interpretation of both the Elektriciteitswet 1998 and the AVG by approving the GSN use cases. Therefore, during the broad deliberations, the key stakeholders must make concessions on how the institutions can be interpreted less strictly to enable more smart meter data access. The new interpretations must then be established in the GSN code of conduct. For example, DSOs can be permitted to access power levels of smart meter data in more cases. Establishing the new interpretation of the Elektriciteitswet 1998 and AVG in the GSN is the most straightforward option because the GSN was specifically designed for the energy sector. Moreover, multiple independent parties oversee the approval process of new GSN use cases, making the GSN a fair means for unambiguous interpretation of the established legislation. This will also satisfy the interests of the AP and privacy-advocating organisations since the GSN provides in a fair process. After concessions are made, the GSN Working Group should apply this new interpretation when they approve new use cases because the GSN Working Group is the entity that must execute this new interpretation. This way, new use cases can contain, for example, power levels of smart meter data with low levels of aggregation when DSOs need this for LV grid congestion prevention measures. However, any reconsiderations and concessions made during deliberations must be approved by the AP, as privacy is a fundamental value that should not be unnecessarily infringed upon, except when it serves a clear public interest. Moreover, even after agreeing on new interpretations of the AVG and Elektriciteitswet, checks and balances must be built in by default. That means that it must always be possible to revise the re-interpretations once they are not appreciated or require further adjustment. Therefore, AP should closely monitor the types of complaints that arise concerning the sharing of smart meter data with DSOs. These complaints should be carefully examined and discussed as they could provide feedback on how the established institutions are interpreted. This way, a safety mechanism can be built to safeguard fair enforcement of the AVG and Elektriciteitswet 1998.

The second challenge that must be discussed within the same deliberations is how the sector should respond to new emerging legislation. The advent of the new Energiewet and the AI Act will inevitably lead to new complexities concerning congestion and grid management. The suggestions priorly mentioned, like re-interpretation of the established legislation, redefining the legal duty of DSOs and the application of encryption, are topics that require ongoing discussion as the institutional landscape evolves. Therefore, during the deliberations, the elements of new legislation that might impact the operation of the LV grid must be proactively discussed to prevent the emergence of new grey institutional areas.

The third challenge stems from the second lesson drawn from the Basmati example: DSOs must be granted space and resources for LV grid innovation. Implementing drastic measures, such as encryption methods for large data volumes, may not be necessary immediately. However, future challenges that DSOs will face remain unclear. Therefore, extensive testing and piloting are crucial to developing and preparing drastic technological measures. Homomorphic encryption is a promising method, according to the literature research. However, given the current use of high levels of aggregation and anonymisation, implementing homomorphic encryption would be redundant now. However, once lower aggregation levels and less anonymisation are permitted by new GSN use cases, then homomorphic encryption might become very relevant. Or homomorphic encryption could even function as a prerequisite for lower aggregation levels and less anonymisation.

Therefore, the technology and infrastructural adjustments must be already developed and tested. This exemplifies the urgent need for piloting and testing for DSOs. Under the current institutions, there is no room for extensive testing of technology that can directly or indirectly contribute to improved congestion management. In the broad deliberations, it is also essential to reconsider how DSOs are granted smart meter data access to innovate and develop solid solutions that will be required in the future. For example, the new Energiewet could include clauses that enable DSOs to test with small amounts of high-granular data without the data owner's permission under the supervision of the GSN or AP. This way, DSOs can technologically keep ahead of the congestion problems.

11.6. Stakeholder Engagement

Re-interpretation of the institutions is only possible if this new interpretation reflects the values and interests of the stakeholders. Therefore, the values and interests of the stakeholders must be brought together and aligned. However, there are no democratically responsible solutions that can immediately alter stakeholder's values and interests. Therefore, efforts must be put into educating data owners to explain why their data is valuable for congestion management and the benefits for all stakeholders. If data owners understand the benefits, the chance of their interests changing in favour of LV grid management can increase. This can be achieved by piloting with the data owners and discussing the pilot results.

