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Master Thesis

Asset Taxonomies to Enhance Strategic Decision-Making in Expanding Electrical Grid Capacity Using Existing Assets

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ABSTRACT

Until recently, the electricity grid could accommodate the transition towards more renewable generation and usage of energy. However, currently, the maximum hosting capacity of the grid is reached in large parts of the Netherlands. This hampers the growth and sustainability of the Dutch economy. Capital investment in new infrastructure is constrained by workforce shortages, prompting Distribution System Operators (DSOs), like Liander, to explore alternative solutions such as Dynamic Thermal Rating (DTR). This enables more efficient use of existing assets by adapting capacity limits based on real-time or forecasted conditions. Effective DTR implementation requires well-structured and coordinated Strategic Asset Management (SAMP), involving the integration of various initiatives related to thermal modeling, load forecasting, environmental and operational data monitoring and the incorporation of individual asset ratings into network simulations and decision-making processes.

This research investigates how an asset taxonomy, used to classify electrical grid components and associated initiatives, can serve as an architectural view to support strategic decision-making in enhancing the capacity of the electrical grid using existing assets. Through the application of the Design Science Research Methodology (DSRM), an asset taxonomy of the electrical grid, as operated by Liander, is developed. Existing DTR initiatives and relevant policy documents are mapped to this taxonomy. A workshop including a fictional case study within Liander's Asset en Product Management (APM) department was conducted, allowing for testing the taxonomy's ability to support strategic decision-making.

Responses to a survey conducted at the end of the workshop indicate that the taxonomy is perceived as clearly structured and useful for identifying gaps and avoiding redundancies between initiatives. However, its effectiveness in supporting impact assessment, collaboration and prioritization across the initiatives appears limited. Thus, while the results are promising, further refinement is needed to enhance the taxonomy's value as a strategic decision-making tool.

Keywords: Strategic Decision-Making, Strategic Asset Management Plan (SAMP), Asset Management, System Engineering, Asset Taxonomy, Dynamic Thermal Rating (DTR), Distribution System Operator (DSO)

CONTENTS

1 INTRODUCTION

Grid congestion is an increasing issue in the Netherlands. Caused by the energy transition, more and more electricity is consumed. A large contributor to this increase is the electrification of heating and transportation. Illustratively, the number of installed heat pumps is expected to increase by 300,000 per year, while the number of charging stations for electric vehicles is projected to increase from 500,000 to 2 million in 2030 [1]. In addition, industries are rapidly electrifying and require more and larger connections to the electricity grid. Thus, the demand of electricity is increasing across the board, resulting in a higher load on the transport and distribution grid.

Not only is the demand of electricity rising, the mismatch between loads and generation is also growing. A large share of the electricity in the Netherlands is supplied by weather-dependent sources, i.e. solar and wind energy [2]. Generally, the instances with high (renewable) energy generation have a low demand for electricity, and vice versa [3]. The mismatch between loads and generation can eventually lead to capacity and congestion problems in the distribution grid [4].

Until recently, the existing electricity grid could cope with the transition towards more renewable generation and usage of energy as the hosting capacity was not reached [5, 6]. However, currently, the hosting capacity is reached in large parts of the Netherlands [7]. As a result, construction projects are delayed, the growth of (new) economic activities is hindered and further integration of renewable energy sources is obstructed causing significant social costs [8]. Therefore, grid reinforcement is required. This involves, foremost, upgrading or rebuilding of transformer stations and reinforcing power lines [5, 9, 10]. This is a significant challenge for distribution system operators (DSOs), like Liander, which are responsible for maintaining a reliable transportation and distribution grid. The rate at which the grid can be reinforced is insufficient due to a limited availability of workforce [11]. Therefore, DSOs are looking for other (temporal) solutions to enhance the capacity of the grid in the short term. In case of Liander, this is where Dynamic Thermal Rating (DTR) projects come into effect.

Within the strategy of Dynamic Thermal Rating, the thermal limits of electrical assets are determined based on environmental conditions [12]. As these environmental conditions fluctuate over time, the limits of the assets become dynamic. In general, the dynamic limits found by implementing DTR are higher than the static capacity limits as specified by the manufacturer of the assets [12, 13]. Although the benefits of DTR are well established, its application has traditionally been limited to the transmission grid. Recently, however, there has been growing interest in extending the concept to distribution grids. This is an approach Liander is currently pursuing.

There are multiple initiatives within Liander related to increasing the capacity of the electricity grid while using existing assets, similar to the application of DTR. To achieve a comprehensive solution for enhancing grid capacity, these initiatives have to be integrated effectively [14]. However, identifying gaps or overlaps among these initiatives is challenging, making it difficult to ensure the alignment towards a cohesive approach. This challenge can be viewed as a form of strategic decision making, which in this case refers to the process of identifying, evaluating and selecting the most effective options to achieve organizational objectives. Consequently, there is a need for tools to support this strategic decision-making process.

This form of decision-making is closely related to the development and implementation of Strategic Asset Management Plans (SAMPs). These guide organizations in aligning asset-related decisions with their long-term objectives [15, 16]. SAMPs rely on a structured understanding of the asset portfolio to support integrated planning and prioritization. However, a unified framework to classify and evaluate assets and their associated initiatives in this context is currently lacking. As a result, decision-makers can struggle to compare initiatives, recognize synergies, or identify critical gaps in the current approach to grid capacity enhancement.

To support strategic decision-making in alignment with asset management principles, there is a need for a structured tool. Systems Engineering offers concepts that can help with this. Within Systems Engineering, a System of Interest (SoI) is defined as *"The system whose life cycle is under consideration in a particular project or context. It includes the system itself, as well as any enabling systems, interfacing systems, and relevant stakeholders"* [17]. Multiple views can be obtained from this SoI, each giving a different perspective of the system. In the context of SAMP and DTR, the views can be used to assess the current state of the initiatives linked to the relevant assets of the electrical grid.

As the implementation of Dynamic Thermal Rating typically starts with focusing on individual assets and gradually expands to the scale of the overall electrical grid, an architectural view of the System of Interest can be useful in defining and prioritizing the DTR initiatives in a structured way. Such an architectural view offers a high-level representation of the system's structure, showing how key components are organized and interact [17].

An asset taxonomy is defined as *"a structured classification of assets into hierarchical levels based on function and location"* [18]. Therefore, it can be used to systematically classify and organize the components of the electrical grid and the associated DTR initiatives and thus serve as an architectural view of the system.

However, traditionally, asset taxonomies have been used for purposes like asset classification, inventory management and maintenance planning. Asset taxonomies as a tool for strategic decision-making are understudied. Specifically, there is insufficient exploration of how a tailored taxonomy can systematically classify assets and research initiatives, providing a unified platform for strategic thinking. The gap in existing research is substantiated in Chapter 2, where relevant literature is reviewed.

This research aims to bridge the gap by creating a taxonomy that classifies Liander's assets such that it enhances the strategic alignment and effectiveness of ongoing initiatives related to increasing the capacity of the electrical grid using existing assets.

1.1 Research question

To address the research gap described previously, the research question guiding this study is:

How can an asset taxonomy support strategic thinking in increasing the capacity of electrical grids using existing assets?

The research will be guided by the following sub-questions:

- *What is an effective way to represent a taxonomy of the assets involved in the electricity grid of Liander?*
- *How can the various initiatives related to the load capacity increase with existing assets be mapped to the taxonomy?*
- *Does the taxonomy support strategic thinking in increasing the load capacity of the existing electricity grid?*

1.2 Approach and thesis outline

The research described in this report has followed the design science research methodology (DSR) [19, 20, 21]. It is an iterative process in which the following six activities can be distinguished, various feedback loops within the activities can be implemented.

1. Problem identification and motivation
2. Definition of objectives for a solution
3. Design and development of artefacts
4. Demonstration of solving the problem by implementing the artifact
5. Evaluation of the solution
6. Communication of the problem

A foundation for the problem identification and motivation has already been made in this chapter, it will be substantiated in Chapter 3 as more context from literature is provided. In Chapter 4, the research approach is further elaborated on. It starts with providing organizational context for the remainder of this research in Section 4.1, followed by a more in-depth explanation of the DSRM process in this research in Section 4.2. Chapter 5 introduces the asset taxonomy as designed, while the validation of this design in a workshop incorporating a case study is presented in Chapter 6. In Chapter 7, a reflection on the achievement of the design objectives is presented. In Chapter 8 an interpretation of the results, the contribution of the research to existing research and limitations of the conducted research are discussed. Finally, the research is concluded in Chapter 9.

2 STATE OF THE ART

Building on the problem outlined in Chapter 1, this chapter explores the current understanding and application of Strategic Asset Management Plans (SAMPs) as a central element in aligning asset information with long-term organizational objectives. While Chapter 1 identified the difficulty of organizing asset data to effectively inform strategic planning, this chapter examines the state of the art in asset management literature to assess how this challenge has been addressed to date. By reviewing key concepts, frameworks, and research themes related to SAMPs, this chapter identifies the gap that this study aims to address — namely, the lack of a structured approach to selecting and organizing asset information for strategic decision-making.

2.1 Strategic Asset Management Plan

An Asset Management Plan (AMP) is a form of documented information that outlines the specific activities, resources, costs and timescales required for managing an individual asset or group of assets, in order to meet an organization's asset management objectives [15]. In contrast, a Strategic Asset Management Plan (SAMP) provides a higher-level framework that aligns the organization's asset management policy, objectives and strategies with broader business goals [15]. The SAMP can essentially be seen as a planning tool [16]. The SAMP defines the overall approach for developing and managing both the asset portfolio and the asset management system. It establishes priorities and practices that guide decision-making over the long term, taking into account organizational needs, stakeholder expectations, and current asset capabilities. The SAMP thus serves as a critical link between the organization's high-level business strategy and the detailed, tactical actions outlined in individual AMPs.

Figure 2.1 shows how the SAMP is located at the core of the asset management framework. It links the high-level organizational strategic plan and the asset management policy with the more detailed asset (life cycle) management plans. The SAMP encompasses both the development of asset management plans and the strategic development plan for asset management capabilities. These strategic directives guide the operations related to asset life cycle stages.

Effective asset management, and thus successfully implementing a strategic asset management plan, has various benefits [16]. The primary outcomes of effective asset management are the realization of value and the achievement of organizational objectives. A systematic approach to asset management offers additional benefits, including enhanced *assurance* meaning better organizational oversight and accountability. This ensures that the right decisions are being made, appropriate resources allocated and that assets can meet required performance levels over their lifespans. More specific benefits of proper

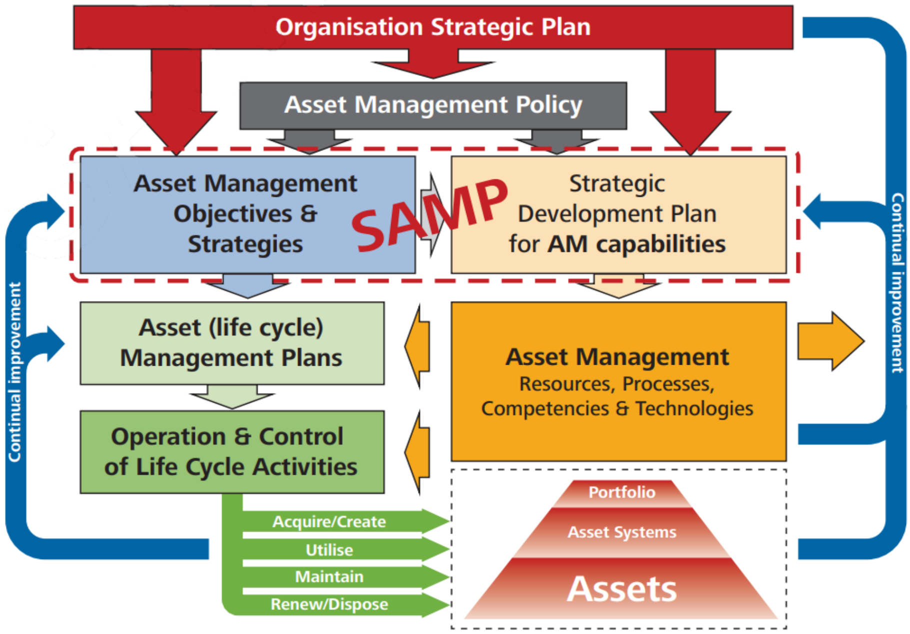

Figure 2.1: Primary elements of an asset management system (adapted from: [16])

asset management can be described as well, for this research relevant aspects are described here [16]. Asset management supports *better decision making* as it leads to greater rigor, clarity and consistency in the use of data and the evaluation of alternatives. It also improves *risk and opportunity management* by enabling organizations to systematically identify, assess and control them. Furthermore, asset management promotes *coordination and communication*, like collaboration, understanding and alignment across all areas of the organization.

In order to achieve those aforementioned benefits, understanding the current condition and performance of assets is essential [16]. The existing assets and asset systems represent the 'as-is' starting point for creating a SAMP. It begins with identifying what assets and systems exist. However, this is not sufficient. To inform effective decision-making, knowledge of asset conditions, capabilities, risks and criticalities is necessary. Assets vary in, among others, type, age, function, location and usage. Organizing and selecting the relevant asset information to be included in the SAMP is challenging. Where do you start? What information would best contribute to the SAMP? Where do you stop, both in terms of volume and detail? The information included in the SAMP will have to be selective. Criteria such as *summary of asset portfolio*, *state of the assets* and *supply and demand of assets* can be used to guide the collection of information [16].

2.2 Research gap

From the previous section, it follows that while a Strategic Asset Management Plan plays a structured role in aligning organizational strategy with asset-level decisions, a significant challenge remains in effectively translating the current state of assets into actionable strategic insights. As discussed previously, understanding the 'as-is' condition of assets is crucial for developing a SAMP. However, achieving this requires a structured, consistent framework for organizing the relevant asset information in a way that supports strategic analysis and decision-making aligned with the organizational objectives.

A scoped literature review of existing research on SAMPs has been performed to investigate whether there is a structured framework for organizing asset information that facilitates strategic decision-making. A search for articles containing *"strategic asset management plan*"* in the title, abstract or keywords on *scopus.com* gave sixteen relevant articles. A high-level analysis is performed on these articles. Summaries of these articles can be found in Table 2.1. Subsequently, the articles have been grouped based on shared research themes. The results of this clustering are displayed in Table 2.2.

From Table 2.2 it can be seen that despite there is literature addressing various aspects of strategic asset management, ranging from planning maintenance to evaluating the performance of the SAMP, there is no literature focusing on how asset information should be structured in a way that support the creation of a strategic asset management plan. Specifically, the literature lacks frameworks for classifying and structuring asset data that are linked to strategic decision-making within Strategic Asset Management Plans. The research, as presented in this report, will address this gap by focusing on the structured classification of asset data to support strategic decision making related to organizational goals.

Table 2.1: Summary of reviewed articles

Article ID	Citation	Title	Authors	Key Themes / Keywords	Summary / Notes
A1	[22]	Strategic asset-management planning	D. Stewart et al.	Asset information systems, asset life-cycle, data processing	This article focuses on the management of assets, which involves systematic planning, acquisition, deployment, use, control, and decommissioning of capital assets.
A2	[23]	Saskatchewan bridge management from a spatial perspective	D. Watt et al.	Functional redundancy, bridge maintenance, inspection, GIS	In this article, a strategic plan to develop a methodology to manage the prioritization of maintenance plans with consideration for sustainability and both existing and proposed service levels related to bridges is presented.
A3	[24]	Assessing asset integrity in the water industry - A UK perspective	S. De Rosa	Investment planning, risk-based, assessment methodologies	This article discusses strategic asset management techniques, assessment methodologies and investment planning models aimed at managing water supply infrastructure performance.
A4	[25]	Development and implementation of an asset management framework for wastewater collection networks	R. Younis and M. A. Knight	Strategic management, business intelligence, multi-perspective approach	This paper introduces a framework for developing, implementing and communicating a multi-perspective asset management plan incorporating socio-political, opererational/technical and regulatory perspectives.
A5	[26]	Dealing with internal inspection uncertainty in pipeline integrity management	S. Turner and M. Uloko	Inspection data, measurements, maintenance and replacement	This article focuses on dealing with errors in inspection data to ensure safe operation, while enabling long-term planning for maintenance and replacement.
A6	[27]	Introduction to an asset management program development methodology	J. Zeb and H. Nasir	Infrastructure management, strategic planning, Asset Management Program Development Methodology	In this research, an approach for effectively creating and managing infrastructure asset management programs is introduced. It ensures efficient development, implementation and continuous improvement.
A7	[28]	Development of strategic asset management planning in the petroleum industry	M. Kusumawardhani et al.	Asset Integrity Management, strategic planning, risk management	In this paper, the evolution and implementation of strategic Asset Integrity Management planning in the petroleum industry is examined. It focuses on the processes involved in formulating an AIM strategic plan.

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Article ID	Citation	Title	Authors	Keywords	Summary
A8	[29]	Multi criteria decision model for risk assessment of transmission and distribution assets: A hybrid approach using analytical hierarchy process and weighted sum method	B. Chattopadhyay and A. Rodriguez	Multi-criteria decision model, analytical hierarchy process, decision-making model	This article proposes a hybrid multi-criteria decision model (MCDM) combining the weighted sum model (WSM) and analytical hierarchy process (AHP) to prioritize risks for assets in the electric power industry. The method applied to a strategic asset management plan provides a solution to asset risk ranking.
A9	[30]	Infraestruturas de Portugal experience on developing a strategic asset management plan	M. M. Pinheiro	Performance management, stakeholder expectations, long-term planning	In this paper, the importance of a strategic asset management plan is discussed. It emphasizes its role in aligning the organization's asset management efforts with business goals and stakeholder expectations.
A10	[31]	Developing a dynamic interactive strategic asset management plan for wastewater facilities using rapidly emerging business analytics tools and techniques - A case study at City of Houston	P. Pradhan and F. Rabbi	Business intelligence, utility management, decision-making tool, asset life-cycle	This paper describes the City of Houston's initiative to update its asset inventory and condition assessment for its wastewater infrastructure. A methodology for updating the SAMP, including a dynamic decision-making tool for asset life-cycle analysis is developed.
A11	[32]	Integrated RAMS, LCC and Risk Assessment for Maintenance Planning for Railways	A. Thaduri and U. Kumar	Life Cycle Costing, Risk Assessment, RAMS	in this article, an integrated methodology for maintenance decision-making is proposed. The methodology incorporates Reliability, Availability, Maintainability and Safety, Life Cycle Costing and Risk assessment into the planning process. It introduces a framework for applying these components across different planning levels.
A12	[33]	Optimizing the life cycle of physical assets through an integrated life cycle assessment method	J. de Almeide Pais et al.	Life Cycle Assesment, econometric model	This paper introdyces a new econometric model for evaluating the Life Cycle Assessment of physical assets, integrating maintenance, technology upgrades, and sustainability investments to assess asset depreciation and replacement time.

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Article ID	Citation	Title	Authors	Keywords	Summary
A13	[34]	Over 10-years of Houston's Digital Transformation Journey led by Domain Specialists - Lessons Learned	F. Rabbi and . Pradhan	Informed decision-making, databases, long-term strategic plan	This paper discusses how the City of Houston utilizes the Advanced Infrastructure Analytics Platform to support strategic asset management and decision-making. The platform integrates a wide range of internal and external data sources to provide insights for improving operations, planning and long-term strategic asset management.
A14	[35]	A BIA-Based Quantitative Framework for Built Physical Asset Criticality Analysis under Sustainability and Resilience	M. Aghabegloo et al.	Multi-attribute decision making, criticality analysis, prioritization	This paper introduces a framework for criticality analysis of physical assets, combining assets based on sustainability, resilience and business continuity. A case study demonstrates how the framework can guide asset management planning by identifying key assets.
A15	[36]	Measuring the Performance of a Strategic Asset Management Plan through a Balanced Scorecard	J. E. de-Almeida-e-Pais et al.	SAMP performance, Key Performance Indicators, asset management objectives	In this article, a tool for measuring the performance of a SAMP using a Balanced Scorecard, which align organizational objectives with asset management goals and support the achievement of these goals. The BSC framework helps track performance, ensuring the SAMP evolves in response to internal and external changes.
A16	[37]	Life Cycle Investment in the Water Sector – a Case Study	J. E. de-Almeida-e-Pais et al.	Life Cycle Investment, Econometric models, asset value	This paper explores the use of an econometric model to evaluate the life cycle of assets, emphasizing the balance between initial investment, maintenance costs and profits. It highlights the importance of managing assets to increase their value while incorporating risk and availability factors. A case study is presented.

Table 2.2: Thematic clustering of articles

Cluster ID	Cluster Name	Theme Description	Assigned Articles	Key Insights
C1	Strategic maintenance planning (framework)	These articles focus on developing strategic asset management frameworks that support the planning of maintenance of assets.	A1, A4, A6, A7, A9, A10	Emphasis on multi-perspective planning frameworks and alignment with business goals; strong focus on implementation strategies and long-term value creation.
C2	Prioritization of asset management via risk-based models	This cluster includes papers that focus on risk-based asset management using structured models.	A3, A8, A14	Use of multi-criteria and analytical decision models (e.g., AHP, MCDM) to prioritize assets based on risk, resilience, and sustainability.
C3	Life Cycle Costing (models)	These articles discuss life cycle thinking and (financial) modeling for optimal long-term investments and maintenance planning.	A11, A12, A16	Integration of cost, risk, and performance over asset lifespans; models help determine optimal replacement and investment strategies.
C4	Managing inspection data	These papers focus on maintaining asset health via inspections and uncertainty modelling.	A2, A5	Attention to inspection data accuracy, uncertainty, and impact on maintenance planning; ensures operational reliability and safety.
C5	Data-driven planning	These articles explore how data can be used to improve or complement asset management practices.	A10, A13	Emphasis on digital platforms and analytics tools to enhance decision-making; supports dynamic, responsive infrastructure planning.
C6	SAMP performance evaluation	This article focuses on evaluating the performance of asset management system against organizational goals.	A15	Introduces performance metrics (e.g., Balanced Scorecard) to align asset management outcomes with strategic objectives and enable continuous improvement.

3 THEORETICAL FRAMEWORK

This chapter establishes the theoretical foundation for the research by exploring key relevant principles. It begins with a brief introduction to Systems Engineering, leading to the concept of architectural views. The chapter then examines the theory of taxonomies and outlines a systematic approach for their development. Finally, it introduces additional concepts from design thinking and public participation that are integral to the research.

3.1 Systems Engineering

As introduced in Chapter 2, asset management traditionally focused on the realization of value and the achievement of organizational objectives by effectively using assets during their lifetime [15]. However, the landscape of asset management is becoming increasingly complex as it evolves [38]. Modern organizations increasingly operate within complex socio-technical environments, where systems are composed of interconnected physical assets, digital technologies and various stakeholders [39, 40, 41]. These systems span organizational boundaries and evolve continuously in response to changing requirements and technological advancements. To manage such complexity, a structured approach is essential.

Systems Engineering (SE) offers a methodology for addressing complexity through the coordinated development, integration, and management of systems [42, 43]. Rather than focusing solely on individual components, SE emphasizes the relationships between parts of a system and the value delivered to stakeholders as a whole. The set of interacting systems is commonly referred to in literature as a System of Interest (SoI).

A cornerstone of systems engineering is the use of architectural views, which are structured representations of systems from different perspectives. These views help address specific concerns like functionality, performance, or organizational structure [44]. No single representation can capture the full breadth of a complex system. Instead, multiple complementary views are necessary to provide a comprehensive understanding [45]. The views structure information in such a way that it supports communication, decision-making, and alignment across diverse groups.

In the context of this research, taxonomies can be seen as a specific type of architectural view. Namely, a structured classification scheme that organizes the elements of a complex domain into meaningful categories. Building on this foundation, the next section expands his theoretical foundation by exploring the history, principles, and methods of taxonomy development. Followed by an introductory theoretical framework on additional concepts and principles relevant to this research.

3.2 Taxonomies

In the following section, background information on taxonomies is presented. It starts with a brief introduction to the history of taxonomies, followed by the exploration of the concept of asset taxonomies. Building on this foundation, key principles and a mathematical foundation for taxonomies are presented. After this mathematical intermezzo, a method to develop a taxonomy is introduced. While this method is not described in detail, some key insights are presented. The goal of this section is to provide the necessary background on taxonomies, enabling the reader to follow the taxonomy design process in the remainder of this research.

3.2.1 History of taxonomy

Taxonomy is defined as *"the study of the general principles of scientific classifications"* [46]. The artifacts produced through such studies are also referred to as taxonomies. The term itself originates from the Greek words taxis (arrangement) and nomos (law) [46]. This reflects the aim of the discipline, which is to organize and classify.

It is believed that Aristotle (384-322 BC) began the practice of systematic classification in his *History of Animals*. Here, he grouped animals based on shared characteristics [47]. However, it was Carl Linnaeus (1707-1778) who formalized the hierarchical system that persists in biological sciences today. The Linnaean model, which organizes organisms into categories such as kingdom, class and species, is what most people think of when mentioning taxonomies [47].

However, the theory of creating taxonomies is not limited to biology. Over time, taxonomies have been applied in fields like information systems, knowledge management and machine learning with each adapting the core principles of categorization, hierarchy, and meaningful differentiation [46].

3.2.2 Asset taxonomy

Since a taxonomy is a systematic classification of items into hierarchical groups based on factors common to all items in such a group, the theory can be applied to assets of an organization as well. Assets are all items, things or entities that have potential or actual value to an organization [15]. Classifying assets into hierarchical groups results in a so-called asset taxonomy.

In ISO 14224 a framework that can be used for the collection of reliability and maintenance data for equipment in all facilities and operations within the petroleum, natural gas and petrochemical industries is provided [18]. A tool useful in handling this data is an asset taxonomy, and thus a guideline of creating such a hierarchy is provided by the standard. A schematic of this can be found in Figure 3.1, while the associated definitions are given in Table 3.1.

Levels 1 to 5 of the taxonomic structure, as described in ISO 14224, represent a high-level categorization. This has been implemented because an equipment unit can be used across different industries. Specifying the operating context within the taxonomy is essential for accurately analyzing the reliability of similar equipment, which is the objective of the asset taxonomy as proposed in ISO 14224 [18]. Levels 6 to 9 are related to the subdivision of the equipment unit into lower indenture levels. These indenture levels follow a hierarchical parent-child relationship.

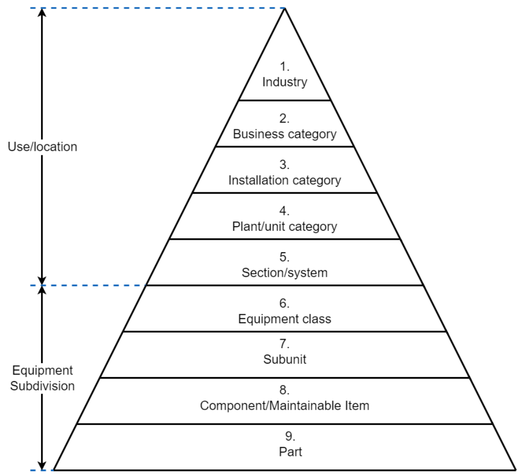


Figure 3.1: Taxonomy classification with taxonomic levels (adapted from: [18])

Table 3.1: Definitions of asset taxonomy levels [18]

Main category	Taxonomic level		Definition
Use/location data	1	Industry	Type of main industry
	2	Business category	Type of business or processing stream
	3	Installation category	Type of facility
	4	Plant/unit category	Type of plant/unit
	5	Section/system	Main section/system of the plant
Equipment subdivision	6	Equipment class/unit	Class of similar equipment units, each equipment class contains comparable equipment units
	7	Subunit	A subsystem necessary for the equipment unit to function
	8	Component/maintainable item	The group of parts of the equipment unit that are commonly maintained/replaced as a whole
	9	Part	A single piece of equipment (this level is considered optional)

3.2.3 Development of taxonomy

While ISO 14224 provides a solid foundation for developing an asset taxonomy, it does not describe how to identify, formulate and apply shared characteristics for the categorization of assets. Furthermore, the definitions as given in the standard are related to the petrochemical industry. Thus, additional literature is needed to support the creation of an asset taxonomy suited to the objectives of this research.

3.2.3.1 Mathematic description of taxonomies

Before diving into the method to create a taxonomy, it is valuable to briefly explore the mathematical foundation of taxonomies. This perspective offers a more detailed description of the concept and highlights structural requirements that the taxonomic structure should fulfill.

Taxonomies not only have a mathematical foundation, they can be entirely defined mathematically. A taxonomy T is a set of n dimensions D_i $(i = 1, ..., n)$ each consisting of k_i $(k_i \leq 2)$ mutually exclusive and collectively exhaustive characteristics C_{ij} $(j = 1, ..., k_i)$ such that each object under consideration has one and only one C_{ij} for each D_i [48]. A mathematical equation that states this definition is shown in Equation 3.1.

$$T = \{D_i, i = 1, ..., n | D_i = \{C_{ij}, j = 1, ..., k_i; k_i \leq 2\}\} \tag{3.1}$$

The mutually exclusive property guarantees that no object can have more than one characteristic within a dimension. The collectively exhaustive property, on the other hand, ensures that each object has one characteristic in each dimension. Together, these properties ensure that each object has exactly one of the characteristics in each dimension.

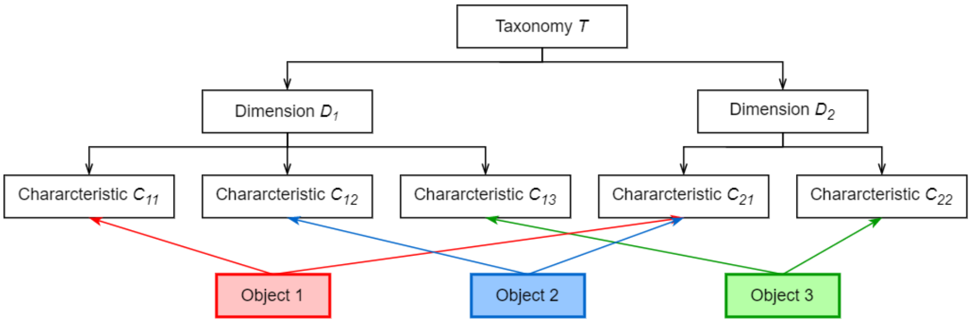


Figure 3.2: Extended taxonomy design process

An example of such a taxonomy illustrated in a schematic structure is presented in Figure 3.2. What can be seen in this figure is a tree-like structure consisting of dimensions and characteristics. Each of objects under consideration contains exactly one characteristic from each dimension. While the aim of this research is not to connect objects to characteristics this way, we are interested in creating a tree-like structure based on shared characteristics. Therefore, the taxonomy development method described in the same research that describes the mathematical definition is of interest. This will be elaborated in the following section.

3.2.3.2 Taxonomy development method in the domain of information systems

Figure 3.3 presents the taxonomy development method, known as the *extended taxonomy design process (ETDP)* as proposed in [49]. The method is designed to guide researchers through the entire taxonomy design by stimulating critical reflection and careful design decisions. The ETDP has been structured to align with the Design Science Research Methodology (DSRM), making it more intuitive for most researchers as DSRM is widely used.

A detailed explanation of each step in the process, as shown in Figure 3.3, can be found in [49]. In this section, key aspects making the proposed method particularly interesting will be highlighted. The first of these is that ETDP urges the researchers to clearly define the problem to be solved by the taxonomy and its contextual background. This forms a structured foundation for the taxonomy's development.

Once this foundation is established, the design and development phase can start. Like the DSRM process, the taxonomy development method is iterative. Within the process there are various re-entry points, as can be seen in Figure 3.3. Two approaches can be chosen in the design of the taxonomy, namely the empirical-to-conceptual and the conceptual-to-empirical. The first should be implemented if no classification structures exist, in this the process starts with an unorganized list of objects. If an existing structure is chosen to serve as a starting point for the taxonomy, on the other hand, the conceptual-to-empirical method should be chosen. When doing multiple iterations of the design and development method, the two approaches can be implemented alternately.

When creating an artifact for a complex problem, it can be hard to determine whether the design successfully meets its objectives or if more iterations of the design process are necessary. To address this challenge, ending conditions have been introduced. These conditions help to determine when the iterative process should stop.

A distinction between objective and subjective ending conditions can be made. Objective ending conditions help to demonstrate whether the designed taxonomy meets the essential criteria for a taxonomy. This involves, among others, verifying that the taxonomy is mutually exclusive and collectively exhaustive, as introduced in Section 3.2.3.1. The full list of objective ending conditions can be found in Table 3.2. On the other hand, the subjective ending conditions focus on ensuring that the taxonomy is applicable. As this is a subjective matter, often a consensus between researchers working on the taxonomy is reached. The subjective ending conditions are presented in Table 3.3.

Next to verifying the underlying structure of the taxonomy through the ending conditions, the taxonomy's effectiveness in fulfilling the objective should be evaluated. Therefore, the use of taxonomy evaluation goals is suggested. Such evaluation goals should be defined before designing the taxonomy and should be revisited in the final step of the process. Based on existing literature on taxonomy, a list of potential evaluation goals is proposed, as shown in Table 3.4. However, other goals can be implemented if needed.

Although the described method provides a thorough and structured approach for developing a taxonomy, not all of its aspects of the method have been implemented in this research. The identification and motivation of the problem as well as the definition of the solution objectives have been carried out as part of the DSRM process. However, these steps were not followed precisely as outlined in the ETDP. Additionally, the building approach chosen in the design and development phase has been the conceptual-to-empirical as an existing structure has been used as a starting point. No ending conditions have been used in the research, while the performance of the taxonomy has been evaluated based on the objectives of the solution. A more detailed outline of the process as carried out in this research can be found in Section 4.2

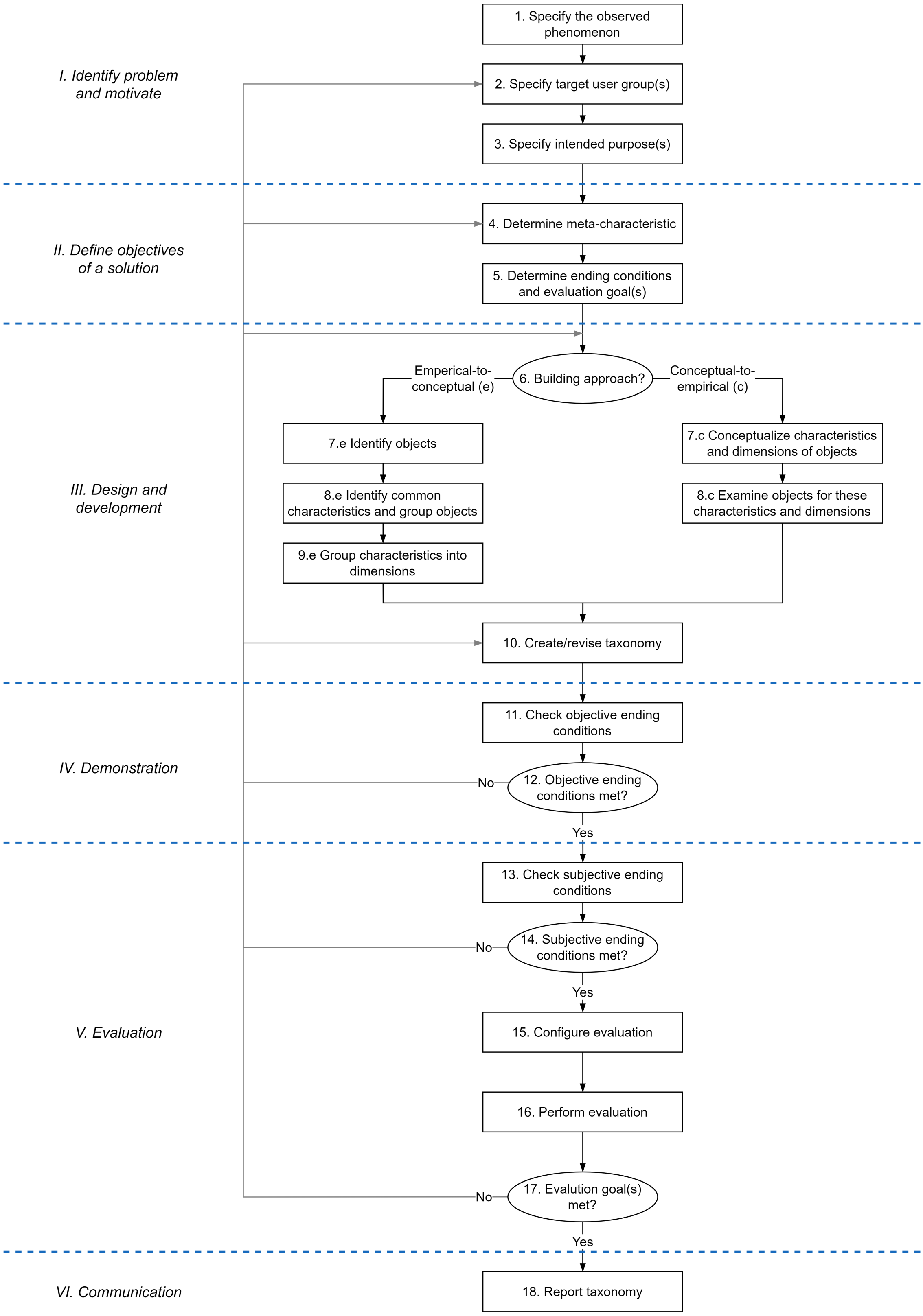


Figure 3.3: Extended taxonomy design process (adapted from: [49])

Table 3.2: Objective ending conditions (adapted from: [48])

Objective ending condition	**Comments**
The taxonomy fulfills the definition of a taxonomy (as displayed in Equation 3.1)	*Specifically, it consists of dimensions each with mutually exclusive and collectively exhaustive characteristics*
All objects or a representative sample of objects have been examined	If all objects have not been examined, then the additional objects need to be studied
No object was merged with a similar object or split into multiple objects in the last iteration	If objects were merged or split, then we need to examine the impact of these changes and determine if changes need to be made in the dimensions or characteristics
At least one object is classified under every characteristic of every dimension	If at least one object is not found under a characteristic, then the taxonomy has a 'null' characteristic. We must either identify an object with the characteristic from the taxonomy
No new dimensions or characteristics were added in the last iteration	If new dimensions were found, then more characteristics of the dimensions may be identified. If new characteristics were found, then more dimensions may be identified that include these characteristics
No dimensions or characteristics were merged or split in the last iteration	If dimensions or characteristics were merged or split, then we need to examine the impact of these changes and determine if other dimensions or characteristics need to be merged or split
Every dimension is unique and not repeated	If dimensions are not unique, then there is redundancy/duplication among dimensions that needs to be eliminated
Every characteristic is unique within its dimension	If characteristics within a dimension are not unique, then there is redundancy/duplication in characteristics that needs to be eliminated
Each cell (combination of characteristics) is unique and is not repeated	If cells are not unique, then there is redundancy/duplication in cells that needs to be eliminated

Table 3.3: Subjective ending conditions (adapted from: [48])

Subjective ending condition	**Questions**
Concise	Does the number of dimensions allow the taxonomy to be meaningful without being unwieldy or overwhelming?
Robust	Do the dimensions and characteristics provide for differentiation among objects sufficient to be of interest? Given the characteristics of sample objects, what can we say about the objects?
Comprehensive	Can all objects or a (random) sample of objects within the domain of interest be classified? Are all dimensions of the object of interest identified?
Extendable	Can a new dimension or a new characteristic of an existing dimension be easily added?
Explanatory	What do the dimensions and characteristics explain about an object?

Table 3.4: Taxonomy evaluation goals (adapted from: [49])

Evaluation goals	Taxonomy users aim to use the taxonomy to...	Taxonomy designers provide...
Describing	... describe a certain phenomenon	... characteristics and dimensions that serve as a basis to describe a certain phenomenon
Identifying	... identify one specific object that represents a certain phenomenon	... characteristics and dimensions that serve as search criteria to identify one particular object
Classifying	... classify objects that represent a certain phenomenon	... characteristics and dimensions that serve as a scheme to classify one particular object
Analyzing	... analyze objects that represent a certain phenomenon	... characteristics and dimensions that serve as a basis to determine similarities and differences of objects
Clustering	... cluster objects based on similarities and differences to consider types of objects rather than individual objects	... characteristics and dimensions that serve as a basis for grouping a set of objects in such a way that objects in the same group are more similar to each other than to those in other groups

3.3 Additional relevant concepts and principles

In addition to the taxonomy development method, which offered useful guidance for this research, this research applies a range of concepts and principles to ensure that the created artifact is not only grounded in theory but also contextually relevant and usable. In this section, these concepts and principles are introduced.

3.3.1 Design Thinking

First, the Design Thinking (DT) methodology is introduced, as it provides a structured, user-centered approach that fits well with the goals of this research. Since the study addresses a complex, real-world problem involving multiple stakeholders, DT offers practical methods for developing effective solutions. Elements of the DT process are also reflected in the research methodology, making it a useful perspective for both analysis and reflection. This section outlines the key phases of Design Thinking to support the use of user-focused and iterative thinking throughout the research.

Design Thinking is a human-centered problem-solving methodology used to develop solutions by understanding users' needs [50, 51, 52]. The DT process is characterized by its user-centered focus and collaborative nature. By involving users throughout the collaborative process, Design Thinking helps to reduce risks and uncertainties associated with innovation [51].

Five phases can be identified in the framework [50, 51, 52], this has been illustrated in Figure 3.4. An elaboration on the phases is presented below.

1. **Empathize**
   The objective of this phase is to develop a deep understanding of users, involving their needs, experiences, motivations and challenges, through interviews and observations.
2. **Define**

Based on the insights gathered in the empathize phase, this stage involves putting together the findings of the previous phase into a clear and concise problem statement.

3. **Ideate**
   In the ideation phase, teams generate a wide range of ideas and possible solutions. Brainstorming and creative thinking techniques are used to explore multiple approaches without immediately judging or narrowing them down.
4. **Prototype**
   In this phase, representations of ideas are created to explore potential solutions. Prototypes serve as experimental tools that help teams visualize how a concept might function in the real world.
5. **Test**
   Prototypes are tested with users to gather feedback and understand what works, what doesn't, and why. This phase often leads to revisions and may cycle back to earlier stages as needed.

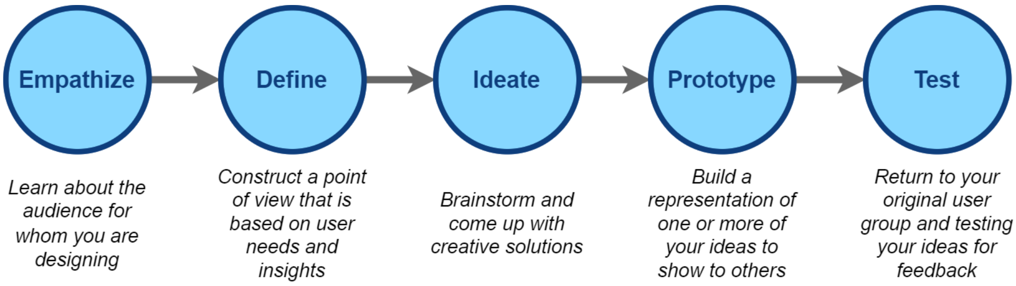


Figure 3.4: Process of Design Thinking (adapted from: [53])

Although not explicitly labeled as such, most of the steps of the Design Thinking methodology have been implemented in the process of this research. These steps align closely with those of the Design Science Research Methodology (DSRM), which was used as the framework of this research as elaborated on in Section 4.2. The 'empathize' and 'define' phases of DT correspond to the first phase of DSRM in which the problem is identified and motivated. Similarly, the 'ideate' and 'prototype' steps as specified in the Design Thinking framework are aligned to the design and development phase of DSRM. Finally, the 'test' phase in DT parallels the evaluation step in DSRM, though DT emphasizes on a more direct and iterative user testing compared to the broader evaluation focus in DSRM. In this research, the final design was evaluated through a case study that simulated a real-world scenario and involved real users, thereby reflecting the 'test' phase of the Design Thinking methodology.

Design Thinking not only offers a framework for human-centered problem-solving, it also provides a variety of tools that support the process [54]. Several of these tools have been adapted to suit the specific context and objectives within this research, specifically the workshop as described in Section 6. The following section elaborates on the selected tools and their application within this study.

- **Storytelling**
  In the context of the workshop, storytelling was used to create a relatable setting in which participants could evaluate the designed taxonomy. Instead of presenting the taxonomy in isolation as an abstract system, it was embedded within a narrative that illustrated the environment, the user, and the specific situation in which the

taxonomy would be applied. This narrative approach helped participants better understand the intended purpose and functionality of the design by placing it within a realistic scenario. By imagining how the taxonomy would be used in practice, participants were able to engage more meaningfully with the evaluation process, offering feedback that was grounded in actual use cases rather than theoretical assumptions.

- **Brainstorming**
  During the brainstorming phase of the workshop, a method closely aligned with the *blue-card method* was implemented. This approach ensures that all participants contribute equally by first generating ideas individually before sharing them with the group. By doing so, the method helps to prevent the so-called ”boss effect”, where participants rely on more senior persons to provide ideas [54]. By encouraging independent idea generation prior to group discussion, the method ensures a more balanced and inclusive ideation process. This was a deliberate feature of the workshop, aimed at capturing a broader range of perspectives and minimizing hierarchical influence.
- **Value/ease grid**
  In the workshop, placing ideas of an impact-effort matrix is a key feature of the decision-making process. The impact-effort matrix closely resembles the value/ease grid. Here, impact is directly related to value, and effort is related to ease. Although both frameworks are conceptually similar, the impact-effort terminology was chosen for its greater relevance to the participants' operational context.

In summary, Design Thinking provided practical tools that supported the user-centered nature of this research. By adapting and integrating the tools within the workshop setting, it is ensured that the designed solution remains aligned with user needs and the practical application. A further elaboration of the workshop is described in Section 6.

3.3.2 Public participation spectrum

As mentioned previously, this research builds on the knowledge and experience of people working at Liander, specifically within the Asset en Product Management department. To be able to incorporate their expertise in the design, these people have to be involved in the process. To contextualize this involvement, the principle of the *public participation spectrum* is introduced. The public participation spectrum provides a structured model to determine the level of stakeholder involvement [55] and will be elaborated on in this section.

The public participation spectrum has been developed by the International Association of Public Participation (IAP2). Within the spectrum the public involvement, five levels have been specified [55]. In Figure 3.5, the five levels have been illustrated. The arrows in the illustration represent the information flow between various participants. Below, a textual elaboration on these levels is given.

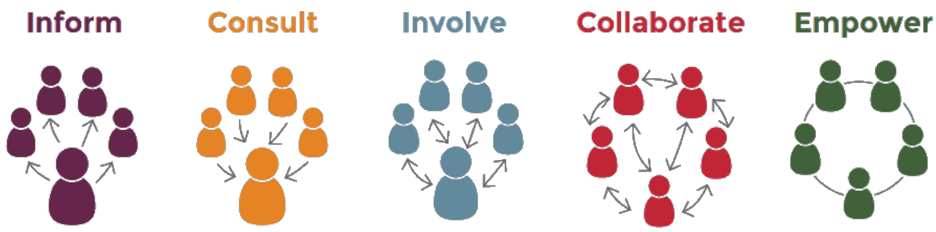


Figure 3.5: IAP2 Spectrum of public participation (adapted from: [56])

- **Inform**
  Here, participants are provided with balanced and objective information to help them understand the problem, alternatives and opportunities [56, 57]. In the context of this research, this ensures transparency and creates a foundation for further engagement of the participants.
- **Consult**
  This level focuses on gaining feedback from the public on analysis, alternatives or decisions [56, 57]. During the research process, Liander staff may be consulted to provide their perspectives on preliminary taxonomy structures as well as providing information on the work they are performing. The latter can be used as input in the design process.
- **Involve**
  Involvement means working directly with participants throughout the process to ensure that their concerns and aspirations are consistently understood and considered [56, 57]. Here, staff actively provide input for the research, thereby shaping the taxonomy based on their operational knowledge and needs.
- **Collaborate**
  This level goes a step further by working together with participants in each aspect of a part of the research process [56, 57]. An example of this could be cross-functional teams co-designing an artifact. In the context of this research, collaboration could involve co-creating elements of the taxonomy or validation methods together with domain experts.
- **Empower**
  In the level of empowerment, design and development responsibilities are given to participants [56, 57]. However, within this research, empowering stakeholders is not applied as the study does not provide a framework or methodology for developing an asset taxonomy in the context of Liander. Instead, the taxonomy has been developed by the researcher.

This spectrum of public participation provides a structured way to involve Liander staff throughout the research process. By selecting appropriate levels of participation during this research it is ensured that the perspectives of practitioners are meaningfully integrated into the design of the taxonomy. This approach not only improves the relevance and usability of the artifact, but also fosters a sense of ownership among those who will ultimately work with it.

3.3.3 The role of visualization

Taxonomies can be a relatively abstract concept, especially to people who have not seen or studied them before. As this research and the intended usage of the asset taxonomy will involve people with various roles in the organization of Liander, it is important to keep all of these people on the same page. There are various ways a taxonomy can be presented, ranging from technical data sheets to more visual solutions. In this section, the importance of visualization in the design process is elaborated.

Visualization of ideas involves translating information, which can come in various forms, into images that can be directly seen [54]. These images can make complex or unfamiliar concepts into something more accessible and concrete to a wide audience.

In multidisciplinary environments, participants will bring different backgrounds and interpretations. This is where visualization plays a vital role in reducing the risk of miscommunication. Text, in particular, is subject to varying interpretations by different individuals [54]. When an idea is explained using text, all participants will form their own images in their heads. As these 'mental models' can vary significantly between individuals, this can create misalignment. However, when ideas are presented visually in the first place, the risk of unmatched mental models is reduced significantly [54].

During the concept development phase, visualization becomes incredibly key. The concepts will emerge from imagination, with the brain creating pictures of something that does not yet exist. Visual representations are not only essential for helping others understand the proposed ideas but also for convincing them of the strength and value of those concepts [54].

In the context of this research, visualization will not only be used to support communication between the researcher and various stakeholders, but also to co-create and refine the taxonomy in a collaborative and iterative manner.

4 RESEARCH APPROACH

With the relevant concepts and principles introduced in the previous chapter, the design research can begin. This chapter outlines the approach taken in the research. It begins by describing the organizational context in which the study takes place. This context provides an essential foundation of the choices made throughout the remainder of the research process. Understanding the structure, goals and operational environment of Liander helps to ground the research in practice and ensures that the developed solution is both relevant and applicable.

Following the organizational context, the Design Science Research Methodology (DSRM) is introduced. This is used as the guiding framework for the research as it supports the structured development and evaluation of an artifact aimed at addressing a complex problem. A detailed explanation of the methodology and the way this is applied in this research is provided in Section 4.2.

4.1 Organizational context

This section provides an overview of the organizational context in which this research has been conducted. Since this research has been executed for and in collaboration with Liander, relevant aspects of the organization are discussed. The section begins with a general introduction to the (Dutch) electricity grid, explaining the various types of grids and their corresponding voltage levels, as well as their structural layout. Subsequently, the role of Distribution System Operators is described, leading into the situation and challenge of Liander that is relevant to this research. Because this challenge concerns load capacity limits of the grids, the different types of limits are also introduced.

4.1.1 Electricity grid

The term *grid* is defined in the Dutch Electricity Act (article 1, sub i) as '*one or more connections for the transport of electricity and the associated transformer, switching, distribution and sub-stations and other auxiliary equipment, except insofar as these connections and equipment are located within the installation of a producer or consumer*' [58]. The electricity grid arranges the transport of electrical energy from international level to local level, with consumers being at the local level.

The main reason for losses in the electricity grid is the resistance of the cables [59]. According to Ohm's law, for the same power, the losses are lower for higher voltages. Therefore, a high voltage is implemented for the transportation of electricity over long distances. On the contrary, connecting installations of consumers to the grid is safer and practical at lower voltages [60]. For these reasons, various voltage levels are implemented within the electricity grid. Higher voltage levels are used for the transportation and lower voltage levels are used for the distribution of electricity. Within the Netherlands, a more extensive subdivision of four categories is used, namely the synchronous, transmission, regional distribution and local distribution grid. A schematic representation of these categories can be found in Figure 4.1, while an explanation can be found below.