Doing consent-based pilots with small groups of data owners has three advantages. First, by performing consent-based pilots, Alliander can test advanced technologies with smart meter data for which no GSN use cases exist. Neither does the AVG apply once consent is provided, which enables unrestricted use of smart meter data. Second, by sharing the test results and educating the data owners about the purposes of the pilots, stakeholder engagement can be increased as data owners become acquainted with the new technology. This way, the pilots can build trust between data owners and stakeholders, altering data owners' privacy-related interests concerning sharing smart meter data. Also, Alliander can gauge the actual values and interests of the data owners. This information on the data owner's values and interests can be used during deliberations with the sector's key stakeholders. Third, the pilot results and the stakeholder engagement can be used during the deliberations with the key stakeholders. Successful pilots can be used to showcase that data owners' interests have changed and that a new interpretation of established institutions is required to reflect the new interests of the data owners in the GSN. Ensuring that the key stakeholders engage with data owners by piloting and education can be arranged using the MFFBAS platform. This solution will be operationalised in the Recommendations.

11.7. Alignment with related work

In the related work, Wang et al. (2023) emphasized that sharing energy data is essential for transitioning to a sustainable energy system. This assumption was confirmed through interviews conducted during this research. Data sharing enhances observability, facilitating improved congestion management and better integration of DERs. Also, Wang et al. (2023) stresses the importance of PETs for sharing energy-related data. PETs are effective solutions to secure smart meter data. Aggregation and anonymisation proposed by Souri et al. (2014) are fitting for the smart meter data case. However, the level of data aggregation is indirectly governed by the principle of 'data minimisation,' which remains subject to the interpretation of AVG, highlighted in this research as an obstruction to increasing observability. This makes it less effective as a clear solution for increasing observability. Wang et al. (2023) also proposed encryption methods like homomorphic encryption for sharing energy-related data. However, implementing homomorphic encryption requires institutional adjustments to make it beneficially operational as it requires granular data collection by DSOs, making them sensitive to privacy infringement in case of data breaches.

Also, during the research, system operations departments emphasized that, from a technical standpoint, they can manage the expected grid congestion if they are granted access to more smart meter data. However, as Kunneke (2018) argues, the development of such technical advancements must be accompanied by evolving institutions that can support these changes. This statement also applies to this research, as an institutional shift is needed to enable these technical advancements. Moreover, as the urgency for better congestion management and technological capabilities evolves, stakeholders' values also evolve. For instance, adopting smart meters for congestion management introduces the privacy values and interests of data owners. However, Milchram et al. (2018) highlights that the societal acceptance of new technologies, such as the use of smart meters for congestion management, is not determined solely by their technical feasibility. Rather, it is deeply influenced by the values and interests of the stakeholders involved. This research agrees with this statement because smart meter data is not yet fully accessible to DSOs, although technically, the opportunities for accessing and using it are feasible. To deal with the changing stakeholder values considering grid operations, the GSN was introduced as a regulatory framework to facilitate the implementation of smart meters. This aligns with Kunneke (2018)'s argument that institutions must evolve in tandem with technological progress. However, simply having the technical capability to use smart meter data for congestion management is insufficient to ensure societal acceptance. Just like Milchram et al. (2018) points out, societal acceptance of technology is dependent on the core values of stakeholders. However, in the case of smart meter data, the values and interests of stakeholders, particularly DSOs and data owners, are in significant conflict, leading to a trade-off between increasing grid observability and safeguarding data owner's privacy. This conflict complicates the creation of institutions that are acceptable to all parties. According to Milchram et al. (2019), institutions should emerge from the evolving values and interests of the stakeholders. Yet, the current GSN seems to predominantly reflect the values of data owners, leaving the values of DSOs underrepresented, like operational efficiency. Consequently, based on Milchram et al. (2019)'s assumption that institutions must reflect the changing values and interests of all stakeholders, the current institutional framework appears incomplete. This highlights the need for further institutional development that balances both privacy concerns and the operational needs of DSOs.

11.8. Reflection on Research

11.8.1. Effectiveness of the Research Approach: DSR

The related work emphasized incorporating stakeholder interdependencies between the technical landscape, institutions, and stakeholder values into the research. Structuring these system requirements can be a complex process. However, DSR provided a solid framework for collecting system requirements through the relevance cycle, using various methods like interviews and literature research. Once the requirements were collected, they were structured using theory from the Rigor cycle. This approach laid a strong foundation for analyzing the problem. In this regard, DSR was highly beneficial. However, DSR typically involves the creation of actionable tools that can be directly implemented in practice. In contrast, the artefact produced in this research primarily focused on explaining and mapping the current system. While it offers a concise yet clear overview of the existing problem, it does not fully meet the criteria for DSR as outlined by Hevner (2007). However, this research does propose a recommendation which can be regarded as the final artefact of the Design Cycle.

11.8.2. Effectiveness of the Research Methods: Systems Thinking

The Systems Thinking approach offered a structured way to integrate the technical landscape, institutional context, and stakeholder values and interests. Moreover, it contributed to visualising the interrelations between the system's components. This approach allowed for the identification of valuable insights into how stakeholders' interests influence different loop outcomes and how the three balancing loops in the system can be affected. However, this research gathered a wide range of values and interests, making it difficult to incorporate them all into one figure. As a result, only the most relevant interests were included to avoid confusion and ensure the figure remained clear and comprehensible. However, this does not mean the not-incorporated interests have no impact on the system's outcome.

11.8.3. Additional research limitations

A significant limitation of this research is that the values and interests of data owners were derived from interviews with organisations and stakeholders representing a general perspective. This approach offers a somewhat superficial view of how society perceives DSOs accessing smart meter data for grid congestion management, potentially overlooking diverse opinions and nuances within the broader population. For example, there is a possibility that some data owners may actually support providing DSOs access to their smart meter data. Future research can address this limitation by directly engaging with a broader and more diverse sample of data owners rather than relying solely on organisations and stakeholders that provide a generalised perspective. This can be achieved by applying methods like surveys, focus groups, or interviews with data owners. Suppose future findings suggest that the balance between privacy concerns and the operational needs of DSOs is not overly skewed toward privacy. In that case, there are grounds to reconsider the GSN and grant DSOs more open access to smart meter data.

Another source of confusion in this research is that some interests identified during the relevance cycle through interviews and literature review are also presented as means for increasing observability. This overlap makes the report difficult to follow, as it is sometimes unclear whether a particular point refers to stakeholder interests or actionable means.

This research was mostly performed using resources from Alliander, such as respondents. It allowed for a time-efficient research process, but it also caused limitations. Although one DSO-related respondent was from Stedin, most other respondents were from Alliander. This might have caused a bias towards the need for smart-meter-based observability in general. This can be attributed to the fact that Alliander has fewer measuring sensors installed in its grid infrastructure than other DSOs, which may amplify the perceived severity of the observability problem. Future studies should incorporate a broader range of perspectives of DSOs beyond Alliander to mitigate the potential bias identified in this research.

Another limitation of this research is that the literature sources did not always focus specifically on data sharing at the household level but rather on data sharing between businesses, as exemplified by the insights from Wang et al. (2023). This limitation arises from the scarcity of research directly linking observability with AVG and Elektriciteitswet considerations at the household level.

12 Conclusion

The objective of this research was to address the existing gap in the academic literature on identifying obstructions and opportunities for increasing smart meter-based observability on the LV grid by applying a holistic approach. This approach incorporates the technical and institutional aspects of the system as well as the values and interests of the data owners and DSOs. The results were derived through literature research, desk research, and interviews with important sector stakeholders. Furthermore, the findings were validated and evaluated in collaboration with AP and ACM, two governmental regulatory bodies overseeing personal data processing and LV grid management, respectively. This chapter will summarise the research findings and conclude with recommendations and potential future research directions.

12.1. Main findings

This research was motivated by emerging developments like electrification and integration of DERs, which increasingly cause grid congestion. DSOs in the Netherlands have the legal duty to manage the LV grids to keep them reliable, safe and affordable. To address this, more granular smart meter data is required to enable data-driven congestion management. Accessing and using smart meter data for congestion management is a controversial measure. While smart meter data can potentially improve grid congestion management, it might also expose data owners' energy use patterns, revealing personal habits. However, grid congestion is increasingly becoming a critical problem and threatening the reliability of energy provision. Therefore, DSOs are eager to use smart meter data to increase LV grid observability and improve congestion management. However, certain measures are subject to established and upcoming regulations. This limits DSOs from processing smart meter data, leading to a lose-lose situation, with worse congestion management and data owners risking unplanned access to smart meter data when DSOs must access smart meter data for emergencies. Furthermore, incorporating smart meter data introduces new privacy-related values and interests, making implementation more complex. Most academic research has been conducted on developing technical measures to improve privacy, such as PETs. Although promising technology-based solutions for increasing observability exist, established institutions and opposing values and interests obstruct their application for increasing observability and remain underexplored. The LV grid system is highly complex and contains intertwined technical, institutional, and social components. Critical interdependencies that obstruct increasing smart meter-based observability can be identified by embracing this complexity and applying a Systems Thinking approach. By understanding the system's complexities obstructing smart meter-based observability, recommendations can be synthesised to solve them and turn this lose-lose situation into a win-win. These two elements were captured in the main research question that formed the spine of this research:

MRQ: What are the barriers to increasing smart meter-based observability on the low-voltage grid and how to overcome them?