- The *synchronous grid* has both an international and national function. Via this grid, the Dutch electricity grid is connected to the grid of neighbouring countries. Additionally, the grid is used to transport electricity from large power plants (larger than 500 MVA) and feed the electricity into the transmission grid [60].
- The *transmission grid* subsequently transports the electricity further into the country. Smaller power plants (10 to 500 MVA) and large industrial consumers (more than 10 MVA) are attached directly to this grid [60]. The transmission grid will be referred to as the high voltage grid (translated from the Dutch 'hoogspanningsnet') throughout this report.
- The *regional distribution grid* can be used both as a transport and distribution grid. Smaller electricity generators are attached to this, as well as industrial consumers (0.3 to 10 MVA). Mainly, this grid is used to feed electricity into the local distribution grids [60]. In the remainder of this report, the local distribution grid will be referred to as medium voltage grid (translated from the Dutch 'middenspanningsnet'). If required, a distinction between transport and distribution will be made.
- Finally, via the *local distribution grid*, electricity is delivered to (or retrieved from) the smaller connections, like houses [60]. In the remainder of this report, the local distribution grid will be referred to as low voltage grid (translated from the Dutch 'laagspanningsnet').

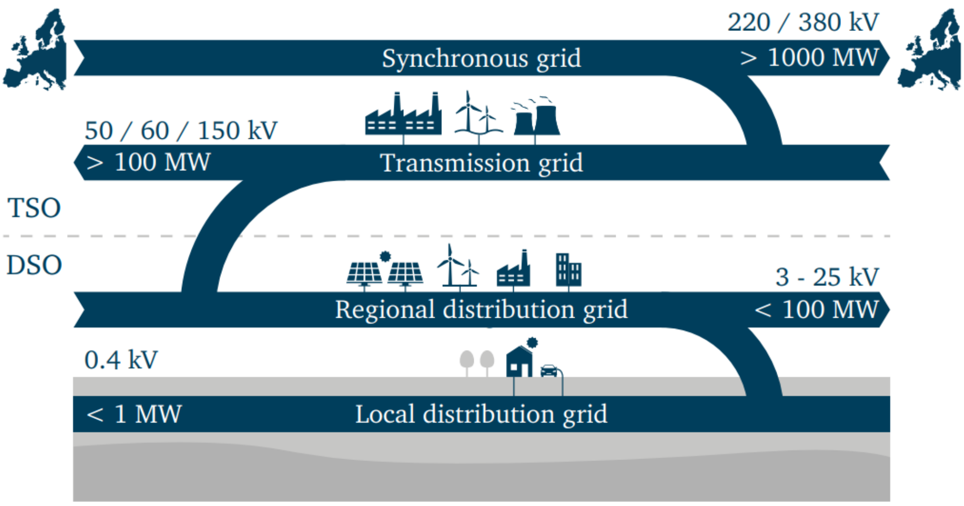
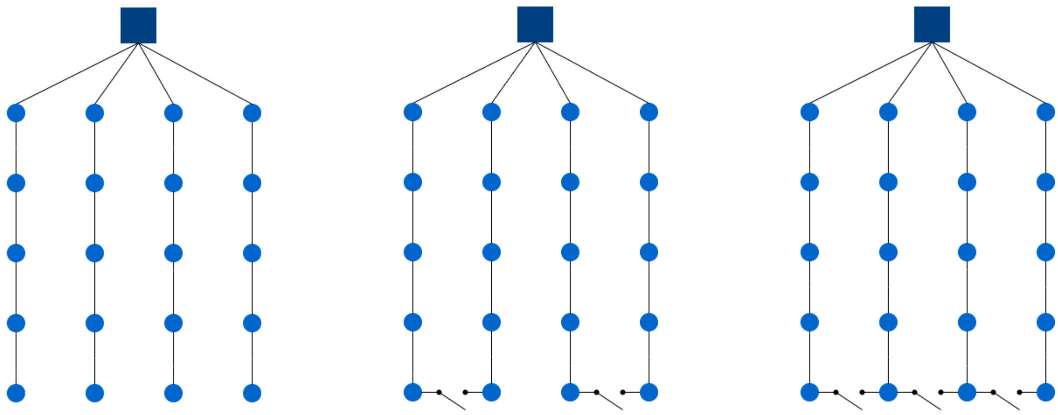


Figure 4.1: Overview of the categories of the electricity grid [60, 61]

4.1.1.1 Grid structure

An electricity grid consists of various components, the connections between these components can be configured in various ways. A distinction is made between radial, ring and meshed grid [60]. A schematic representation of each of these structures is given in Figure 4.2. Here, the squares denote substations, while the dots represent the consumers and/or producers connected to the substation.

- In a *radial grid*, each consumer/producer is connected to a substation via a single connection. There are no switching options, meaning that an interruption in the grid results in a loss of supply [60].
- In a *ring grid*, each consumer/producer can be reached from the substation via two connections. Usually, ring grids are operated as radial grids. To achieve this, a network opening is implemented. By moving this network opening, a power interruption can be restored. Therefore, a ring grid is more reliable [60].
- The *meshed grid* has even more redundancy than the ring grid, making it again more reliable. Each consumer/producer can be reached via more than two connections. Similar to the ring grid, a meshed grid is usually operated in a radial manner, with network openings at nodes where multiple connections converge [60].



(a) Radial grid (b) Ring grid (c) Meshed grid

Figure 4.2: Schematic representation of grid structures (adapted from: [62])

High voltage grid

Typically, transport grids are designed in such a way that in case of a malfunction electricity can still be supplied [60]. Since the high voltage grid serves a transport function, the high voltage grid is also designed with redundancy. Multiple connections from source to load are in place. Thus, transport grids generally use meshed structures. This mesh is not limited to a national level. In fact, high voltage grids have international connections to allow the exchange of electricity between countries, again making the grid more reliable.

Medium voltage grid

As discussed previously, the medium voltage grid can fulfill both a transport and a distribution role. The medium voltage transport grids are built with a similar philosophy as the high voltage grid, in case of a malfunction electricity still has to be supplied. While the high voltage grid is considered a meshed grid, the medium voltage transport grid is typically built in ring structures.

Besides transport grids, medium voltage distribution grids often implement ring or meshed structures, albeit radially operated [60]. Within the grid, a main ring, subrings and branches can be identified. The main ring starts at the substation and runs through a network opening back to the substation. A separation from a main ring that can be connected at its end to the same feeding cable by closing a network opening is referred to as a subring. Meanwhile, a separation from a main ring or subring, which cannot be connected to another feeding cable at its end by closing a network opening, is called a branch. The number of substations contained in subrings and branches is lower than in the main ring [60]. Typically, the conductor diameter of the cables in the latter is larger than of the cables used in the branches and subrings.

Low voltage grid

Low-voltage networks are typically arranged in a radial configuration [60]. Branches start at a substation and usually have no connection to another substation. However, there are also situations with ring-shaped and meshed structures. In general, meshed operation leads to better voltage management and reduced network losses. A major disadvantage, however, is that in the event of a fault, this results in larger short-circuit currents. More complex protection is also required. Therefore, new low-voltage networks are constructed in radial configurations [60].

4.1.2 Distribution System Operator

The Dutch government has divided the management of the electricity grid over the Transmission System Operator (TSO) and Distribution System Operators (DSOs) [63]. The synchronous and transmission grid are operated by the Transmission System Operator. TenneT is the TSO in the Netherlands (and part of Germany) and is public property. The regional and local distribution grids are operated by the Distribution System Operators. Within the Netherlands, six DSOs are active, each being the exclusive operator within a region. The regions corresponding to the DSOs are displayed in Figure 4.3.

Figure 4.3: Distribution System Operators in the Netherlands (adapted from: [64])

DSOs are responsible for the construction, operation, management and maintenance of distribution grids (medium and low voltage) [65]. Traditionally, DSOs are obliged to connect all producers and consumers according to a 'first come, first served' principle. This non-discriminatory principle functions effectively when there is sufficient capacity, but lately as a result of grid congestion, it has resulted in unfavorable societal consequences. As of 2023, projects with a positive impact on Dutch society, like the construction of housing, healthcare and education facilities, in congestion-affected areas can be prioritized by the distribution system operators [66]. This measure is a temporal solution, the DSOs have to actively work on enlarging the capacity of the grid in order to manage the climate goals of the government.

Alliander has formulated the goal for 2030 to offer customers an affordable and reliable energy system. Achieving this goal would result in making the energy transition of the Netherlands possible. Resulting in being climate neutral by 2050, as agreed by the Dutch government.

The strategy of Alliander consists of seven pillars as listed below [67]. Each having their own specific goals and steps that help achieve the aims for 2030.

1. *Excellent management: optimizing maintenance and improving customer service*
2. *Reducing demand for transmission capacity*
3. *Improving network use*
4. *Scaling up*
5. *Sharing data and developing new market services*
6. *Developing infrastructure for heat and sustainable gases*
7. *Creating future-proof foundations*

The research as presented in this report is part of the third pillar. This pillar focuses on using the existing grid more efficiently. As a result the grid congestion can be decreased without having to make large changes to the grid. Within this pillar, various themes can be identified. The research described in this report focuses on the theme of increasing the load on existing assets, internally referred to as *Zwaarder Belasten Assets (ZBA)*. Here capacity limits of (critical) assets are sought. It has been accepted that by increasing the load on these assets the lifetime decreases, as long as more customers can be connected to the grid. Increasing the capacity limits of the assets takes place in steps. First, the nominal capacity is changed to a (higher) static limit. Subsequently, a cyclic capacity is defined. Finally, a dynamic capacity is desired. In Section 4.1.3, an explanation of the different capacities is given.

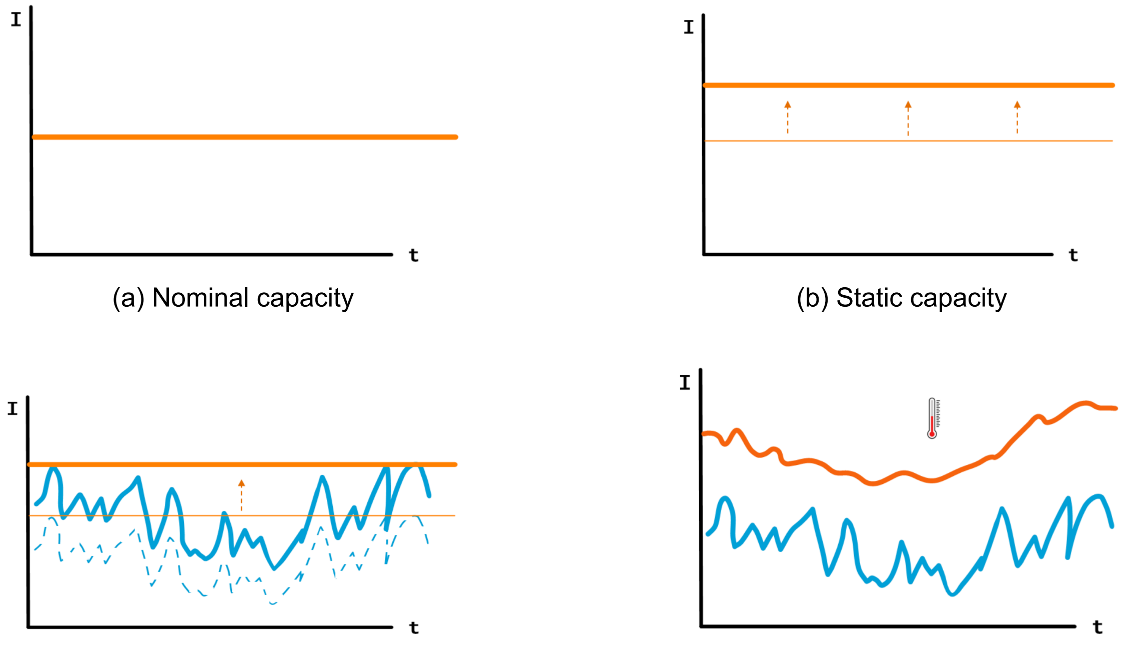
In order to define these limits in a safe manner, current- and temperature measurements are employed. Various teams and departments are working together to implement the new policies regarding the loading of components. The department of *Asset- & Product-management (APM)* is one of the driving forces of Zwaarder Belasten Assets. APM is responsible for maintaining, digitizing and standardizing the assets of Liander.

4.1.3 Load capacities

Within Liander, a distinction is made between asset limits and grid limits. Asset limits refer to assets like cables and transformers. Grid limits, on the other hand, refer to the limits of a set of assets in which the assets together define the limit. In the context of a hierarchical division of the electrical grid, grid limits are located at higher levels, while the asset limits are involved in lower levels of the hierarchy. Since this research focuses on strategic decision-making for capacity-enhancing initiatives at the asset level, asset limits are of primary interest. In this section, the various types of limits are elaborated on.

Asset limits

As described previously, various types of asset limits can be described. This ranges from nominal to dynamic capacities. A description of the capacity limits follows, while an artificial visualisation of the limits in (I,t)-diagrams is displayed in Figure 4.4,



(a) Nominal capacity

(b) Static capacity

(c) Cyclic capacity

(d) Dynamic capacity

Figure 4.4: Different types of capacities

Nominal capacity is a continuous standardized capacity limit based on either an IEC norm or specification of the supplier. The limits are generically defined for types of assets. In Figure 4.4a it is shown that the capacity does not vary over time. In addition, this limit does not consider specific environmental factors.

Static capacity is again a standardized capacity limit based on continuous loading of the asset. However, it is no longer determined by IEC norm or suppliers, but by location-specific environmental conditions such as air and soil temperatures. The static capacity is determined by optimizing the maximal continuous load after optimizing for the thermal limit of the asset. This newly found limit is generally higher than the nominal capacity, as shown in Figure 4.4b. The newly found limit can be generic for an asset class or specific for a type of asset. Optionally, a static limit can be defined for certain periods of the year (instead of the whole year) like a winter-capacity.

Cyclic capacity is no longer based on a continuous load profile. Instead, a load profile varying over time is used. The profile can be based on historical or forecast data, but should be representative of future loading. In addition, the environmental conditions can either be chosen to be constant or varying over time. Similar to static capacity, the cyclic capacity is found using the thermal limits of assets. Generally, by using a non-continuous load profile, the capacity limit is higher than is the case with continuous loading. The cyclic capacity states the peak load capacity to which the load profile can be raised. A visual representation of this can be found in Figure 4.4c, here the load profile is depicted in blue.

Dynamic capacity is a time-dependent load limit. It is based on actual (real-time) and asset-specific load profiles. Environmental aspects can either be measured or predicted. By addition of sensors, such predictions can be validated. In Figure 4.4d the dynamic capacity of a component is depicted in orange, while the load profile is again shown in blue. In the figure it can be seen that the capacity limit is no longer constant over time.

Grid limits

Next to the asset limits, Liander also works with grid limits. Some of the grid limits are introduced below.

Reliable installed capacity (Bedrijfszeker Installatievermogen (BZIV)) is the maximal capacity of an installation such that in case of maintenance or malfunction operational reliability is ensured, as established by grid architects. It is determined by simulating what the capacity of the installation would be if components within the installation fail, in so-called *ketenbelastbaarheidsstudies*. The lowest capacity as found is set to be the BZIV. In this simulation nominal capacities of components are used.

Although not yet implemented within the organisation of Liander, it is desirable to have different BZIV limits for different seasons of the year. Generally, due to a lower ambient temperature, installations can be loaded more heavily in winter. This heavier loading could result in connecting more customers to the electricity grid throughout the year.

Additional non-redundant capacity (Additionele Niet-Redundante Vermogen (ANRV)) is extra installation capacity that becomes available when spare transformers are turned on. This extra capacity can be totaled with the BZIV. Spare transformers are typically only used in case of maintenance or malfunction. Customers that use the ANRV are considered disconnectable (afschakelbaar). These customers are disconnected from the grid if one of the main transformers fails and thus the spare transformer is needed to provide electricity to the non-disconnectable customers. Thus, by make use of ANRV, more customers can be connected to the grid. However, the availability of electricity cannot be guaranteed to these customers.

TenneT limits are introduced if the capacity of installations of Liander is limited by the capacity of the high voltage transport grid as operated by TenneT. The capacity limits as described above do not take into account the limits of the high voltage grid, therefore TenneT limits are introduced. TenneT limits are only considered if these are lower than the ANRV or BZIV.

4.2 Methodology

The research presented in this report follows the Design Science Research Methodology (DSRM), a widely used approach in the design and development of solutions to complex problems. DSRM is an iterative process consisting of six key steps: problem identification and motivation, definition of the objectives for a solution, design and development, demonstration, evaluation and communication [19, 20]. Based on insights in the evaluation and/or communication step, adjustments to the objectives or design can be made, making the DSRM an iterative process. A schematic representation of the DSRM process is displayed in Figure 4.5. In the following sections, each phase of the research methodology is elaborated.

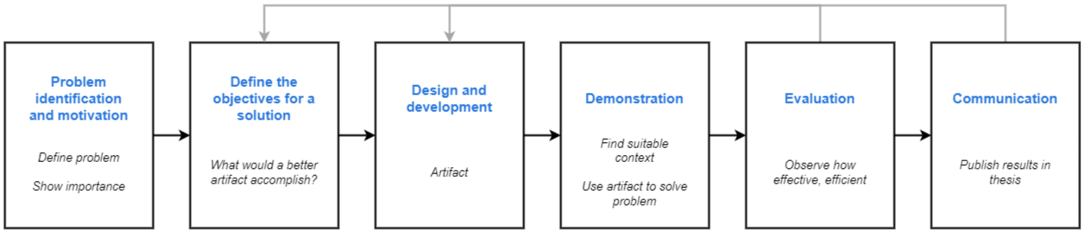


Figure 4.5: DSRM process model (Adapted from: [19])

Problem identification and motivation

The first step in DSRM involves defining the research problem and justifying the value of finding a solution. Identifying the problem requires a clear understanding of the current state and the significance of solving it. This phase also defines why the solution is needed, which encourages both the researcher and the audience to engage with the research findings [19, 20]. It also provides insights in the researcher's perspective of the problem.

In this research, the problem was identified through discussion with supervisors from the University of Twente and Liander. This process coincides with consulting as defined on the spectrum of public participation as introduced in Section 3.3.2. The problem is described in Chapter 1. To define the research gap associated with this problem, a state of the art literature review has been performed. The findings of this analysis can be found in Chapter 2.

Define the objectives for a solution

Once the problem has been defined and the solution justified, the definition of the objectives or requirements for the solution can start [19, 20]. These objectives follow from both the problem definition and insights gathered through the literature study.

In this research, some of the requirements are derived from the problem definition, while others follow from either analyzing the operational context or performing a literature study. While the operational context is described in Chapter 4.1 and the results from the literature study are displayed in Chapter 3, the requirements for the solution are given in Section 5.1.

Design and development

The design and development phase focuses on creating an artifact to address the problem as identified in the first phase [19, 20]. Several steps leading to the final artifact can be identified.

The first major step in designing the artifact is related to the first subquestion as described in Section 1.1 and involves creating the asset taxonomy of the electrical grid as operated by Liander. This process is guided by some of the findings from the literature study, as presented in Section 3.2.

Following the taxonomy creation, relevant initiatives aimed at enhancing asset capacity are investigated. These initiatives, as well as relevant policy documents, are mapped to the taxonomy. To identify and gain an understanding of the initiatives, interviews are conducted with colleagues involved in these projects. Additionally, internal documents available through Liander's *Intranet* and *Confluence* are reviewed to identify key policies and initiatives.

After mapping initiatives and policy documents to the asset taxonomy, feedback is collected from the interviewed individuals to validate the accuracy of the mappings. This iterative feedback process ensures that the final mappings align with the real-world operational context of Liander. Looking at the public participation spectrum, this resembles consulting and involving participants. In Chapter 5.2 the asset taxonomy is presented.

Demonstration

In the demonstration phase, the artifact is applied in a fictional case study during a workshop with colleagues from Liander. An elaboration on the case study can be found in Chapter 6. The demonstration process highlights the strengths and limitations of the artifact, providing valuable insights for future refinements. From this workshop feedback has been collected, which can be used in the next step of the DSRM.

Evaluation

The evaluation phase assesses the effectiveness of the artifact in meeting the defined objectives and solving the identified problem. This evaluation considers how well the taxonomy and its associated mappings fulfill the objectives as set in the second phase of the DSRM process. The evaluation process is described in Chapter 7.

Communication

The final phase of the DSRM methodology involves communicating the research findings to relevant stakeholders. This step ensures that the results of the research are shared with the broader community and those who will directly benefit from the findings.

In this research, the results are communicated through this report, which documents the research process, the developed artifact, and the evaluation outcomes.

5 ASSET TAXONOMY FOR STRATEGIC DECISION-MAKING

In this chapter, the asset taxonomy as a tool for strategic decision-making is built. The chapter focuses on two phases of the Design Science Research Methodology, namely the definition of objectives for the solution (Section 5.1) and the design and development of the solution. This latter phase is broken down into several steps. First, the taxonomy structure is established (Section 5.2). The method outlined in Section 3.2.3 has not been strictly followed, however key aspects discussed there have been kept in mind during the design process. Following this, the mapping of initiatives and policy documents to the taxonomy structure is carried out (Section 5.3). The final design is elaborated on in Section 5.3.3.

5.1 Objectives of the solution

The main objective of the proposed solution is to design an asset taxonomy that supports strategic decision-making within Liander's Asset en Product Management (APM) department, specifically in relation to capacity enhancement initiatives. Since this objective is very broad, it is necessary to decompose it into a set of more specific and actionable objectives.

To structure the solution development process, the main objective has been divided into two categories of specific objectives. This distinction reflects the dual focus of the proposed solution. First, objectives related to the design of the asset taxonomy itself, these define the core functional and structural characteristics the taxonomy must exhibit in order to be usable, scalable, and relevant to Liander's operational environment. Secondly, objectives related to the mapping of capacity enhancement initiatives and policy documents onto the taxonomy, these ensure that the taxonomy not only captures the structure of grid assets, but also supports strategic analysis and planning by linking ongoing projects and policies to asset categories.

Asset taxonomy should...

- ... contain the assets involved within the electrical grid of Liander;
- ... be scalable, adaptable and extendable;
- ... be logically structured and easily navigable for APM users;
- ... allow for mapping of capacity enhancement initiatives and policy documents.

Taxonomy with initiatives and policy documents mapped should ...

- ... provide a comprehensive overview of existing projects aimed at enhancing grid capacity;

- ... enable the assessment of initiatives' impact on the electrical grid capacity;
- ... facilitate:
  - ... exploitation of synergies;
  - ... avoiding redundancies;
  - ... identifying deficiencies;
  - ... setting priorities

  ... between those initiatives.

5.2 Design asset taxonomy

Since one of the objectives for the asset taxonomy is to ensure it is logically structured and easily navigable for APM users, existing asset classification structures within Liander were considered during its design. Several data or asset structures were identified, however none of these resemble a hierarchical classification of the assets.

The Alliander Logisch Datamodel (ALDM) is a model-based framework of how Alliander communicates about reality and records it in its information systems. It is a company-wide communication model in which respective data owners define which data should be recorded by IT and how, as well as the meaning of this data. Essentially, it functions as a dictionary with definitions of a large number of terms. Within the ALDM, a concept similar to Object Oriented Programming (OOP) is implemented, the ALDM makes use of entities and attributes. Entities are things that exist within business terminology, can be uniquely identified and are subject to the recording of attributes. This way, entities resemble the objects from OOP. Attributes within the ALDM are descriptive properties of the entities and are similar to the attributes from OOP. Furthermore, the inheritance concept from OOP is also present within ALDM. Thus, although the Alliander Logisch Datamodel contains a lot of information that can be used throughout the whole organisation and possibly information relevant for this research, it does not provide a hierarchy within the entities meaning it is not an appropriate starting point for the development of the asset taxonomy.

While the ALDM provides a framework for registering both entities and attributes in information systems, Net Registratie GIS (NRG) serves as the actual register for all assets (both above and underground) that are either in operation or ready to be put into operation. It makes use of the structure as provided by ALDM combined with geospatial components. Unfortunately, NRG does not contain or resemble a hierarchical asset structure, making it unsuitable as a starting point for the asset taxonomy too.

After further exploration of potential starting points for the development of the taxonomy, the *ketenanalyse* as implemented within Liander was discovered. The *ketenanalyse*, which translates to chain analysis, allows for the identification of limiting components within each "chain" of the electricity grid. While the underlying principle of the analysis is not of interest at this point, the way in which the chain and subsequently the components of these chains are described is of interest.

Liander has defined five distinct chains within the electricity grid [68], these are listed in Table 5.1. A schematic representation of how and where these chains are positioned within a traditional electricity grid is provided in Figure 5.1. The division of the electricity grid into chains and the subsequent breakdown of these chains into components effectively forms a hierarchical structure of assets. This structure served as the foundation for the development of the asset taxonomy in this research.

Table 5.1: Terminology based on *Ketenanalyse* [68]

Internal terminology	English translation
HS verbindingsketen	High voltage connection
HS/MS transformatorketen	High to medium voltage transformer
MS verbindingsketen	Medium voltage connection
MS/LS transformatorketen	Medium to low voltage transformer
LS verbindingsketen	Low voltage connection

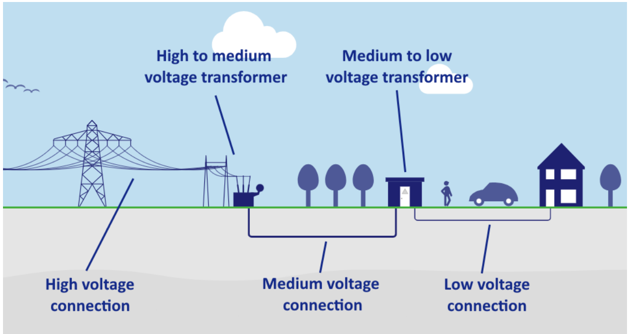


Figure 5.1: Chains electricity grid (adapted from: [69])

Based on the chains as presented in Table 5.1 and Figure 5.1, their breakdown into components [68] and general knowledge of the Dutch electricity grid [60], an initial draft for the asset taxonomy was developed. This draft has been made following the conceptual-to-empirical building approach as shown in Figure 3.3. This draft was reviewed by colleagues at Liander. Feedback from them highlighted that, while the overall structure was solid, a lot of assets were missing, both at lower levels in the taxonomy and at higher levels. For example, regulating and switching stations were not present in the draft. In addition, the terminology did not fit the current terminology as internally used. Based on the feedback on the draft, along with insights gained during a dedicated working session with a Liander colleague, the taxonomy was refined and expanded into its final version. While no ending conditions have been specified in the process, the iterations of the taxonomy development based on feedback from Liander staff follow the iterative character of the extended taxonomy design process as presented in Section 3.2.3.2.

The resulting asset taxonomy does not fully conform to the normative asset taxonomy structures as displayed in Figure 3.1 and the accompanying definitions as presented in Table 3.1. Therefore, adaptations to this normative structure had to be made. This resulted in the taxonomic levels as schematically shown in Figure 5.2 and defined in Table 5.2.