12.1.1. Conflicting Values and Interests

The issue of increasing observability on the LV grid for improved congestion management is a multifaceted challenge involving complex, diverse stakeholder values and interests. Due to the integration of smart meters that handle personal data, new privacy-related values and interests have emerged, adding layers to the already controversial balance between operational needs for increasing smart meter-based observability and privacy preservation.

To overcome this barrier and increase smart meter-based observability, solutions must address the diversity in values and interests. This can be achieved by extensive stakeholder engagement, transparency, educating data owners about the need for congestion management, and learning from feedback provided by the data owners.

12.1.2. Technical challenges

The application of aggregation and anonymisation cuts both ways. While aggregation and anonymisation are privacy-enhancing methods that allow DSOs to access smart meter data, they also reduce the usefulness of the data for congestion management by limiting the data's granularity. This means that when applying aggregation or anonymisation, one is forced to make a trade-off between increasing observability and improving privacy. This complicates its application and feeds the discussion on which aspect of this trade-off should get priority.

However, PETs that use encryption to enhance the privacy of smart meter data do not necessarily have to pick a side in this trade-off. The level of aggregation or anonymisation of the smart meter data is less of an issue because the data is encrypted. Especially when applying homomorphic encryption, where the data does not have to be decrypted for processing. Experimentation and piloting with homomorphic encryption have been limited within Alliander but should be expanded to ensure that, as congestion worsens, these measures are fully developed and ready for implementation. Moreover, positive pilot outcomes can increase the chance of obtaining approval for new GSN use cases.

12.1.3. Institutional challenges

The institutional barriers to increasing smart meter-based observability primarily arise from the strict trade-off between LV grid observability and the data owner's privacy. The Elektriciteitswet 1998 establishes a legal basis for DSOs to access and process smart meter data, a prerequisite for compliant data processing under the AVG. However, the institutions do not provide clear guidelines on the specific contexts and types of smart meter data that may be processed, leaving room for interpretation regarding what falls under the legal duty of the grid operator to manage the LV grid effectively. Moreover, the AP would rather have DSOs to use to use alternatives that do not involve personal data processing. However, sometimes alternatives are just time- and cost-effective. The GSN aims to provide a uniform interpretation of the Elektriciteitswet 1998 and AVG by uniformly applicable use cases. However, an examination of the approved use cases under the current interpretation of established institutions shows that approvals are only granted for use cases that address issues reactively based on a feedback mechanism, leading to a lose-lose for both DSO and data owners. Immediate action is needed to reassess how the GSN interprets the Elektriciteitswet 1998 and AVG because new legislation, such as the Energiewet and AI Act, is emerging and may introduce additional institutional challenges.

To overcome current institutional challenges, re-interpretations of the established institutions must be deliberated to enhance smart meter-based observability while remaining compliant with institutional obligations from the AVG and Elektriciteitswet. This re-interpretation should be established under the code of conduct in the GSN. If the re-interpretation of the established institutions cannot increase smart meter-based observability, then the legal duty of DSOs, in general, should be redefined under the new Energiewet. This can be achieved by initiating broad deliberations with the sector's key stakeholders and discussing how the public duty should be redefined. Increasing stakeholder engagement can enable Alliander to use consent-based smart meter data to pilot new technologies or policies. These pilots can also be used to educate data owners and align values and interests.

12.2. Recommmendations

This section proposes two suggestions that Alliander can seize upon to operationalise the main findings from this research.

12.2.1. Operationalisation of Stakeholder Engagement by Broad Deliberations

To increase stakeholder engagement, it is essential to bring together the key stakeholders, including data owners, the GSN Working Group, the AP, the ACM, DSOs' privacy officers, system operators, and privacy advocacy organizations. These stakeholders must collaborate to develop new agreements on interpreting the existing regulations. This collective effort is crucial to address the pressing need for DSOs to gain greater access to smart meter data. MFFBAS should host a forum for broad deliberations between the key stakeholders. Its platform must be used to discuss and make new agreements on how the AVG and Elektriciteitswet 1998 are interpreted. Moreover, the organisation of MFFBAS could contribute valuable insights through its experience in addressing data-sharing challenges. The MFFBAS platform can also be used to engage with data owners and make arrangements for sharing smart meter data with the DSOs.