All of the assets within Liander's electrical grid are organized according to this structure. Figure 5.3 presents the first four levels of the taxonomy. The initial two levels define the scope of the assets included in the subsequent levels. These levels combined specify that the assets as part of the electrical grid as operated by Liander are displayed in the taxonomy. The third level differentiates between the various disciplines within Liander's operations. First, a distinction between transport and distribution of electricity is made. Subsequently, the distribution of electricity has been divided into voltage levels. At the fourth level, the previously introduced chains as part of the *ketenanalyse* are incorporated. These chains have been slightly redefined to align with more current and practical definitions.

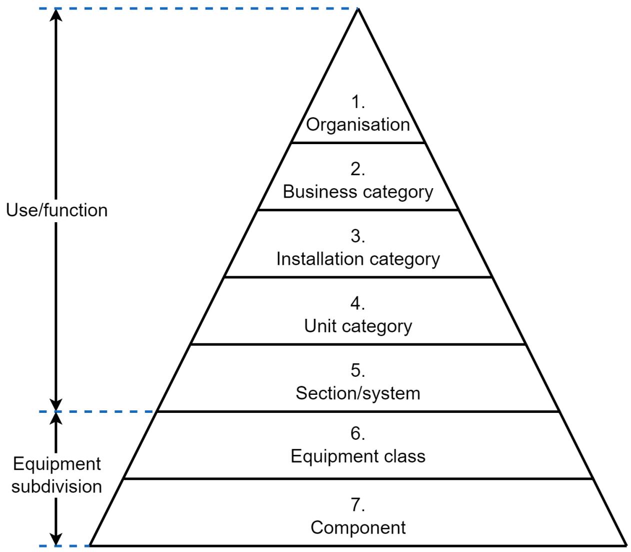


Figure 5.2: Taxonomy classification with taxonomic levels

Table 5.2: Definitions of asset taxonomy levels as implemented in the project

Main category	**Taxonomic level**		**Definition**
Use/location data	1	Organisation	The entity that owns and operates the grid, e.g. Liander.
	2	Business category	The specific type of utility grid, such as the electrical grid.
	3	Installation category	A system-level infrastructure within the grid, e.g. the transmission or distribution network.
	4	Unit category	A physical site or building within the installation, such as a substation.
	5	Section/System	A major functional component within a unit, such as a power transformer.
Equipment subdivision	6	Equipment class/unit	A specific asset or device group within a system, like the core and coil assembly of a transformer.
	7	Component	A replaceable part or subassembly of an equipment class, such as the primary coil of a power transformer.

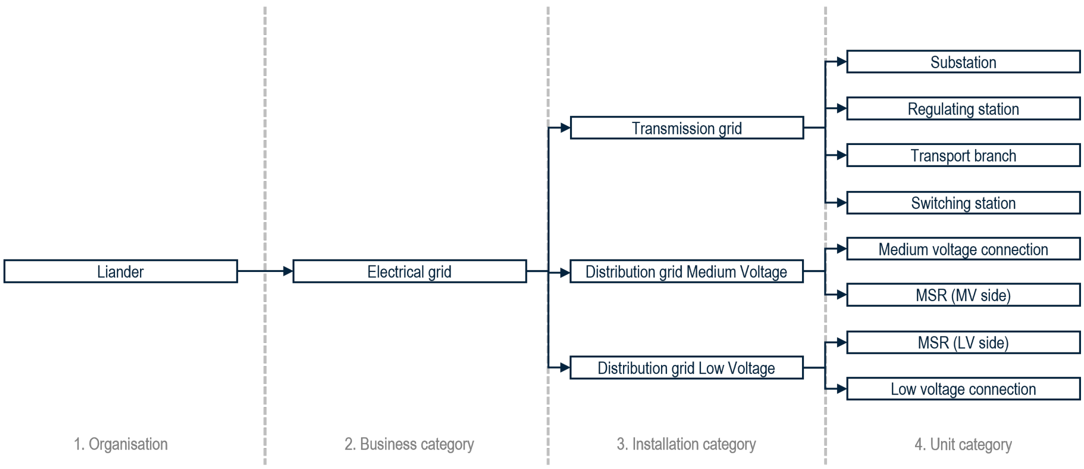


Figure 5.3: Taxonomy: main

For each of the building blocks at the fourth level as presented in Figure 5.3, components have been classified according to the taxonomic levels defined in Figure 5.2 and Table 5.2. For the substation this results in the structure as presented in Figure 5.4. Similar figures have been created for the other blocks and are included in Appendix C.1. By combining all the figures presented in Appendix C.1, the complete asset taxonomy of Liander's electrical grid can be obtained. With this, the last step of the extended taxonomy design process has been completed.

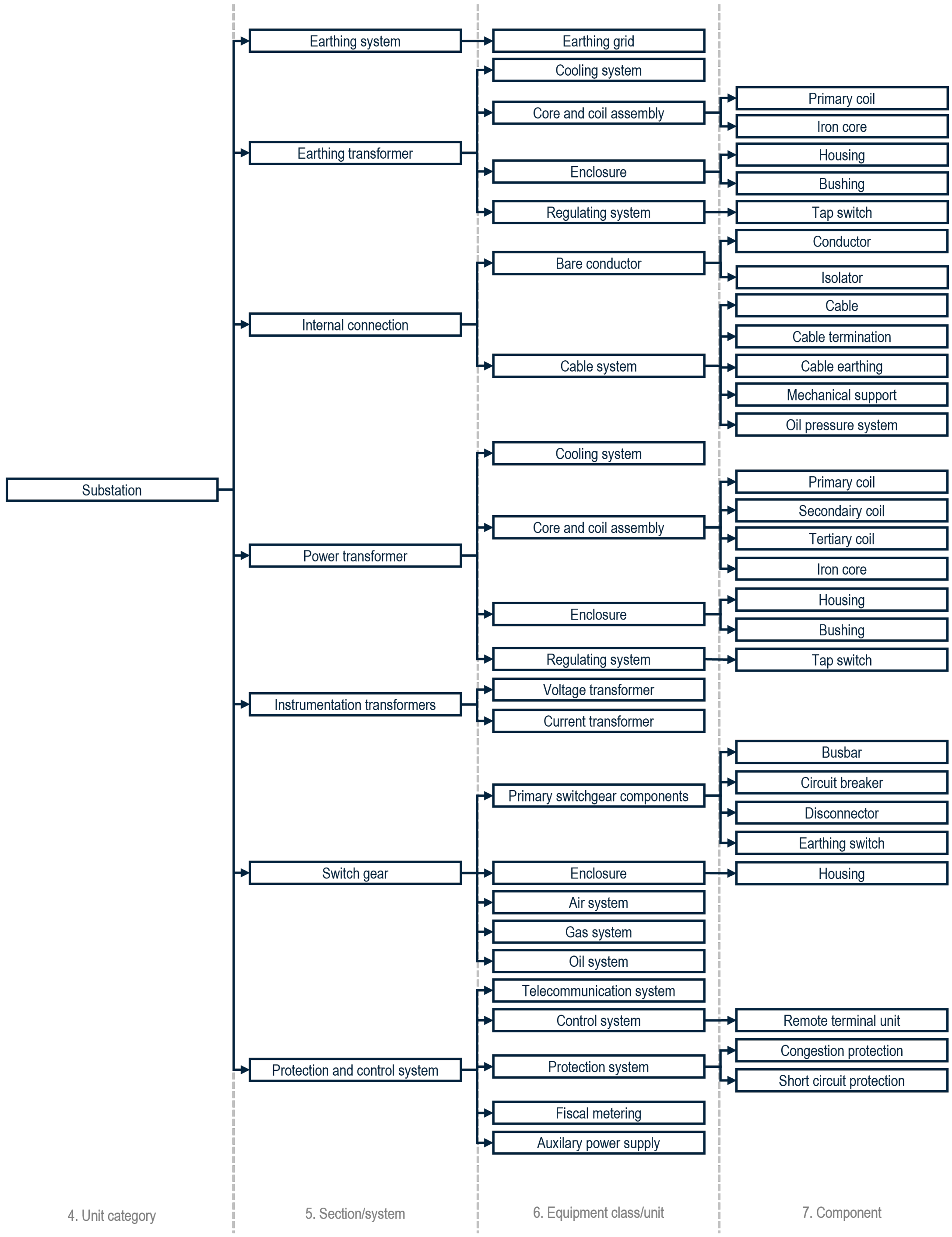


Figure 5.4: Taxonomy: substation

5.3 Mapping of initiatives and policy documents

With the asset taxonomy now established, the mapping of dynamic thermal rating initiatives and relevant policy documents can start. Before those can be mapped, they have to be identified. The identification of DTR initiatives within Liander is elaborated in Section 5.3.1, while the review of policy documents is discussed in Section 5.3.2. The final taxonomy including the results of the mapping process, is presented in Section 5.3.3.

5.3.1 Review of existing DTR initiatives

One of the goals of this research is to present a structured overview of initiatives that can serve as a foundation for strategic decision-making. As such an overview was not readily available, a key challenge has been to identify existing initiatives within Liander, particularly within the APM department, that are aimed at enhancing the capacity of assets. To address this challenge, a series of exploratory conversations were held with various colleagues from the APM department, including policy advisors, asset managers and product owners. These initial discussions helped identify initiatives and pointed to individuals with more in-depth involvement in these initiatives. Interviews were subsequently conducted with these individuals to gain a deeper understanding of the identified initiatives. Both the interview guide used to conduct the interviews and the comparison matrix used for interview analysis can be found in Appendix B.

From the conversations and in-depth interviews, five Dynamic Thermal Rating initiatives were identified. Team DALi (abbreviation for Dynamic Asset Limits) is responsible for developing and managing three of these. Team DALi focuses on the digital side of understanding dynamic asset limits for various types of assets. The Verbindingsteam is also involved in DTR initiatives. The team's mission is to be able to connect more customers to the current grid by enhancing the capacity of connections. One of the projects they are working on to achieve this mission is a model to obtain the thermal limit of these connections. Lastly, as part of the IDLEC program, a collaboration between Liander and the University of Twente, Cyril Dujava has been working on a model for condition-based load monitoring of cables. Table 5.3 presents an overview of all the identified initiatives, including descriptions and the teams responsible for each initiative.

Table 5.3: Capacity enhancement initiatives

Responsible team	Initiative	Description
Team DALi	Statisch/Fysisch blanke geleider model	A model that determines the asset-specific load capacity of bare conductors based on the ambient temperature, solar radiation and air movement.
	Transformatormodel	A model that calculates both the hotspot and top oil temperatures of transformers allowing the optimization of loading while managing the aging processes of the transformers.
	Schakelinstallatiemodel	A calculation method that offers guidelines for assessing the load capacity of switchgear installations by taking into account ambient temperatures and warm-up time.
Verbindingsteam	Dynamisch kabel model	A model that accurately calculates the temperature of high and medium voltage cables, taking into account environmental factors such as soil temperature, moisture levels and load profiles, which can vary over time, enabling the simulation of realistic scenarios.
Cyril Dujava (IDLEC)	Condition-based load monitoring model	A model that relates load to the degradation of cables to provide reliable information in enhancing the load limit of the cables.

5.3.2 Review of policy documents

The Liander *Assetbeleid* (asset policy) is a system of documents that is a normative framework for the implementation, management and approval of activities involving assets [70]. Within the system, a distinction between policy documents (*beleidsboeken*) and policy-supporting documents (*beleid motivatie documenten*) has been made. Policy documents outline certain actions concerning assets, while the supporting documents provide the reasoning and justification for those actions. Policy documents are labeled from B100 to B999, whereas the supporting documents are labeled from B1000 to B9999. Both types of documents have been considered in this research.

Although the list of documents is relatively extensive, not all of these documents are relevant to this research. Documents are considered relevant if they address capacity and/or (dynamic) loading of assets. The full list of documents was filtered accordingly. The process of filtering involved checking the titles for keywords related to the focus of this research. The documents that appeared relevant were then scanned to confirm their applicability. In some cases, this review led to the identification of additional relevant documents through references. The final selection of relevant policy(-supporting) is presented in Table 5.4.

Table 5.4: Relevant policy (supporting) documents

Document	Contents
B300 Bedrijfsvoeren van elektriciteit-snetten [71]	The standards, decision rules and policy criteria for the operation of the electricity grids managed by Liander
B400 Netontwerp en Standaardisatie Distributienetten Elektriciteit [72]	The standards, decision rules and policy criteria for the design and standardization of the distribution networks of Liander
B450 Instandhouden Distributienet [73]	The standards, decision rules, and policy criteria for the maintenance of the electricity grids managed by Liander
B500 Aanleg transportnetten elektriciteit [74]	The standards, decision rules and policy criteria for the design and construction of Liander's transmission networks.
B550 Instandhouden Transportnet [75]	The standards, decision rules and policy criteria for the maintenance of the transmission network managed by Liander
B4350: Overbelastingscriteria DB trafo's [76]	Description of load capacity of distribution transformers in medium voltage rooms based on thermal modelling
B4715: Acceptatiecriteria voor belastbaarheid van MS-kabels [77]	The maximum capacity of medium voltage cables
B5670: Lokale belastbaarheid van vermogenstransformatoren [78]	(Practical) information regarding dynamical loading of distribution transformers based on local properties
B5671: Optimaal benutten schakelinstallaties [79]	The maximum capacity of switchgear installations

5.3.3 Mapping initiatives and policy documents to taxonomy

With the initiatives and policy documents identified, the process of mapping these onto the asset taxonomy can begin. A visual approach has been chosen for this mapping, as it has been proven effective in promoting cross-disciplinary collaboration [54]. A color-coding system has been developed, with the legend presented in Figure 5.5.

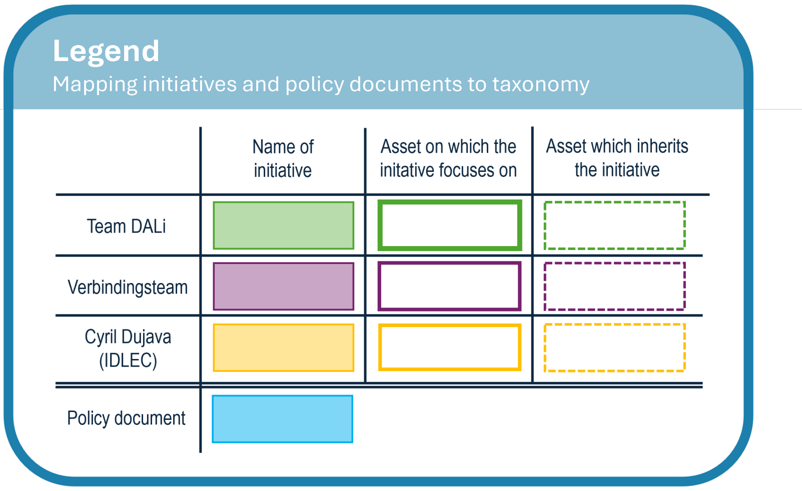


Figure 5.5: Taxonomy mapping of initiatives legend

Policy documents are represented by blue text boxes. In the taxonomic diagrams, these boxes are connected to the underside of the assets that are affected by the respective documents. In Figure 5.6, an example of this is presented. The figure, again, displays the first four levels of the taxonomy, however now with the relevant policy documents mapped to it.

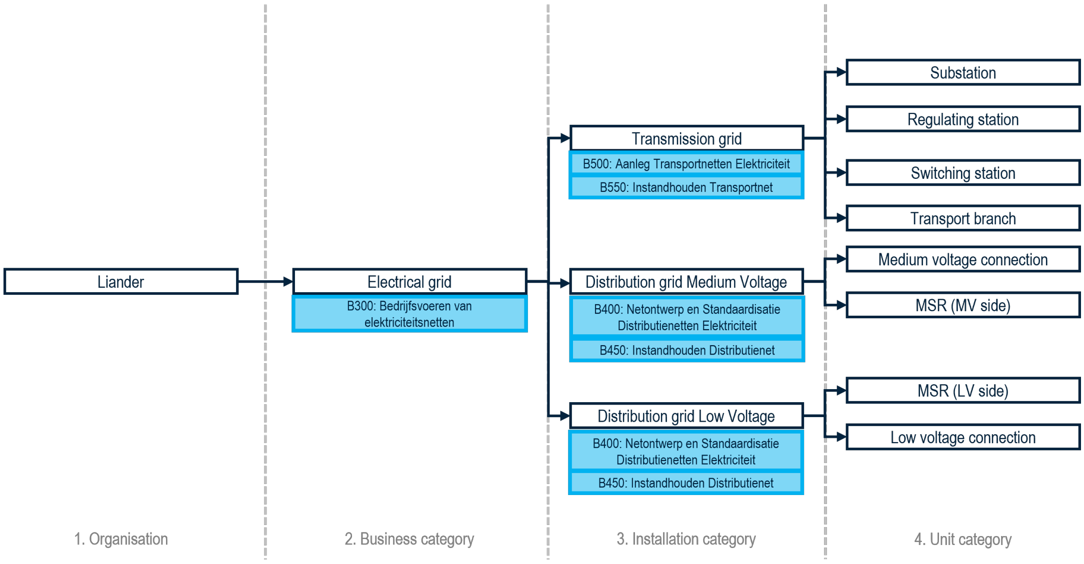


Figure 5.6: Taxonomy: main

While all policy documents are denoted with a single color, multiple colors are used to visualize the initiatives. Each responsible team is assigned a unique color. Initiatives are represented by boxes in the corresponding team color. Within the taxonomy diagrams, these boxes are attached beneath the asset they focus on. Additionally, the targeted asset is outlined in the team's color. Assets that are indirectly impacted by an initiative, meaning the initiative does not directly act upon them but this encompasses them, are shown with dashed outlines in the same team color.

Figure 5.7 presents the taxonomy structure of the substation, including the mapping of initiatives (and policy documents). Here, on can see that the *transformatormodel* is applicable to the power transformer, which is therefore given a colored outline. Since the implementation of this model affects the transformer as a whole, all of its underlying components are also covered and are therefore indicated with dashed outlines in the same color.

Additionally, one can also see that for the cable as part of the cable system used as an internal connection, two initiatives are being worked on. Namely the *dynamisch kabel model* from the *verbindingsteam* and the *condition-based load monitoring model* by *Cyril Dujava*. Both initiatives are attached to the block of the cable, which receives a double outline in the colors representing the respective project teams. Although the *dynamisch kabel model* focuses directly on the cable itself, it also encompasses the broader cable system, including cable terminations, joints and other components. Therefore, the entire cable system is marked with a dashed outline in the color of the *verbindingsteam*.

Again, similar figures have been created for all of the building blocks as presented in the fourth level of the taxonomy structure, these can be found in Appendix C.2. By combining all these diagrams, the complete asset taxonomy of Liander's electrical grid including the mapping of initiatives and policy documents can be obtained.

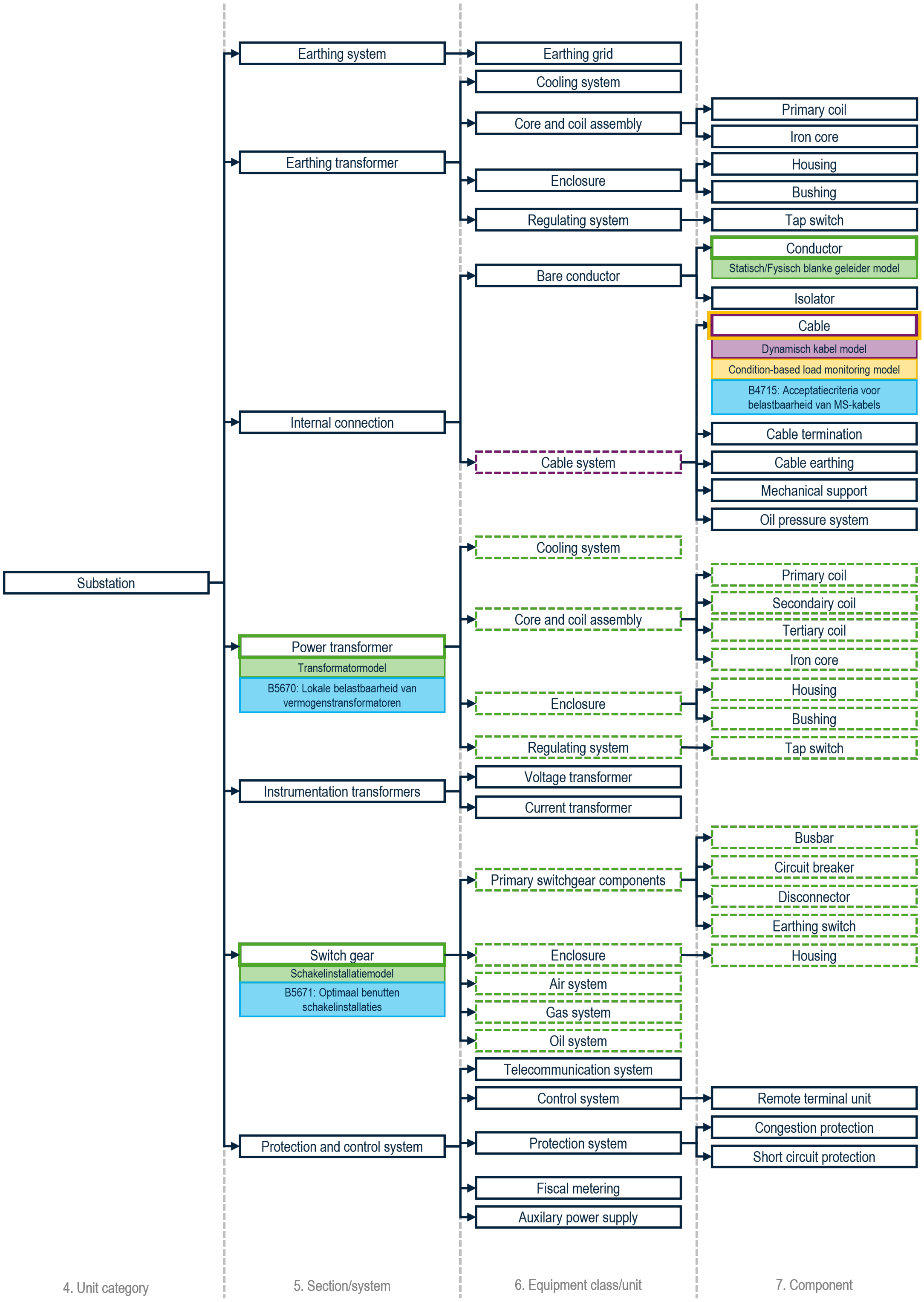


Figure 5.7: Taxonomy: substation

6 CASE STUDY: LIANDER

With the design and development phase, resulting in the asset taxonomy with both policy documents and capacity enhancement initiatives mapped to it, as presented in Chapter 5 now complete, the next phase of the DSRM process can begin. In this phase, the asset taxonomy is demonstrated as a tool to support strategic decision-making. The demonstration involved a case study conducted in a workshop with eleven colleagues from Liander's Asset en Product Management (APM) department. This chapter elaborates on the design of the case study, while the outcomes of the case study are discussed in the evaluation phase as presented in Chapter 7.

6.1 Objectives of the workshop

The primary goal of the workshop is to validate the objectives of the solution as presented in Section 5.1. The first of the objectives to be assessed is whether the asset taxonomy is logically structured and easily navigable for users within the APM department. In addition, the workshop aims to validate the objectives related to the mapping of initiatives and policy documents within the taxonomy.

Accordingly, the workshop aims to validate the following objectives of the asset taxonomy:

1. The asset taxonomy is logically structured and easily navigable for APM users.
2. The asset taxonomy with initiatives and policy documents mapped provides a comprehensive overview of existing initiatives aimed at enhancing grid capacity.
3. The asset taxonomy with initiatives and policy documents mapped enables the assessment of the impact of the initiatives on the electrical grid capacity.
4. The asset taxonomy with initiatives mapped facilitates the...
    - exploitation of synergies...
    - avoiding redundancies...
    - identifying deficiencies...
    - setting priorities...

    ... between the initiatives.

6.2 Participants

A group of colleagues involved within the theme of *Zwaarder Belasten Assets (ZBA)* were invited to participate in the workshop. Most of those invited joined, resulting in a relatively large group of eleven participants. This group included four asset managers, three consultants, two policy advisors, one product owner and finally a department coach.

Although all of these are involved with the theme, they have different perspectives and different areas of expertise. Some are focused on specific research related to individual assets, while others are involved in broader initiatives related to grid capacity enhancement. This mix of knowledge and experience makes the group a strong representation of the various roles within Liander working on the theme of capacity enhancement.

6.3 Workshop design

To facilitate the workshop, several supporting materials were developed. These involve a presentation, a worksheet and a pitch template. The presentation guided the entire session and included all the information necessary for the participants. The slides of this presentation are displayed in Appendix D.2 (Figure D.2 - D.36). The worksheet, used by the teams during the case study, is discussed in more detail in the following sections and it is attached in Appendix D.1. Each team received a printed version on A0-sized paper during the session. The pitch template is attached in Appendix D.3. This template has been distributed to the participants via e-mail.

While some participants of the workshop have been involved in earlier stages of this research, some others were not yet familiar with the research at the start of this workshop. Therefore, the first section of the workshop has been dedicated to introducing the research. This involved the problem definition and motivation, key design objectives, the approach during the design and development phase and finally showing and explaining the final asset taxonomy.

Following this introduction, the goal of the workshop was clearly communicated to all participant, establishing the context for their engagement during the case study.

6.3.1 Approach of case study

With the research and workshop introduced, the case study can begin. This subsection outlines the step-by-step approach during the workshop, detailing each phase of process. A time schedule of the phases can be found in Table 6.1.

Table 6.1: Time schedule of workshop

Phase		**Duration (minutes)**
Introduction		10
Approach		3
Introduce case study		2
	Individual brainstorm	10
	Share findings in group	10
Case study	Impact effort matrix	10
	Prepare pitch	10
	Pitch	20
Reflection		5
Feedback taxonomy		10
Total		**90**

First, the participants were divided into three project teams. These teams have been generated at random, to ensure that the knowledge and expertise of the participants are equally distributed over the teams.

6.3.1.1 Explanation case study

Participants were presented with the following fictional scenario:

> *”A new EU subsidy scheme has been launched to support initiatives aimed at increasing the load-bearing capacity of assets within the electricity grid. Within Liander, only one project can be nominated to receive this funding.”*

In this scenario, each group was asked to act as a multidisciplinary expert team from the APM department. Their task was to determine which strategic focus should be chosen for this new project. The goal is not only to identify a research direction with the highest potential value for Liander, but also to secure the subsidy by building a convincing case for the project.

Although the scenario was designed to reflect a realistic context, as part of storytelling as described in Section 3.3.1, it was explicitly communicated to the participants that it was fictional. This helped to reduce pressure and encourage open discussion among the participants.

6.3.1.2 Brainstorming research direction (individual)

In the first phase, in which participants had to be active, they were tasked with studying the asset taxonomy (as presented on the worksheet) in detail. The aim was to explore potential gaps between existing initiatives and identify areas within the electrical grid that are currently not addressed by initiatives.

Participants were instructed to identify two to three ideas for new projects that could strengthen the capacity of the electricity grid. Each idea had to be written on two separate post-it notes.

This process was carried out individually. This approach encouraged each participant to form their own perspective, free from group influence, ensuring a wide variety of insights and proposals for the next, collaborative stage of the workshop. This reflects the *blue-card method* as described in Section 3.3.1.

6.3.1.3 Identify research directions (group)

After the individual ideation phase, participants shared and discussed the ideas in their assigned project teams. First, similar ideas within the teams had to be combined. Secondly, each group assessed the relevance of their ideas within the context of the asset taxonomy. They were asked to determine which assets would be impacted by the proposed research directions and to physically place one of the post-its onto the corresponding sections of the asset taxonomy.

This activity encouraged dialogue, alignment, and strategic thinking, allowing participants to jointly explore how their ideas fit within the broader asset landscape.

6.3.1.4 Assign impact effort matrix (group)

In this phase, the team is tasked with placing the research directions as identified in the previous step onto the Impact Effort matrix (similar to value/ease grid as introduced in Section 3.3.1) as provided on the worksheet. The remaining post-it notes should be used here. Within the matrix, four categories are distinguished [80]:

- *Quick wins* (high impact, low effort),
- *Major projects* (high impact, high effort),
- *Fill-ins* (low impact, low effort), and
- *Thankless tasks* (low impact, high effort).

The definitions of impact and effort are consciously not provided. This encourages teams to interpret these dimensions independently, resulting in open discussion and reflections. This process gives free space for the participants, while also offering valuable insights for the researchers into the participants' perspectives and decision-making processes.

6.3.1.5 Prepare pitch (group)

In the final stage of the workshop, each group was asked to select one of the proposed research directions. This decision was to be based on the combination of expected impact on the electrical grid and the estimated effort required for implementation.

For this chosen research direction, a three-minute pitch to present their idea to the rest of the participants had to be prepared. The goal of this pitch was to convince the others of the added value of their selected research direction and to demonstrate why it should receive the fictional EU subsidy. To support their pitch, each group used a PowerPoint template that guided them in clearly presenting the rationale behind their selection, elaborating on their proposed solution, and explaining their assessment of the impact and effort involved.

6.3.1.6 Pitch

In this phase of the workshop, each group was given the opportunity to present their pitch to the other participants. Each group had three minutes to present their research direction, followed by a brief period for questions and discussion. This allowed the participants to ask clarifying questions.

6.3.2 Data collection

Since the aim of the workshop is to validate specific objectives for the asset taxonomy, data regarding these objectives has to be collected. One method used for this is a survey. This survey is created in the online tool of *Wooclap.com*. The full list of questions as implemented in the survey is presented in Appendix E.1. Below, a substantiation of these questions is given.

For each of the objectives described in Section 6.1, a question in the survey is formulated. Each question presents a statement related to the respective objective, allowing respondents to express their opinion using a 5-point Likert scale ranging from strongly disagree to strongly agree.

In addition to these questions directly related to the objectives, two open questions are added. The first asks whether the asset taxonomy is a useful tool for strategic decision-making, and if so, why. This question was designed to gather feedback on the design of the taxonomy and provide insights for drawing conclusions. The second open-ended question asks respondents to provide three key words that come to mind when thinking about the asset taxonomy. These keywords were then visualized using a word cloud generated by *Wooclap.com*.

7 RESULTS

This chapter focuses on the evaluation phase as outlined in the Design Science Research Methodology. It assesses the effectiveness of the asset taxonomy as a tool to support strategic decision-making by validating the objectives specified in Section 5.1. Some objectives are validated through the development process itself, while others require input from potential users of the tool. Therefore, feedback collected in the survey taken during the workshop is used to evaluate these latter objectives.

7.1 Evaluation based on development process

This section addresses the objectives that can be evaluated through the development process of the asset taxonomy. The objectives are listed below, followed by an individual evaluation of each.

- The asset taxonomy contains the assets involved within the electrical grid of Liander.
- The asset taxonomy is scalable, adaptable and extendable.
- The asset taxonomy allows for mapping of capacity enhancement initiatives and policy documents.

As no existing classification or inventory of assets within Liander's electrical grid was identified during this research, it is not possible to objectively verify the completeness of the taxonomy against a definitive source. Consequently, the evaluation of this objective relies on the expert judgment of the colleagues who contributed to the taxonomy's development. Their involvement throughout the iterative design process as described in Chapter 5 provides enough confidence that the taxonomy reflects the assets within the electrical grid of Liander.

Since the completeness of the asset taxonomy cannot be objectively verified, it is important that the artifact is designed to be scalable, adaptable and extensible. This ensures that any currently missing assets can be incorporated. Additionally, this flexibility enhances the taxonomy's ability to remain useful over time, which is particularly important with the expected developments in the (Dutch) electricity infrastructure.

As part of this research, not only is the asset taxonomy presented as an artifact, also the underlying structure and definition of the taxonomic levels as presented in Figure 5.2 and Table 5.2, respectively. This structure, combined with the definitions, allows future users to include additional assets into the taxonomy. Furthermore, if deeper levels of detail are required for future analyses, additional taxonomic levels can be integrated into the existing framework. In this way, scalability, adaptability and extendibility are supported by the provided taxonomy structure.

The final objective discussed in this section relates to the mapping of initiatives and policy documents, which serves as a design criteria to support further development of the asset taxonomy as a tool for strategic decision-making. Since this mapping has been successfully carried out, as presented in Section 5.3, this objective can be considered to be validated, too.

7.2 Evaluation based on survey results

In this section, the objectives that the workshop aimed to address, as outlined in Section 6.1, are evaluated. Each objective is reflected in the survey questions provided to the participants, which are included in Appendix E.1. It has been chosen to implement a five-point Likert scale: strongly agree (score 5), agree (4), neutral (3), disagree (2) and strongly disagree (1). The survey results serve as the basis for assessing the extent to which each objective was achieved. In Figure 7.1, results of each question and/or statement have been visualized. The bars in the chart represent the average Likert scale score, with error bars indicating one standard deviation above and below the average. Both bar charts representing the frequency of given answers to each question and the raw data used to generate these charts can be found in Appendix E.2. The following analysis interprets the results in relation to the objectives.

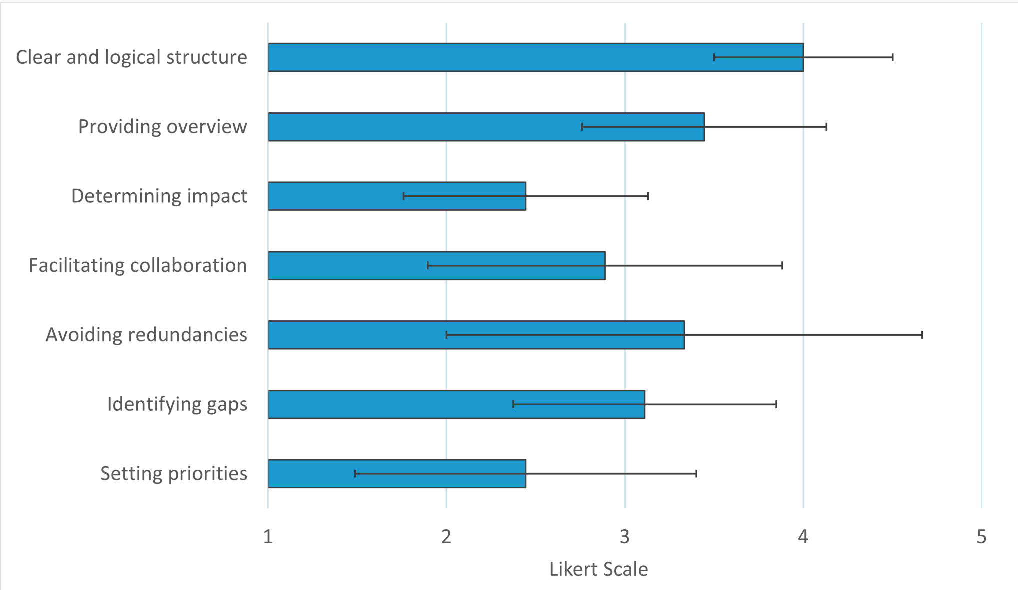


Figure 7.1: Results of Question 1 to 4 indicated by keywords

As can be seen from the results of the first question, the statement *the asset taxonomy has a clear and logical structure*, as presented in Question 1, received an average rating of 4 on the Likert scale, reflecting a general agreement among participants. The relatively small standard deviation shows that the responses are clustered around the average score. Based on the replies, it can be concluded that the taxonomy is generally perceived as clear and logical by the people from the Asset en Product Management department involved in the *Zwaarder Belasten Assets* theme.

From the results on the second question it becomes clear that participants of the workshop generally agreed to the statement that *the asset taxonomy effectively provides an* *overview of existing initiatives and policy documents related to capacity enhancement initiatives*. Although the average score is just below 4 and the standard deviation is larger compared to the one for Question 1, the overall sentiment is positive. These results suggest that the taxonomy is viewed as a useful tool for offering an overview, while also highlighting some potential for refinements.

The statement concerning the taxonomy's role in *supporting the assessment of an initiative's impact on grid capacity* on average scored on the negative side of the Likert scale (2.44), as can be seen from the results for Question 3. While one participant agreed with the statement and others responded neutrally, the conclusion that can be drawn from the results is that certain elements are missing in the overview to effectively determine the impact of initiatives. This points to a need for further development or the inclusion of additional criteria to better support impact assessment.

The results for the first statement in Question 4 indicate a slightly negative overall perception of the taxonomy's ability to *facilitate collaboration between initiatives*. However, the relatively large standard deviation indicates large differences in opinions of participants, making it hard to interpret the results and draw conclusions. Hypothetically, the negative responses are a result of a badly formulated question. It is expected that the formulation 'collaboration between initiatives' is too vague. Alternatevely, the statement could be formulated as 'the asset taxonomy supports shared understanding and communication between stakeholders involved in the initiatives', which offers more context to collaboration. Validating this hypothesis should be the subject of future research.

Looking at the responses on the second statement of Question 4, the average score is slightly above 3 on the Likert scale. This indicates that some participants recognize the value of the taxonomy *in avoiding redundancies within initiatives*. However, the high standard deviation shows a wide range of opinions among respondents. Altogether, this makes it difficult to draw definitive conclusions on this statement.

For the third statement of Question 4, the average score is even closer to 3, indicating a largely neutral perception regarding the taxonomy's role *in facilitating the identification of gaps between existing initiatives*. The relatively low standard deviation suggests that the views of the participants are fairly consistent. From the responses it can be concluded that while the participants show some potential for the taxonomy in supporting gap analysis, there is still room for improvement.

The results on the fourth statement as part of Question 4, the average score is between 2 and 3 on the Likert scale. This suggests a tendency towards disagreement with the idea that *the asset taxonomy facilitates setting priorities within existing and/or new initiatives*. The standard deviation shows some variability in responses, although this is not massive. Thus, based on these responses it can be concluded that the taxonomy currently lack certain aspects required to effectively support setting priorities within initiatives. It is expected that this is closely related to the aspect of assessing the impact of initiatives. As most participants believe the taxonomy, currently, does not effectively determine initiative impact, and understanding impact is essential for prioritization, it follows that the taxonomy does not support prioritization.

7.3 Additional insights from survey

Although Questions 5 and 6 of the survey are not directly related to the objectives of the asset taxonomy, useful insights can be drawn from the responses to these questions. In this section, these insights will be outlined. The raw data used to formulate these insights can be found in Appendix E.2, specifically Table E.4.

In Question 5, respondents were asked whether they considered the asset taxonomy a useful tool for strategic decision-making and were encouraged to elaborate on their answer. In the sixth question of the survey, participants were asked to provide three keywords that first came to mind when thinking of the asset taxonomy used during the workshop. A wordcloud was generated based on these keywords, as displayed in Figure 7.2. The wordcloud is presented in Dutch, but the English translations of the input keywords are provided in Table E.2.

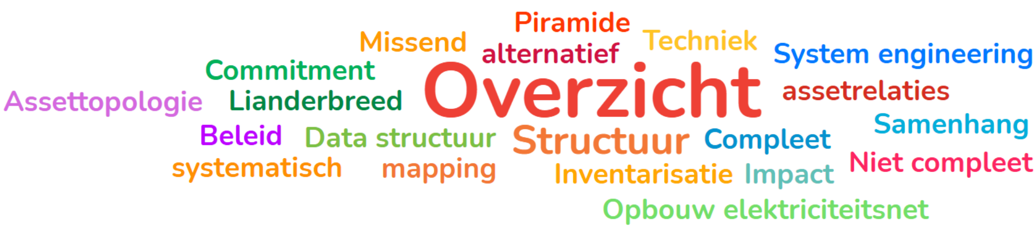


Figure 7.2: Results question 6, Wordcloud

From the responses given to Question 5, as displayed in Table E.1, it can be concluded that the asset taxonomy is generally seen as a valuable tool for structuring information. Several respondents have highlighted the role of the taxonomy in providing an overview of assets and accompanying initiatives. This suggests that the taxonomy supports some important aspects of the process of strategic decision-making. This general view can also be seen in the wordcloud as presented in Figure 7.2, where terms like *overzicht* (*overview*) and *structuur* (*structure*) appear prominently.

However, respondents have mentioned some limitations. Multiple participants note that the taxonomy is missing some information to fully support decision-making. This is reflected in the wordcloud as well, as e.g. *niet compleet* (*not complete*) and *missend* (*missing*) can be found here. Others fear that it will be difficult to implement the tool within Liander as it depends on the input of stakeholders. In addition, someone mentioned that it is too late to implement the tool as initiatives are already being worked on and thus certain decisions have already been made. Future work could explore these limitations in more depth.

In summary, the responses to the open questions support the findings from the questions that implemented the Likert scale. The taxonomy is appreciated as a tool that can be used to lay a foundation for strategic decision-making within the theme of capacity enhancement of existing assets. However, it is not yet considered to be complete in the information it contains, to fully support the process of strategic decision-making. Thus, further improvements and refinements are needed to unlock the full potential of the tool.

8 DISCUSSION

8.1 Interpretation of results

In this section, the results as presented in Chapter 7 are interpreted with the aim of answering the research questions as outlined in Section 1.1. Each sub-question will be addressed individually. Together, these answers will contribute to a comprehensive answer to the main research question.

The first of the sub-questions concerns the development of a taxonomy of assets that acts as an effective way of representing the electrical grid operated by Liander. This development was guided by specific objectives, as presented in Section 5.1, and subsequently evaluated in Section 7.1. Based on this evaluation it can be concluded that, although assessing the completeness of the taxonomy is challenging, the resulting artifact is scalable, adaptable and extendable. Responses to the first question of the survey as part of the workshop indicate that the taxonomy has a clear and logical structure. Therefore, the asset taxonomy developed in this research can be considered an effective representation of the assets involved in the electrical grid, particularly for stakeholders within Liander's Asset en Product Management department.

The second sub-question concerns the mapping of initiatives and policy documents to the asset taxonomy, which was also considered part of the development of the artifact. In Section 5.3 the process of mapping the initiatives and relevant policy documents is described. In this research, a visual approach has been implemented. Here, blocks representing initiatives or policy documents were attached to the taxonomy using to a defined color scheme. While it cannot be claimed that this approach represents the optimal method for such mapping, survey responses to the second question indicate that the taxonomy provided participants with an effective overview of the existing initiatives and policy landscape. This suggests that the chosen visualization method is useful for mapping initiatives and policy documents to the asset taxonomy.

The third sub-question is more challenging to address as it involves the way stakeholders perceive the function and value of the artifact. To evaluate this aspect, a workshop in which participants engaged with the asset taxonomy in a practical context was conducted. The survey at the end of the workshop provides insights useful in answering the sub-question.

The responses on the survey indicate that the asset taxonomy is a useful tool when identifying gaps between initiatives and detecting possible redundancies. However, it currently lacks information to fully support the assessment of initiative impact and the process of prioritization within initiatives. Despite these limitations, most respondents replied positively to the question of whether the taxonomy supports strategic decision-making. Thus, in its current form, the asset taxonomy supports strategic decision-making related to increasing the load capacity of the electrical grid to a certain extent, while highlighting areas for improvement.

With each of the sub-questions now individually addressed, their insights can be combined to formulate an answer to the main research question: *How can an asset taxonomy support strategic decision-making in increasing the capacity of electrical grids using existing assets?*

This research demonstrates that an asset taxonomy can support strategic decision-making by providing a structured overview of electrical grid assets, along with associated capacity-enhancing initiatives and policy documents. This overview serves as a tool for identifying gaps and avoiding redundancies between initiatives. While the taxonomy does not yet cover all aspects of strategic decision-making related to the initiatives, it provides a foundation for more informed decision-making. Future enhancements to the taxonomy's content are expected to further increase its value for the strategic decision-making process.

8.2 Contribution to Existing Research

This research aimed to address a gap in existing literature on the facilitation of strategic decision-making through the systematic classification of assets and related information. In particular, it explored the use of an asset taxonomy as a decision-support tool in the context of increasing electricity grid capacity using existing assets. While asset taxonomies have traditionally been applied for classification, inventory and maintenance purposes, their strategic role in aligning and evaluating capacity-enhancing initiatives has remained underexplored.

By conceptualizing and implementing a structured taxonomy of electrical assets, this research demonstrates how an asset taxonomy can serve as a systems-oriented architectural view of the grid. It enables stakeholders to map and assess existing initiatives and policy documents in a structured manner. This supports the identification of redundancies, gaps, and synergies across initiatives, thereby contributing to more coordinated and informed strategic planning.

As such, the research contributes to existing research by offering both a practical artifact and an evaluative framework that can be adapted by other DSOs or infrastructure-heavy organizations facing similar challenges. It invites further research into the strategic applications of asset taxonomies and their integration into broader asset management and planning processes.

8.3 Limitations and future work

While this research provides a promising approach to using asset taxonomies as tools for strategic decision-making, several limitations should be acknowledged.

Firstly, the design and development of the taxonomy is primarily based on input from a limited group of colleagues within Liander, all involved in the Asset en Product Management department. While this focus on the APM department was a deliberate choice, it introduces a limitation in the research outcome. As a result, the artifact created in this research may reflect a partial view of organizational needs and practices. The availability, roles and expertise of those consulted can have influenced both the structure of and the information contained in the taxonomy. This influence may also extend to the selection and representation of initiatives and policy documents mapped to the taxonomy. Despite the researcher's efforts to identify all relevant elements, it cannot be guaranteed that the taxonomy captures every aspect.

Secondly, the evaluation phase, i.e. based on the survey, relied on feedback from a relatively small number of participants. Nine individuals in total who engaged with the taxonomy during a workshop. Although their responses provided valuable insights, the limited number of participants affects the reliability of the findings. Additionally, the way the workshop was structured and facilitated may have influenced how participants interacted with the artifact, potentially affecting their assessment and responses.

In light of these limitations, several opportunities for future research and development are identified. A first opportunity lies in enriching the content displayed in the taxonomy. Further research could investigate what specific types of information are most relevant to stakeholders when making strategic decisions. One can think of including information regarding nominal or static limits in the taxonomy. By aligning the taxonomy's content more closely with the needs, its utility and impact on decision-making processes could be significantly enhanced, especially in terms of assessing the impact and prioritization of initiatives.

A second step involves increasing user training and familiarization. Educating stakeholders on how the taxonomy can be used as a tool for strategic decision-making may shift their perception of its value and functionality. As users better understand its potential applications, new insights may emerge regarding both its strengths and areas needing refinement, as well.

Although the current research did not explore this in depth, a promising direction for future work lies in the expansion of the structural dimension of the taxonomy. Currently, the taxonomy follows a hierarchical structure as proposed in ISO 14224 [18]. However, introducing 'dimensions' based on other characteristics may improve the applicability of the taxonomy. For instance, one can distinguish different types of distribution transformers, such as whether they are enterable or non-enterable; ventilated or non-ventilated; or located in urban versus rural environments. These characteristics might influence the validity of initiatives, particularly as those become more detailed. Mapping these variants onto the taxonomy would allow for a more precise alignment between initiatives and asset types.

This possible addition of dimensions to the taxonomic structure directly leads to another aspect of future work, namely, the way the taxonomy is displayed and can be navigated. As the taxonomy is already relatively large and will grow in size when more information is added, visualizing it in an effective way might become problematic. Therefore, presenting the structure as less static and more interactive will benefit users. As a solution, programs like *Power BI* might be considered as this supports interactive exploration of the taxonomy. Features like applying filters on information, collapsing of taxonomic levels and displays based on user roles would ensure stakeholders see information relevant to their context. This not only improves usability but also strengthens the taxonomy's role as a practical decision-support tool.

Finally, future work could explore the broader applicability of the taxonomy beyond the current context. For instance, using the taxonomy as a foundation for criticality analysis, risk assessment, RAM analysis (Reliability, Availability and Maintainability) or scenario planning may unlock additional strategic value. These expanded use cases could help integrate the taxonomy more deeply within asset management frameworks and planning tools.

Together, these improvements can contribute to the development of a more robust and versatile artifact. Not only could this enhance its effectiveness within the context of Liander, but it may also offer valuable lessons and applications for other distribution system operators and infrastructure-oriented organizations facing similar challenges.

9 CONCLUSION

The rapid growth in electricity demand in the Netherlands, driven by the electrification of heating, transportation, and industry, has placed significant pressure on the existing grid infrastructure. Coupled with the variability of renewable energy sources, this demand has led to increasingly frequent grid congestion. Grid reinforcement is often the long-term solution, but its implementation is hampered by limitations such as workforce shortages and long lead times. Therefore, innovative strategies that leverage existing assets, such as Dynamic Thermal Rating (DTR), are essential to enhance grid capacity in the short term.

This research explored how an asset taxonomy can support strategic decision-making to increase the load capacity of the electricity grid by better utilizing existing assets. The study aimed to bridge a research and practice gap by introducing a structured classification of grid assets that links ongoing initiatives and relevant policy documents to the assets, thereby supporting more coordinated and informed planning.

Using the design science research methodology, an asset taxonomy was developed and evaluated. The taxonomy provided a clear overview of Liander's electrical grid assets and made it possible to map capacity-enhancing initiatives and policy documents. It facilitated the identification of gaps and redundancies in ongoing initiatives, offering a first step toward strategic alignment. Feedback gathered through a workshop indicated that the taxonomy is a promising tool, but its usefulness and ability to support decision-making would improve with more detailed content. The assessment of the impact of initiatives on the whole system and subsequently prioritization of these initiatives is expected to benefit most of this.

In summary, the research shows that asset taxonomies, traditionally used for operational and maintenance purposes, can also serve a strategic role. When structured and visualized effectively, they can become powerful tools for decision-makers navigating complex infrastructures. While the artifact developed in this research represents a promising first iteration, it also sets the stage for future enhancements within and beyond the context of Liander.

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A USAGE OF ARTIFICIAL INTELLIGENCE

Conforming the guidelines of the University of Twente concerning ”Use of AI in Education at the University of Twente” [81], the following statement can be made.

During the preparation of this work, I used the following tools for the following reasons.

- *ChatGPT* has been used to enhance the academic tone and improve the flow of certain paragraphs in this report.

After using this tool/service, I thoroughly reviewed and edited the content as needed, taking full responsibility for the final outcome.

B INTERVIEWS

B.1 Interview guide to investigate initiatives

Research information

- What is the name of your research?
- What department is involved in the research?
- Is there a document I can read that explains/elaborates the research?
- What is the specific focus of your research? How does your research address current challenges in the electricity grid?
- Does it focus on a specific asset class, asset type, subcomponent etcetera?
- What is the objective of your research?
- Which method are you implementing?
- Do you plan on validating your work? If so, how?
- What data is critical as input for your work?

Integration with other initiatives

- What efforts are made to align your work with other initiatives?
- How does your work connect with other initiatives in this domain?
- Do you see overlap/synergy with other initiatives?

Future work

- Have you identified challenges in your project which need to be addressed? Do you need extra/new information for this?
- Do you see potential of your work in other research areas (within Liander)?
- Do you foresee challenges in integrating your findings into existing operational frameworks?

B.2 Comparison matrix

Table B.1: Overview of Research Themes and Findings

Theme		Interview 1	Interview 2	Interview 3
Research Information	Name	Dynamisch kabel model	Transformatormodel	Condition-based load monitoring model
	Responsible team/person	Verbindingsteam	Team DALi	Cyril Dujava (IDLEC)
	Focus	Capacity limit of cables	Thermal limit of transformers	Capacity limit of cables (and other components)
	Asset class/ component	High and Medium Voltage cable systems, specifically GPLK cables and cable joints	Power and distribution transformers, a specific categorization in these might be relevant	Cables
	Objective	Determine new capacity limits for cables based on models	Determine new capacity limits for transformers based on thermal models	Determine new capacity limits by implementing a condition-based load monitoring model
	Method	Thermal models and condition-degradation models	Thermal model, which encompasses a simplified representation of the numerous components of a transformer	Condition-based load monitoring model
	Input	Properties of cables and data obtained from *meettegel* in combination with load profiles	Relevant properties of transformer, load profile, environmental temperature profile	Operating (environmental) conditions and properties of cables
Other Initiatives	Integration	No integration with other initiatives	Team DALi (responsible for transformatormodel) is working on two other thermal models (schakelinstallatiemodel and blankegeleidermodel)	No integration with other initiatives
	Synergy	No synergy identified	The models worked on by Team DALi use similar underlying principles	n.a.

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Theme (continued)		**Interview 1**	**Interview 2**	**Interview 3**
	Collaboration	Collaborate on targets and overarching starting points with other teams	Team DALi is working on multiple models and this way is collaborating on these, however each model has their own experts	n.a.
Future Work	Identified challenges	Developing a generic framework for more tailored analyses	Deep learning model that is transformer or categorical specific, and many more.	Project is starting up, therefore there are a lot of uncertainties
	Future potential/ scalability	n.a.	Possibly, insights that are useful for the other thermal model	n.a.
	Integration in existing system	No challenges identified	n.a.	n.a.