The most urgent issue for the stakeholders is making new agreements on how smart meter-based observability can be increased following established institutions. To achieve this, key stakeholders must agree on a shared interpretation of existing regulations that permit the approval of GSN use cases that allow DSOs to perform preventive congestion management. This way, the feedback-based mechanism of the current GSN use cases can be disrupted and transformed into a feedforward-based mechanism that allows for preventive congestion management measures. This can be achieved by adopting a broader interpretation of DSOs' legal duty defined by the Elektriciteitswet 1998. This allows them to establish a legal basis for processing personal data, which is required for compliant processing under the AVG. Moreover, the discussion must also reconsider a more flexible interpretation of data minimisation and purpose limitation for congestion management purposes. This way, DSOs are provided with increased smart meter-based observability, which they can use to improve congestion management. Also, this increases the reliability of energy provision. In return, headlong smart meter data readings for emergencies can be prevented, making this a win-win situation for both DSOs and data owners. During the deliberations with the key stakeholders, both the data owners and DSOs will have to make concessions on their values and interests. Only then can the stakeholders bridge the gap between privacy and observability and agree on new interpretations of the Elektriciteitswet 1998 and AVG. To enforce the new interpretations of established institutions consistently, the agreements for these new interpretations should be established in the GSN code of conduct. The values and interests of the stakeholders and the context in which institutions are embedded are constantly changing. Therefore, it is of utmost importance that during the deliberations, prior approved use cases that incorporate the new interpretation of established institutions are revised continuously. This discussion must be based on data owners' feedback on the new use cases and the privacy-related complaints filed with the AP. This way, a safety mechanism is in place to prevent use cases from causing hazardous situations if a use case fails to function fairly. Besides discussing the established institutions, relevant future institutions, like the new Energiewet and the AI Act, must be thoroughly discussed. Although the new Energiewet is not yet in effect, it is already possible to discuss which additions to this law could be relevant. A solid new addition to the Energiewet for Alliander would be to enable encryption-based PETs to permit lower aggregation levels for higher granularity data and increase both privacy and smart meter-based observability. During these broad deliberations, the key stakeholders must also proactively discuss how to act in advance on new potential grey institutional areas caused by the AI Act. Especially in case DSOs plan to leverage AI for congestion management.

The MFFBAS forum should also serve as a platform for increasing engagement between DSOs and data owners. Values and interests can be exchanged by discussing the implications of the trade-off between privacy and observability. Moreover, engaging with data owners allows Alliander to educate them about the purposes for which smart meter data is used and the measures taken to protect their data. This way, the values and interests of the data owners and DSOs can be aligned. The MFFBAS forum should serve as a hub where data owners can participate in open discussions or collaborate in pilots for testing new technologies and policies by providing differential consent.

12.2.2. Operationalisation of Homomorphic Encryption

Another solution discussed is homomorphic encryption. Although immediate implementation under the current institutional frameworks is yet redundant, it is crucial to begin experimenting with this technology because, as congestion problems increase, the need for solutions that provide privacy-responsible data sharing, like encryption, will inevitably become urgent. As the congestion issue increases, higher granularity of smart meter data is necessary, reducing the effectiveness of aggregation and anonymisation. A solid way to safeguard privacy is by applying encryption-based PETs like homomorphic encryption. First, Alliander should operationalise and test homomorphic encryption in pilots. The pilots should be conducted via differential consent with data owners directly engaged through the MFFBAS platform because these data owners have already expressed interest in the topic. To build trust, MFFBAS should host the collection of smart meter data from data owners who are willing to participate in pilots. This way, MFFBAS can function as a trusted third party that uses its existing ICT infrastructure to store the encrypted data available for piloting. The advantage of assigning the role of the trusted third party to MFFBAS is that MFFBAS has no conflicting values and interests with the DSOs or data owners. This can increase data owner's trust and confidence in fair data processing. The encrypted data should be available to Alliander and other DSOs so that experiments can be conducted that contribute to developing technologies and policies for mitigating congestion on the LV grid. A risk of using a trusted third party to manage large amounts of pilot data is that DSOs could use the data for purposes other than developing congestion-mitigating solutions. This potentially leads to unnecessary privacy risks, could reduce trust and spoil the process of aligning the values and interests of the data owners and DSOs. Therefore, to mitigate this risk, the privacy officers of the involved DSO must still oversee the piloting process to ensure that DSOs adhere to purpose limitations. At the same time, the AP should penalize any DSOs that fail to comply with these requirements for using smart meter data. The ACM must monitor whether the intended pilots serve the goal of mitigating congestion and whether the pilots are within the legal duty of the DSOs. During the pilots conducted via this construction, homomorphic encryption must be applied to ensure privacy when testing and developing this PET further within Alliander. Instead of addressing either privacy or observability, like anonymisation and aggregation, homomorphic encryption can positively address both aspects of this trade-off. Therefore, if homomorphic encryption is successfully implemented, both the DSO and the data owner will benefit as it enhances both privacy and observability. This creates a win-win scenario for both stakeholder groups. The pilots must generate enough feedback for further development. Most importantly, they should build trust between DSOs and data owners and align their values and interests, reducing the complexity of increasing smart meter-based observability. Moreover, by testing and developing, Alliander can show the effectiveness of homomorphic encryption, which is crucial in lobbying for GSN use cases or arguing for new clauses dedicated to smart meter data encryption in the new Energiewet.