C TAXONOMY

C.1 Taxonomy diagrams

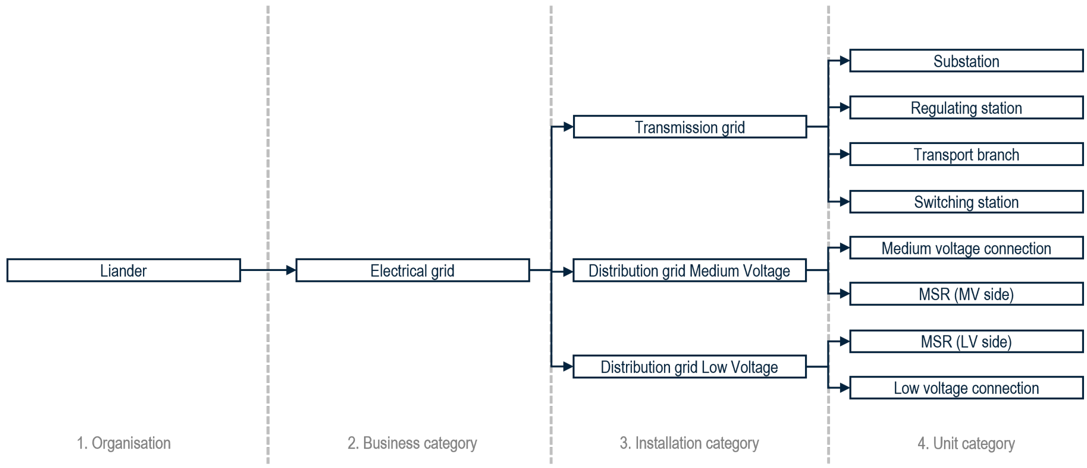


Figure C.1: Taxonomy: main

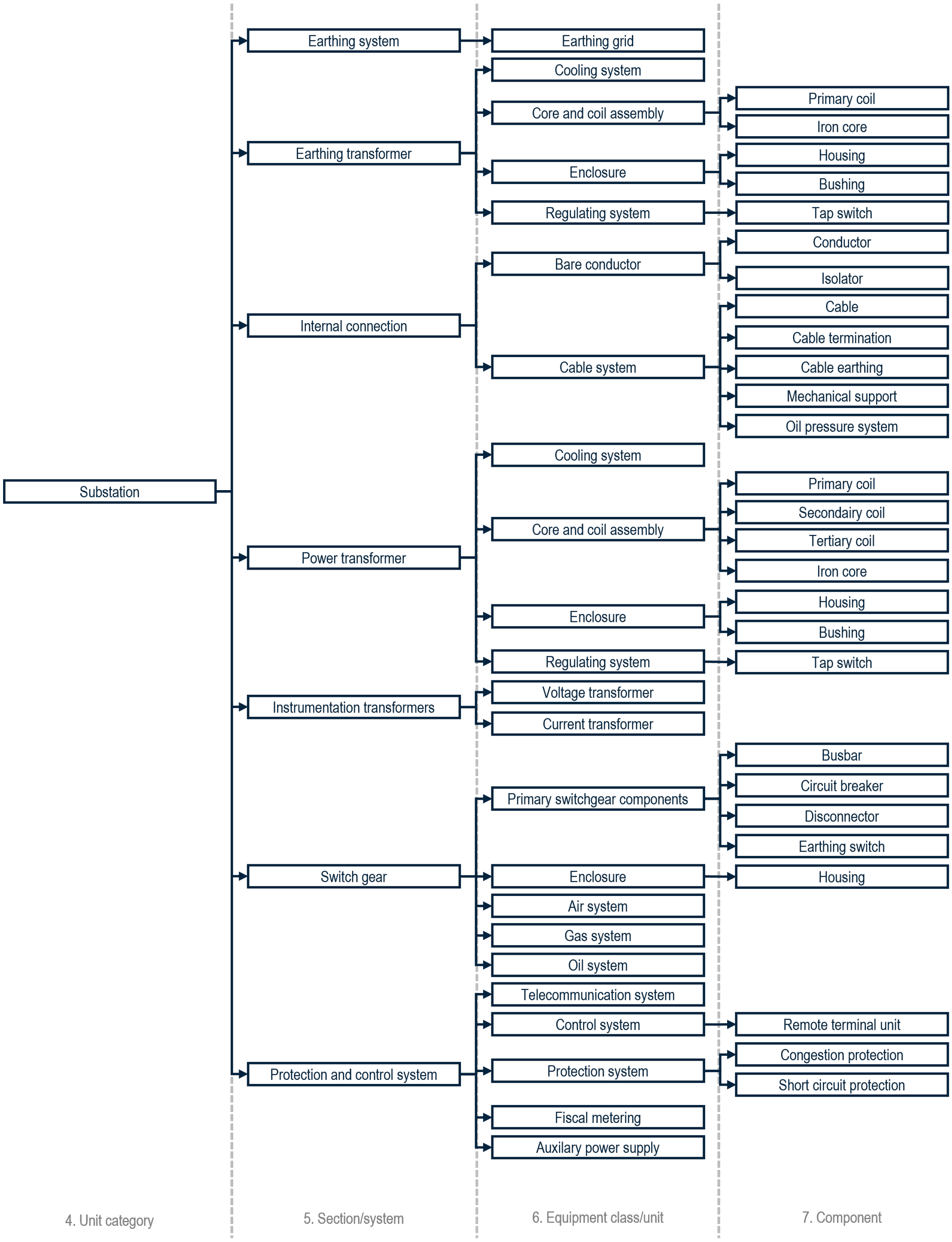


Figure C.2: Taxonomy: substation

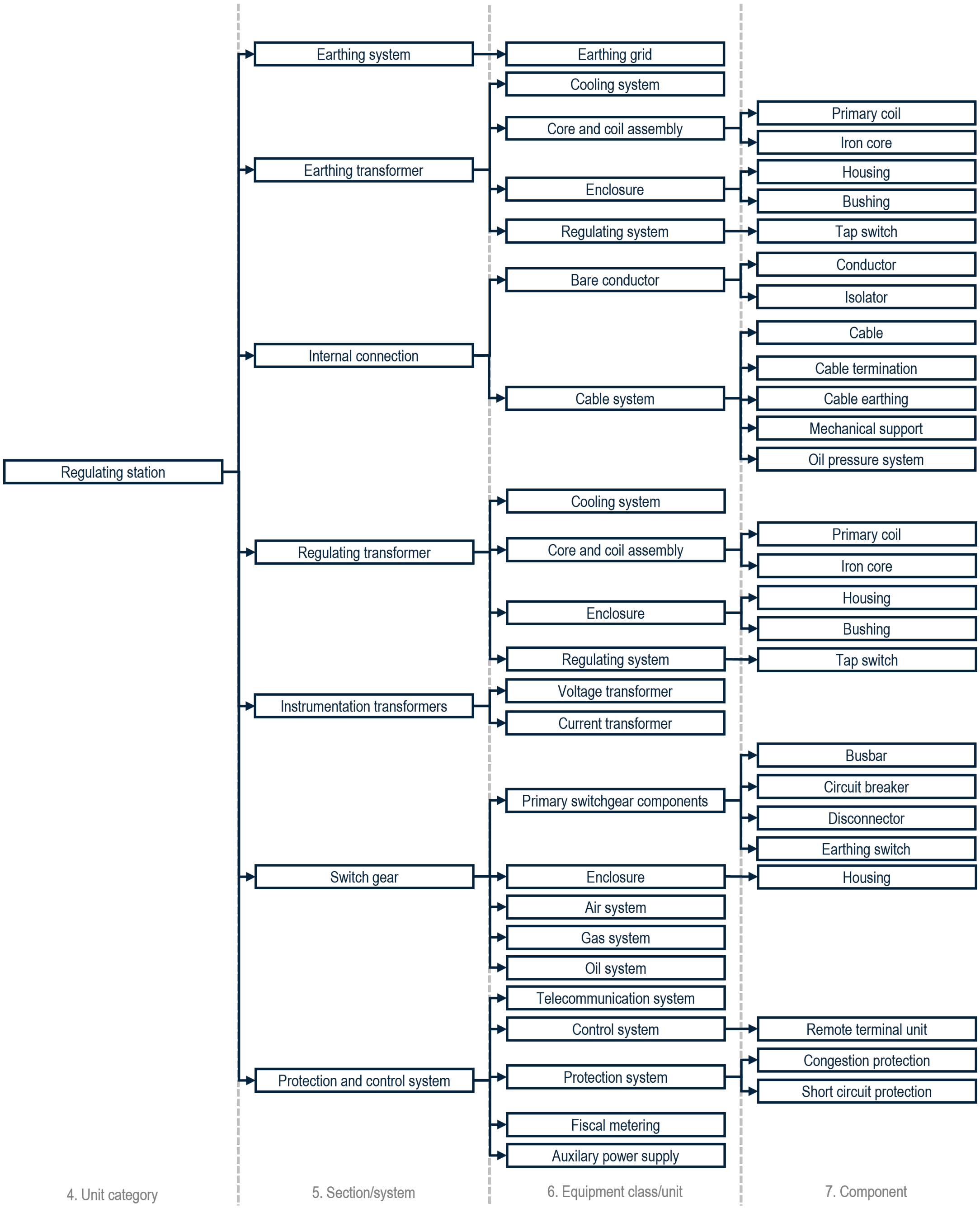


Figure C.3: Taxonomy: regulating station

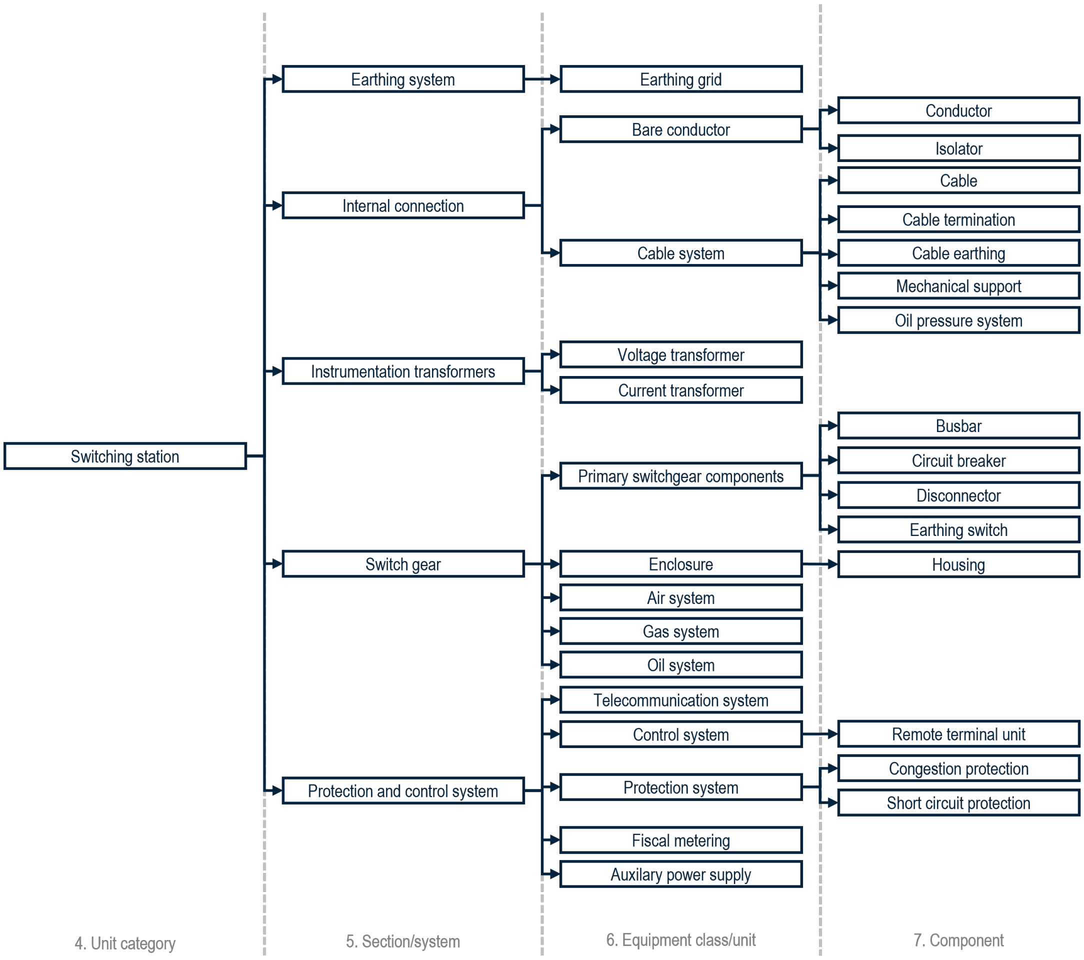


Figure C.4: Taxonomy: switching station

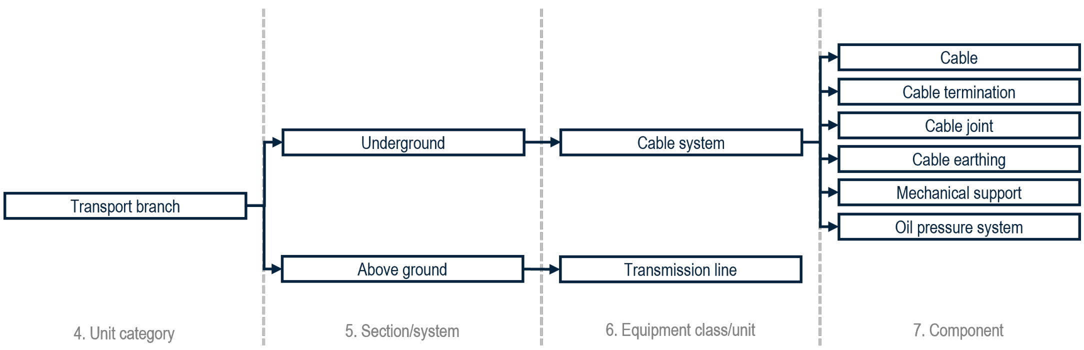


Figure C.5: Taxonomy: transport branch

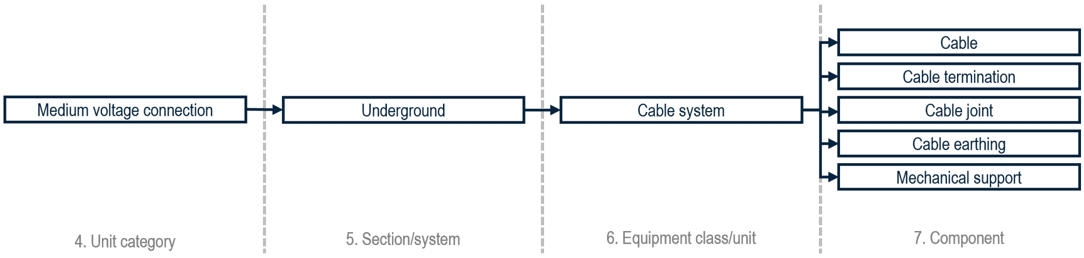


Figure C.6: Taxonomy: medium voltage connection

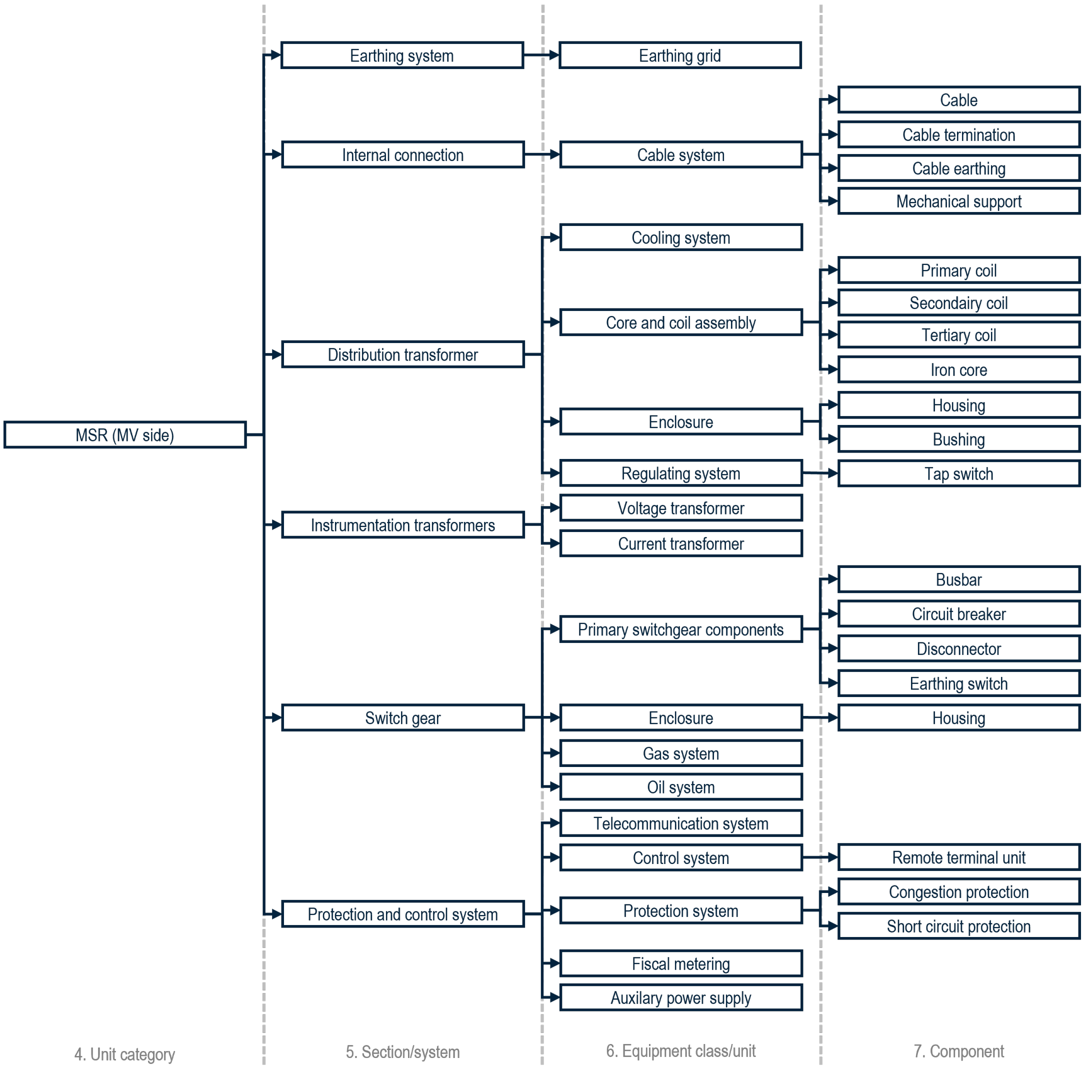


Figure C.7: Taxonomy: MSR (medium voltage side)

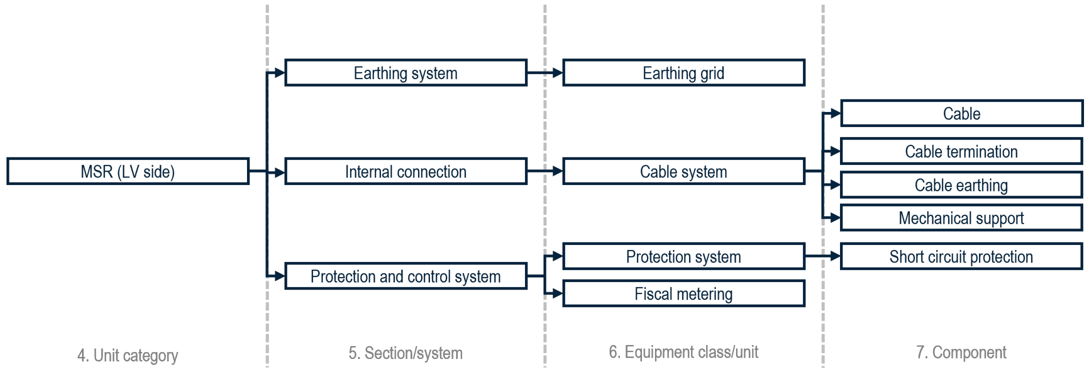


Figure C.8: Taxonomy: MSR (low voltage side)

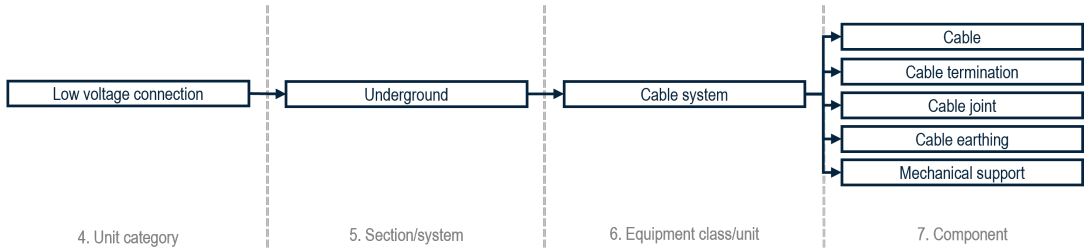


Figure C.9: Taxonomy: low voltage connection

C.2 Taxonomy diagrams including mapping of initiatives and policy documents

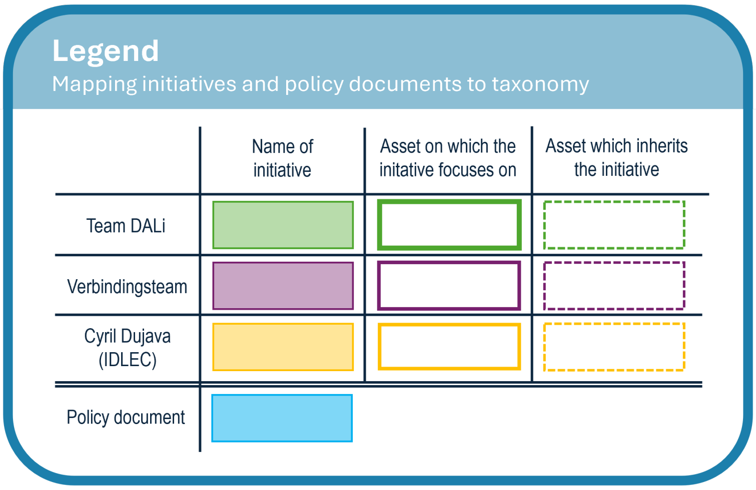


Figure C.10: Taxonomy mapping of initiatives legend

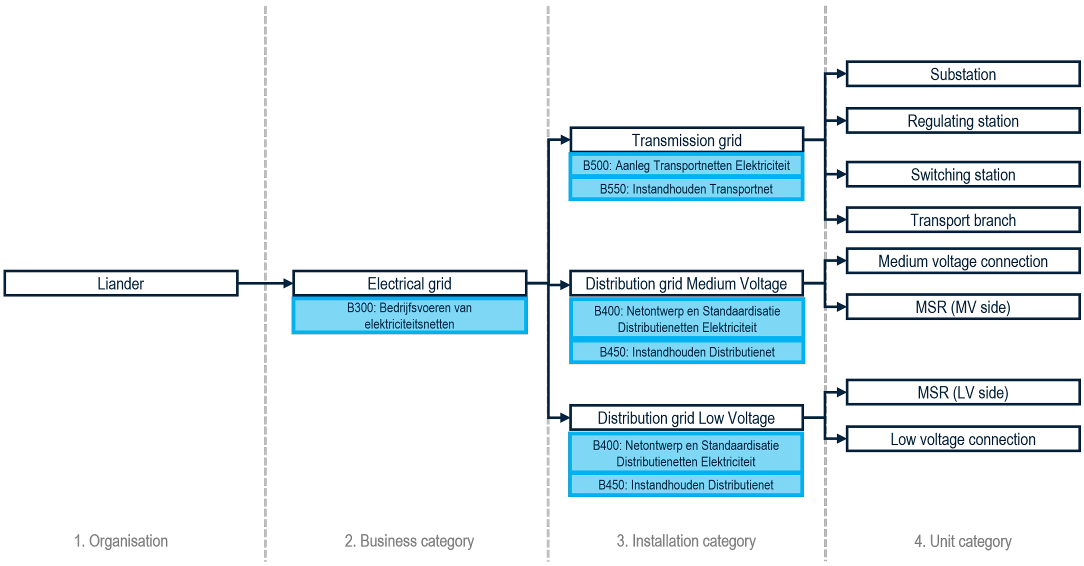


Figure C.11: Taxonomy including mapping: main

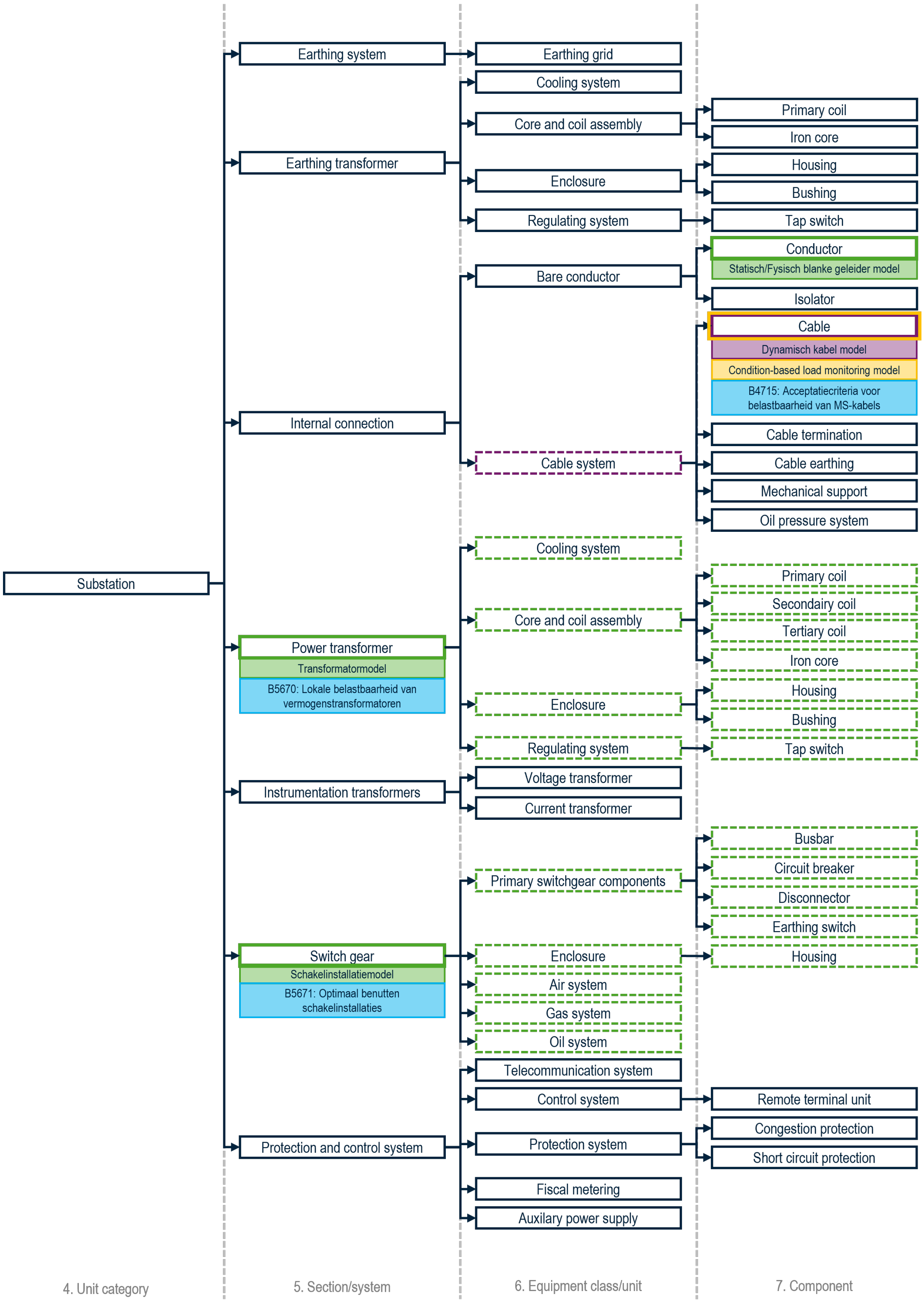


Figure C.12: Taxonomy including mapping: substation

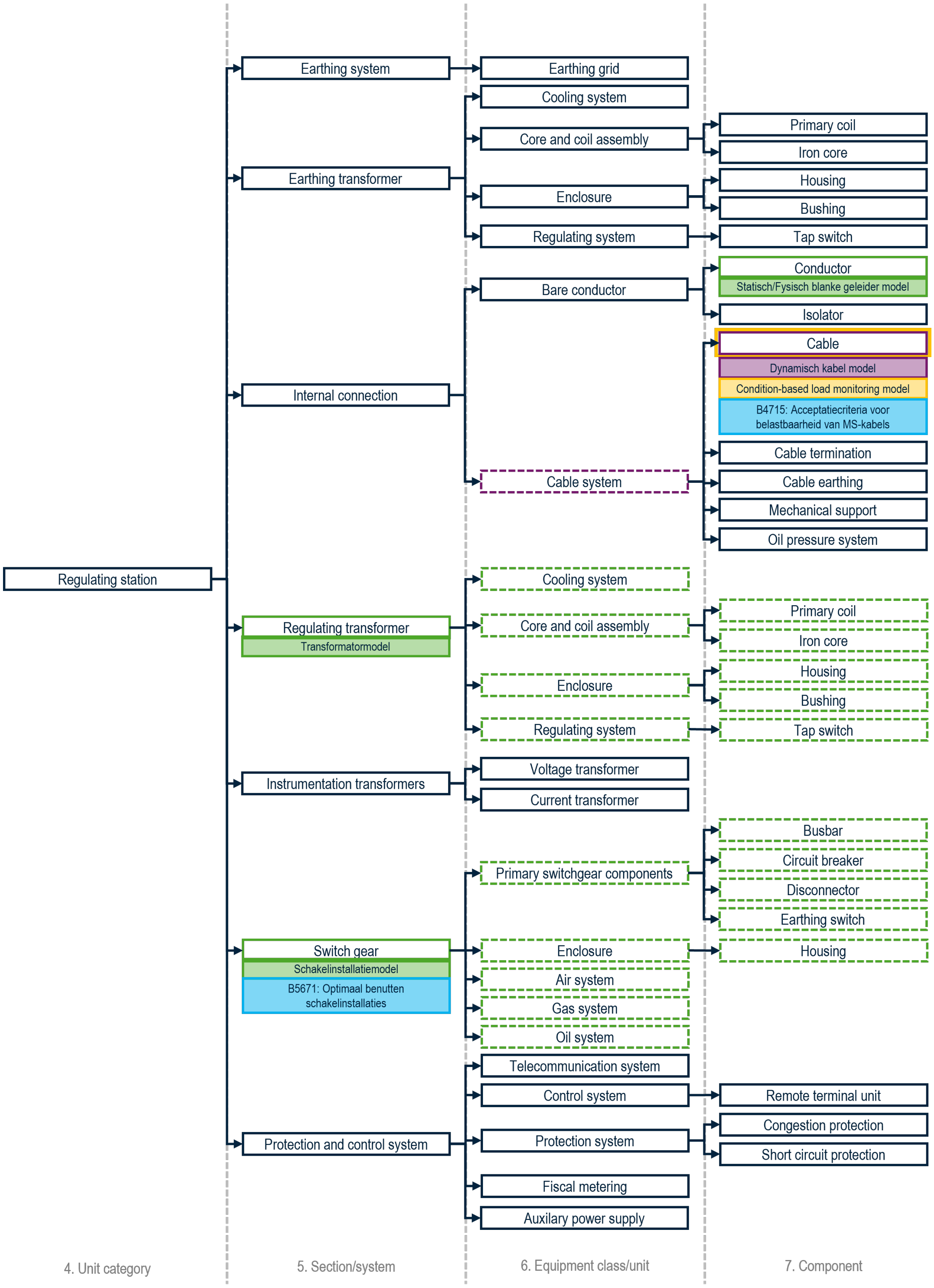


Figure C.13: Taxonomy including mapping: regulating station

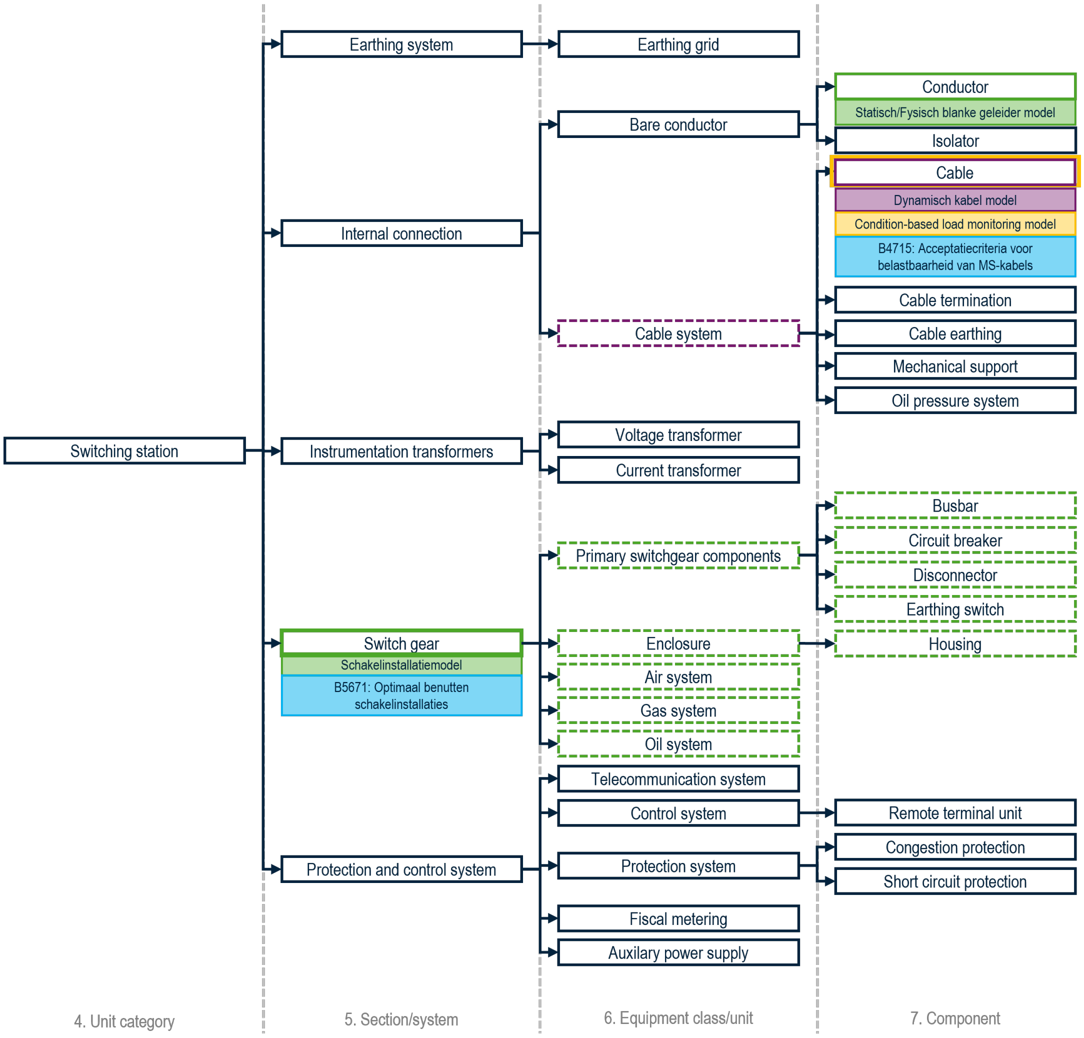


Figure C.14: Taxonomy including mapping: switching station

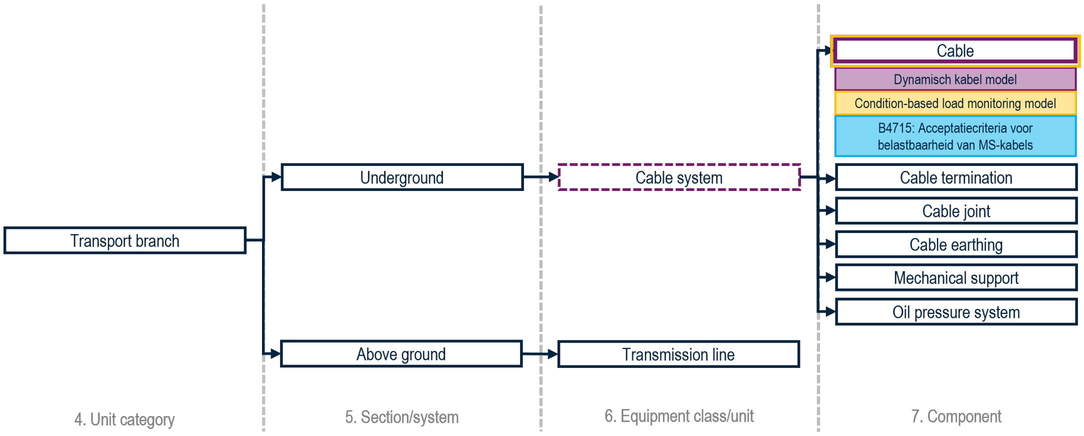


Figure C.15: Taxonomy including mapping: transport branch

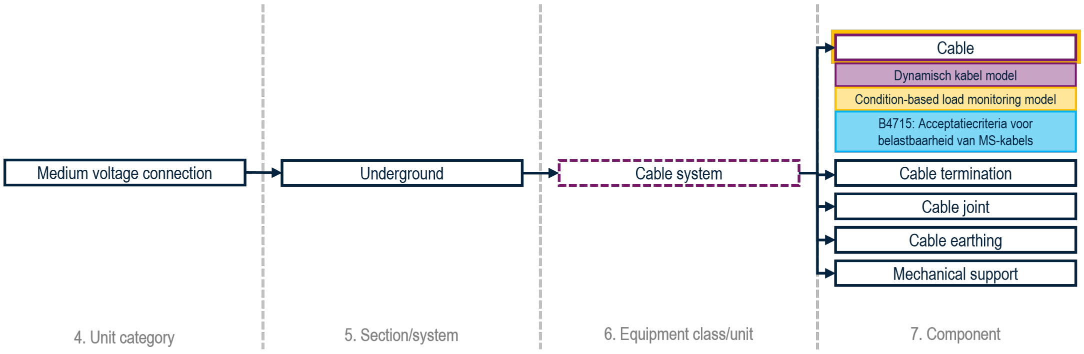


Figure C.16: Taxonomy including mapping: medium voltage connection

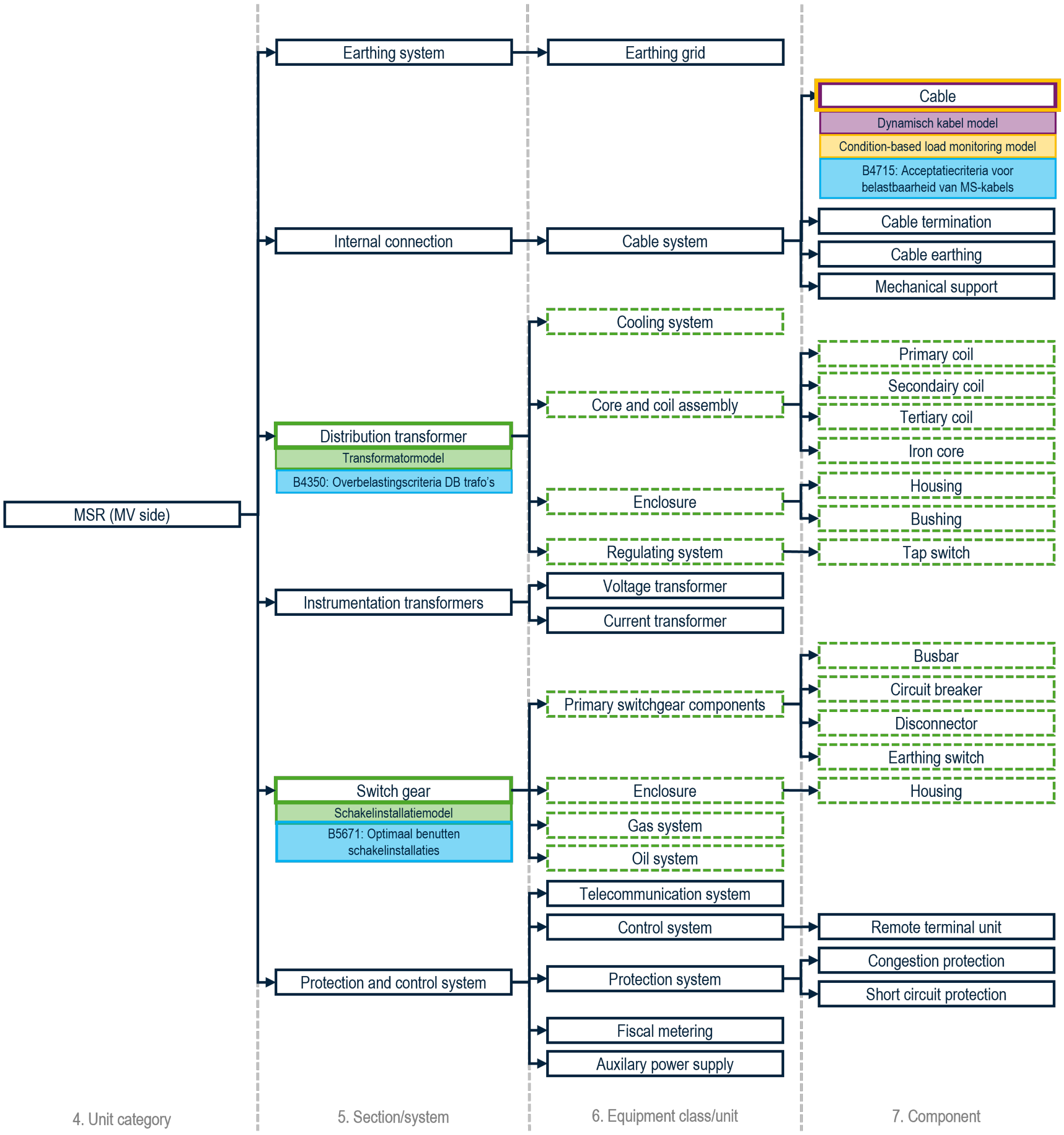


Figure C.17: Taxonomy including mapping: MSR (medium voltage side)

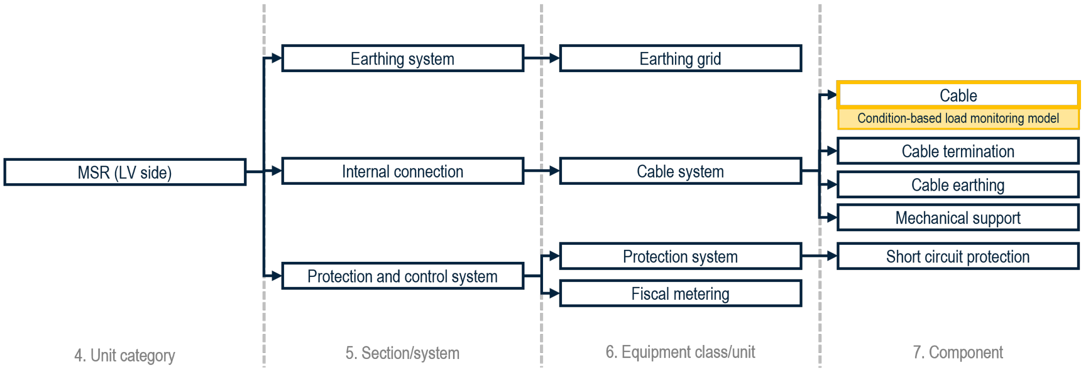


Figure C.18: Taxonomy including mapping: MSR (low voltage side)

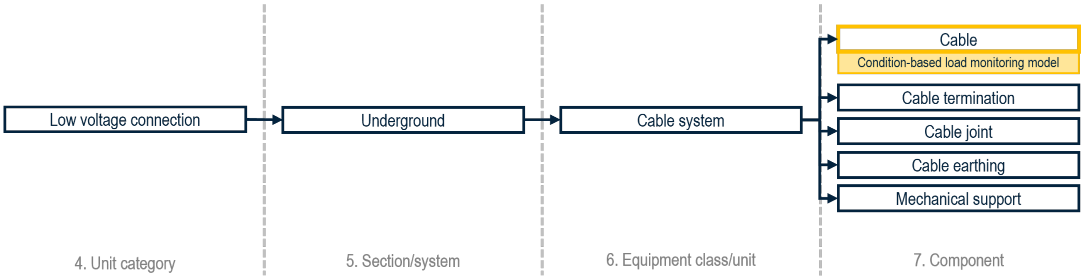


Figure C.19: Taxonomy including mapping: low voltage connection

D MATERIALS WORKSHOP

In this appendix, the materials as used in the workshop are presented, an elaboration on these materials is given in Section 6. Section D.1 displays the worksheet. For the purpose of this report it has been scaled to A4 paper, while originally it has been designed for A0 paper. Section D.2 covers the presentation used as a guide during the workshop. Lastly, Section D.3 presents the template for the pitch that was shared with participants of the workshop.

D.1 Worksheet

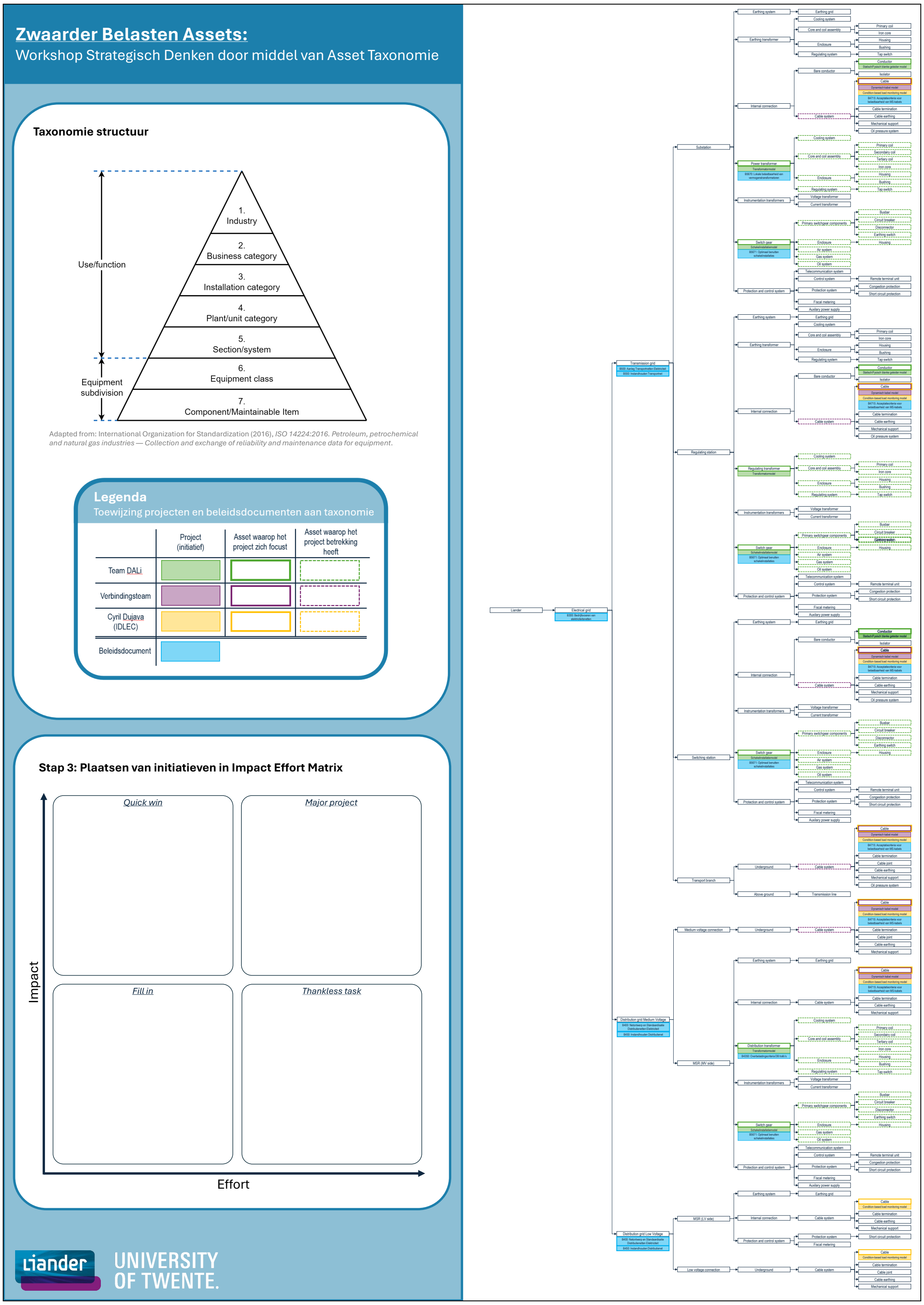


Figure D.1: Worksheet as provided in the workshop

D.2 PowerPoint presentation

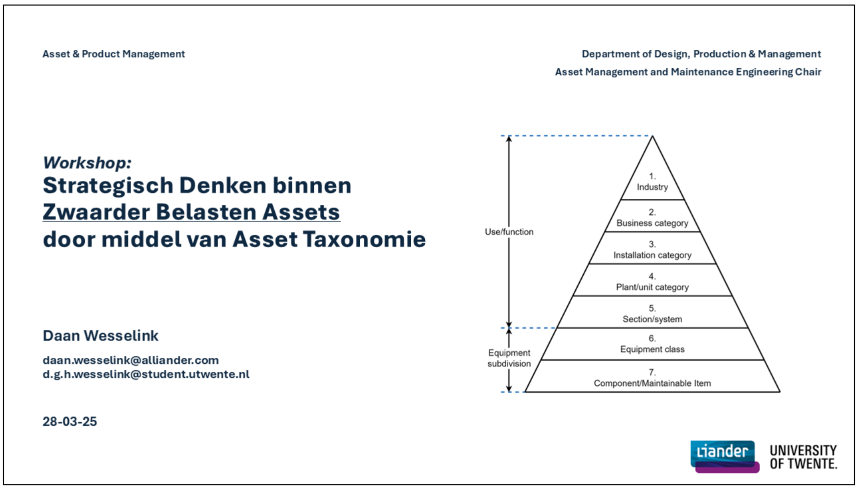


Figure D.2: Slide

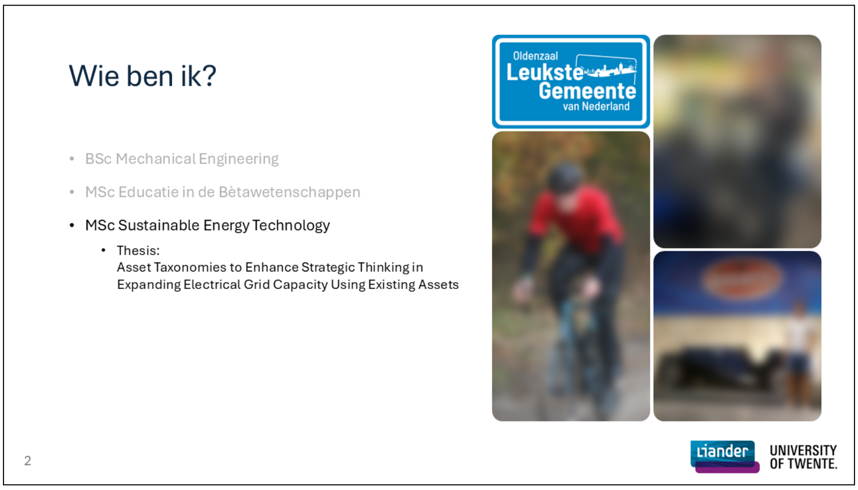
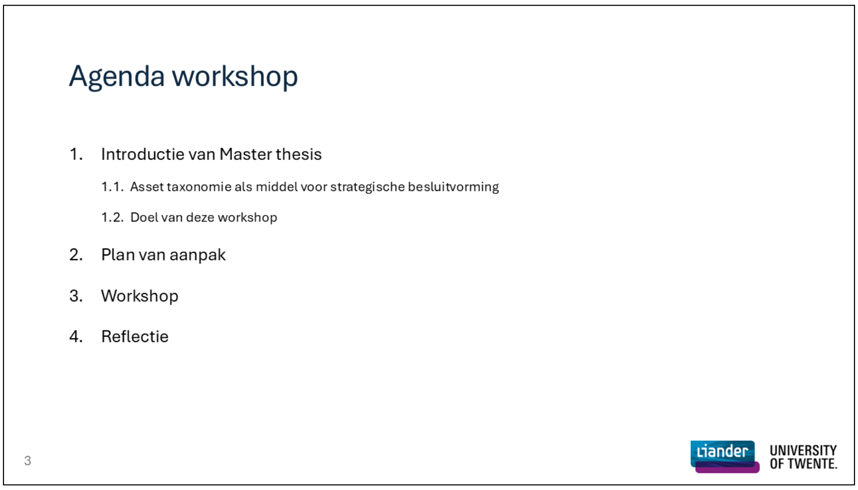