12.3. Reflection on Main Findings

The most important challenge that society faces on the LV grid is grid congestion. Although the main findings of this research do not directly contribute to resolving congestion, they can indirectly contribute to increasing LV grid observability for improved grid monitoring. This enables DSOs' grid operators to prevent and manage grid congestion to increase the reliability of energy provision. Although actionable recommendations for Alliander were proposed in this report, the results clearly indicate that achieving increased observability on the LV grid still requires cooperation and concessions between the key stakeholders. Moreover, the main findings also highlight that increasing observability is a complex exercise requiring alignment of technology, institutions and stakeholder values.

12.4. Future research

This chapter outlines potential directions for future research based on the study's findings concerning the related work. While valuable insights were gained, several areas require further exploration.

12.4.1. Exploring Conflicting Stakeholder Values and Interests

This study applied a general assumption regarding data owners' values and interests. In reality, not all data owners oppose sharing data with their DSOs. Future research should assess societal perspectives on data sharing to uncover the extent to which data owners are willing to support DSOs in addressing congestion management challenges. This future research can contribute to understanding the feasibility of the means from this research, like re-interpreting the institutions or obtaining more differential consent from data owners. Future research must involve extensive data collection from data owners' perspectives by conducting surveys and performing a Q-Method analysis. This research method is used to statistically quantify people's subjective views, beliefs, and attitudes towards a particular topic. It combines qualitative and quantitative approaches like surveys and statistical tests to explore and analyze how data owners perceive issues like sharing energy consumption data with DSOs. The outcome of this research should offer more detailed insights into perspectives on sharing smart meter data with DSOs for congestion management. These could also provide valuable insights during the proposed broad deliberations with AP and the other key stakeholders on a reinterpretation of the AVG for increasing smart meter-based observability on the LV grid.

12.4.2. Exploring Distributed Congestion Management Opportunities

This research primarily focused on increasing observability. However, within the broader context, observability is merely a means to reduce congestion on the LV grid. This research revealed that the ability of Alliander to increase LV grid observability directly is a complex exercise. Moreover, Alliander's toolkit to respond in real time to grid congestion is limited. This raises the question of how much Alliander should prioritize solutions that focus exclusively on increasing observability. Moreover, it might be necessary to apply multiple approaches in parallel. For example, solutions that require less observability on the LV grid but contribute to reducing LV grid congestion are distributed congestion management solutions. Distributed congestion management solutions incentivise consumers and data owners to actively contribute to reducing the congestion issues on the LV grid. An example of such a solution is the implementation of flexible contracts. The advent of Home Energy Management Systems (HEMS) offers numerous opportunities to respond to flexible pricing actively, reducing grid congestion and saving consumer costs. Future research could also explore how implementing Battery Energy Storage Systems (BESS) can reduce congestion on the LV grid. The outcome of this research could provide insight into how Alliander can allocate its focus and resources over multiple congestion-reducing measures to reduce congestion more effectively.

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A Appendix: Interview Respondents

Respondent	Organization	Department
Respondent A	Alliander	Privacy Desk
Respondent B	Alliander	Market services
Respondent C	Alliander	Market services
Respondent D	MFFBAS	Board
Respondent E	Stedin	Gedragscode Slim Netbeheer working group
Respondent F	Stedin, MFFBAS	Board
Respondent G	Privacy First	Board
Respondent H	Logius	Architect data sharing standards
Respondent I	Alliander	System operations MV grid
Respondent J	Alliander	System operations LV grid
Respondent K	ACM	Legal council
Respondent L	Alliander	Digitalization
Respondent M	Alliander	Digitalization
Respondent N	Alliander	Asset and Product management
Respondent O	Alliander	Topology
Respondent P	Autoriteit Persoonsgegevens	Data Privacy