Figure D.3: Slide



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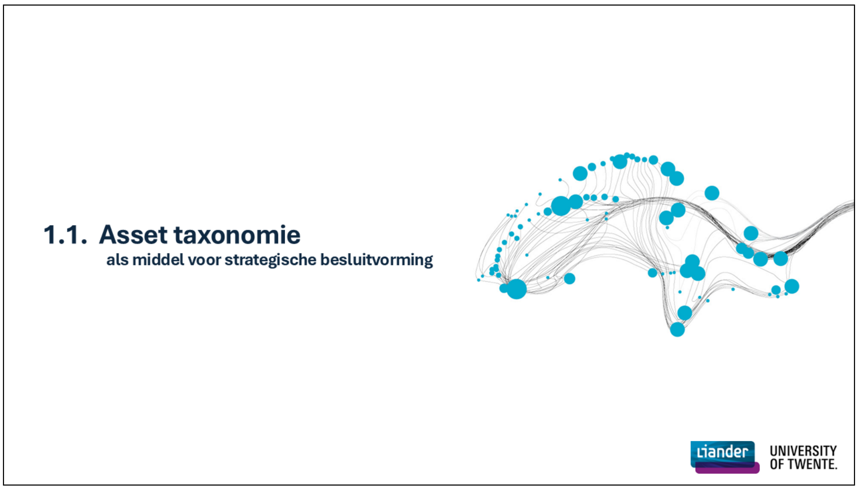


Figure D.5: Slide

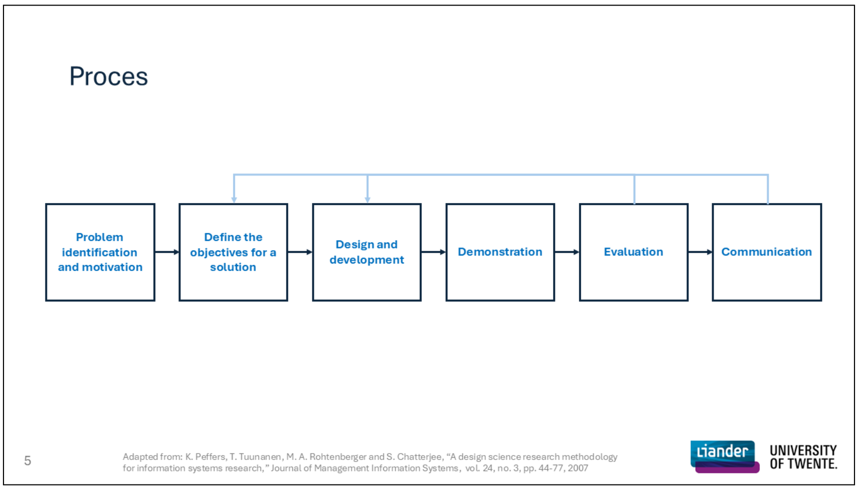
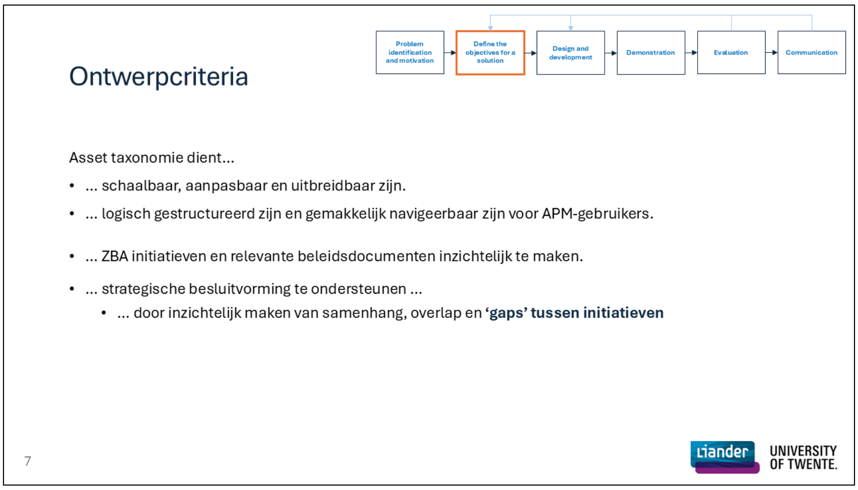


Figure D.6: Slide

Figure D.7: Slide



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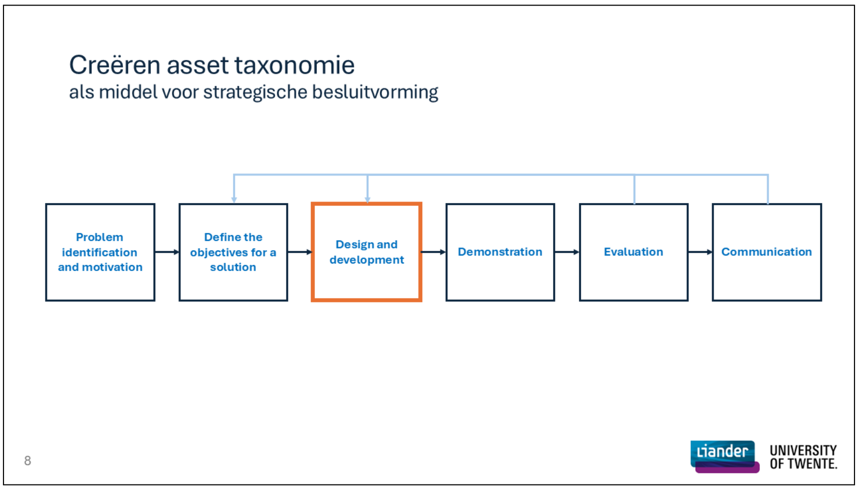

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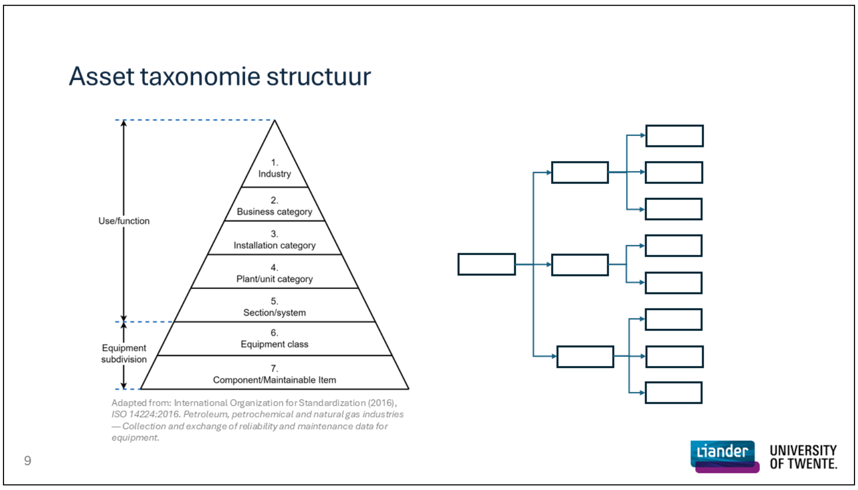


Figure D.10: Slide

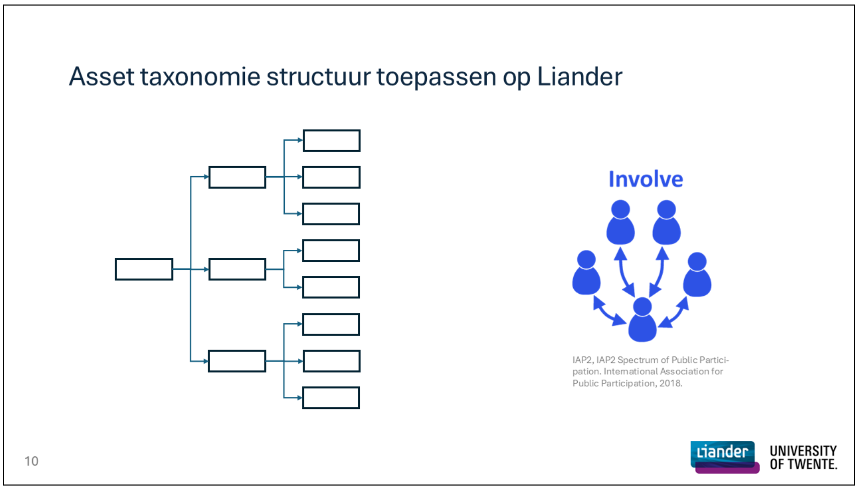
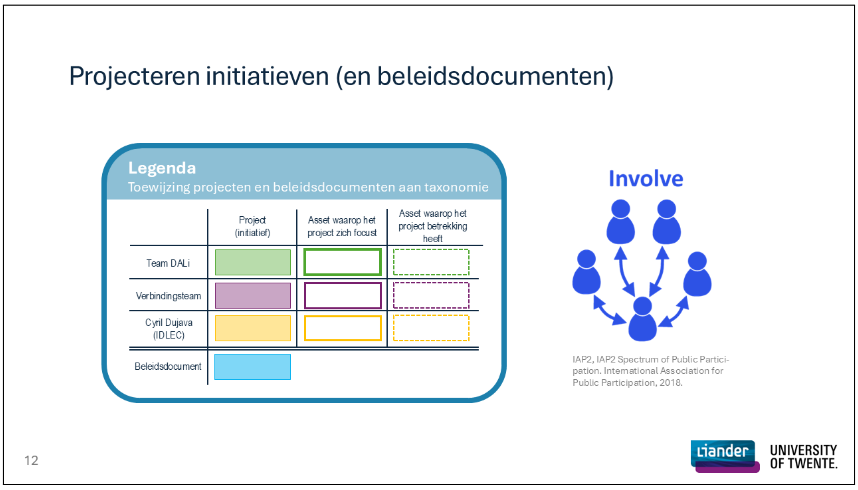


Figure D.11: Slide

Figure D.12: Slide



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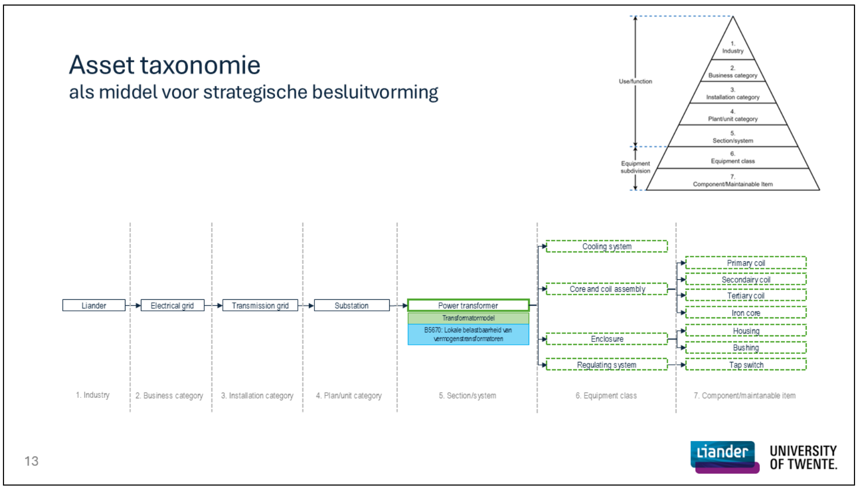

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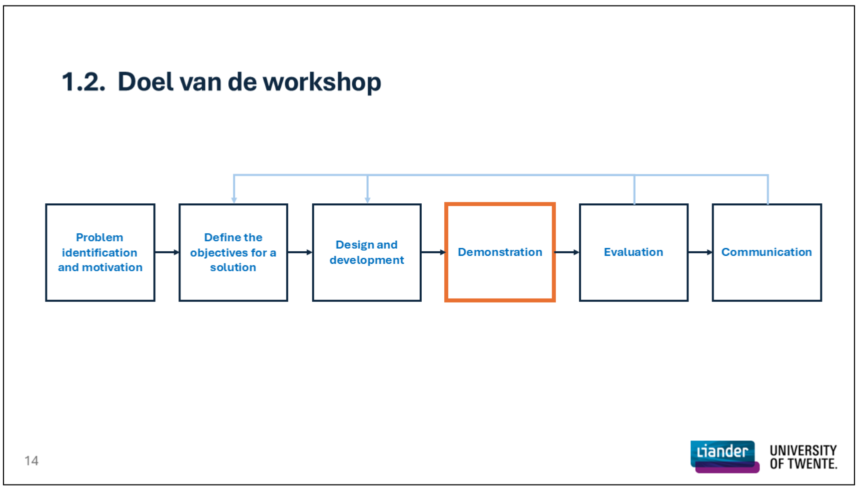

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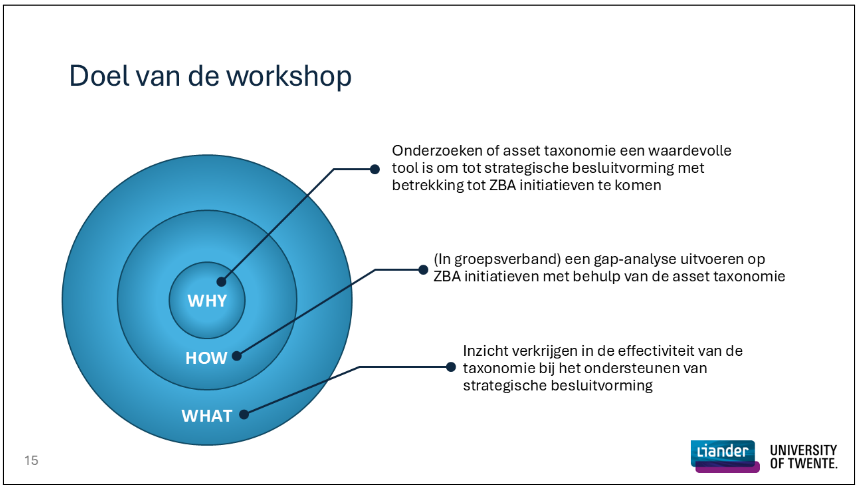

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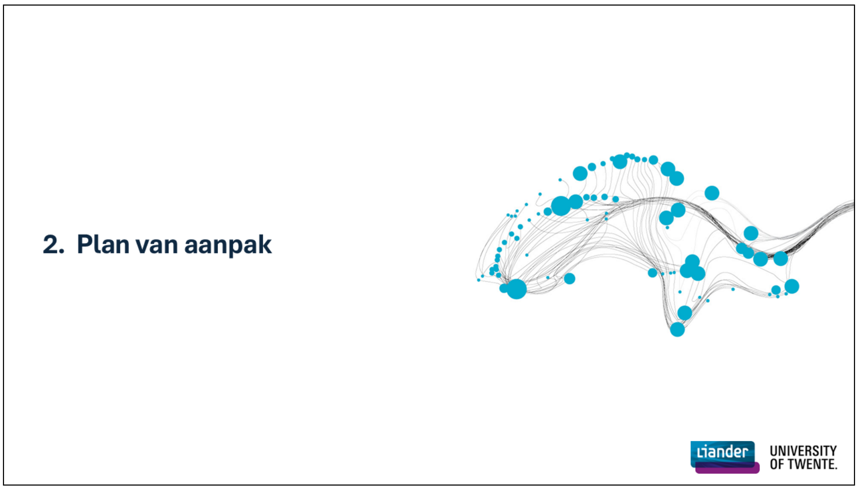

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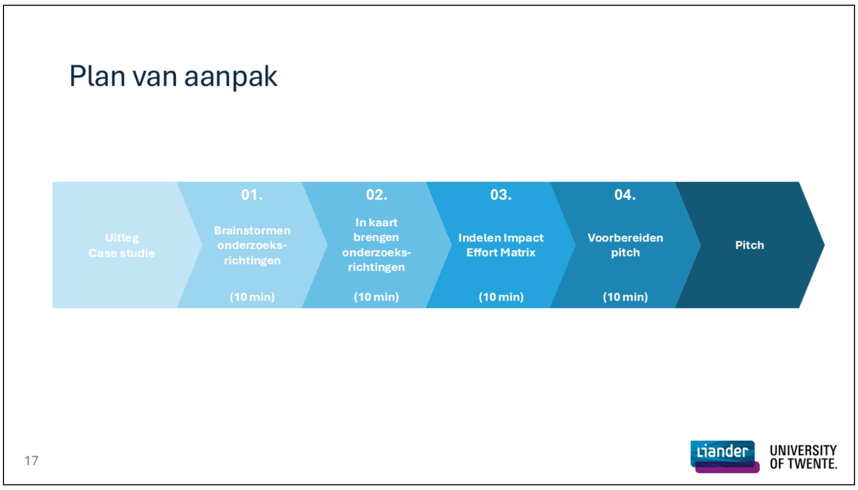

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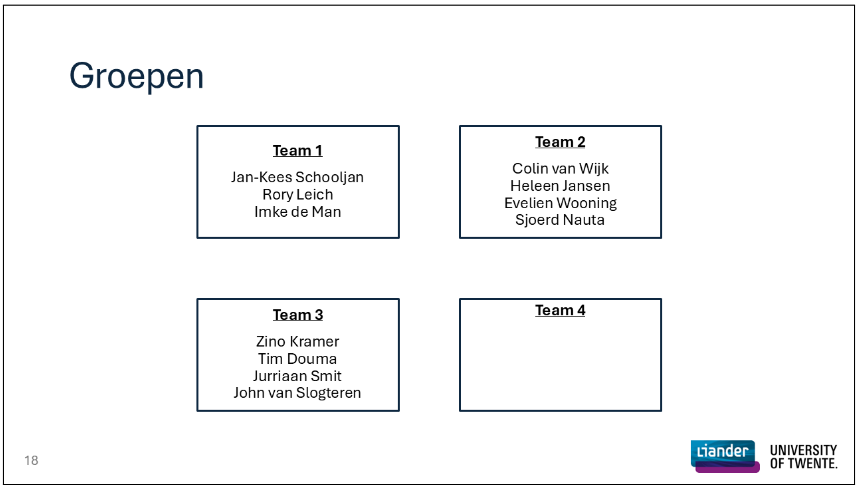


Figure D.19: Slide

Figure D.20: Slide

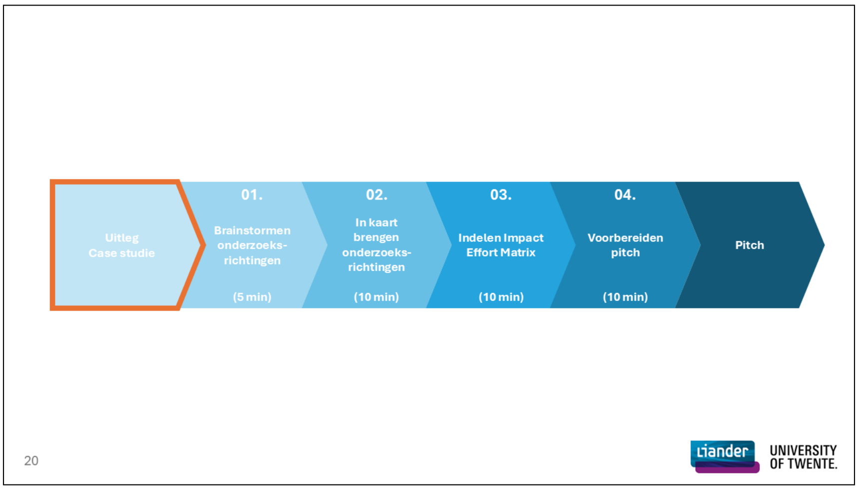
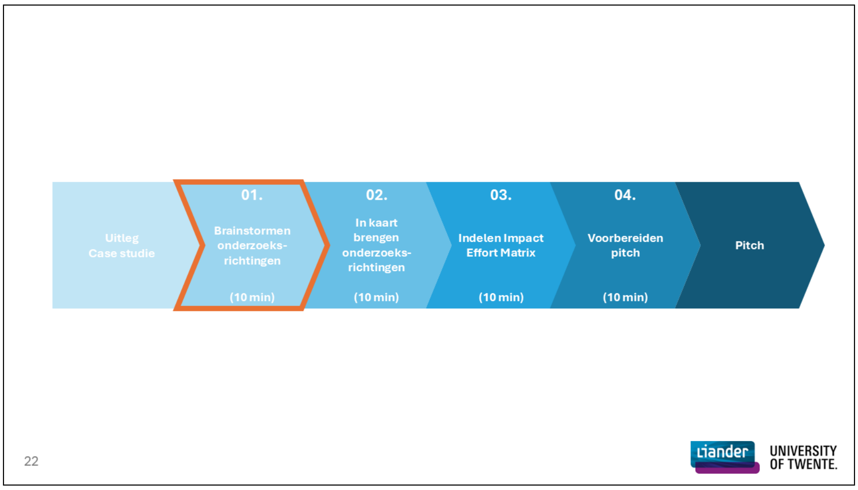


Figure D.21: Slide

Figure D.22: Slide



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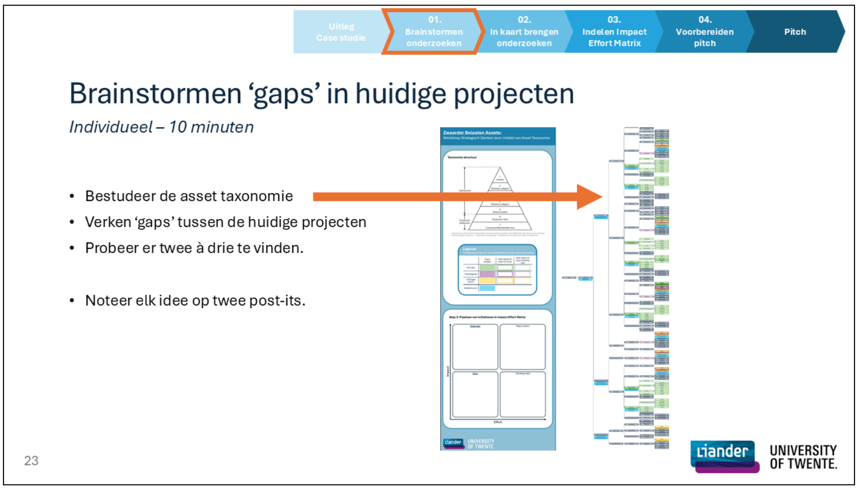

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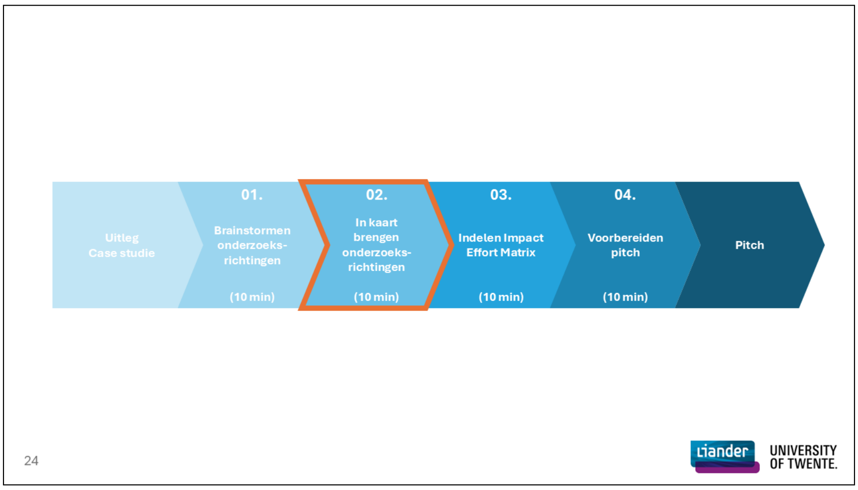
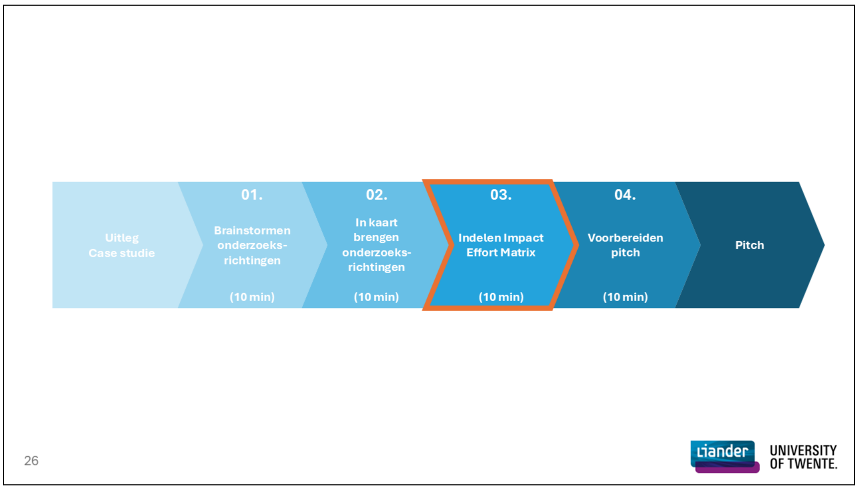


Figure D.25: Slide

Figure D.26: Slide



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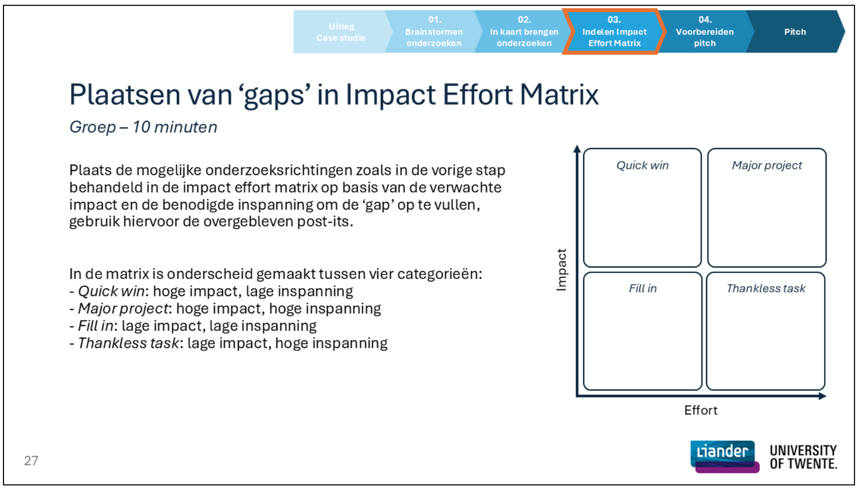

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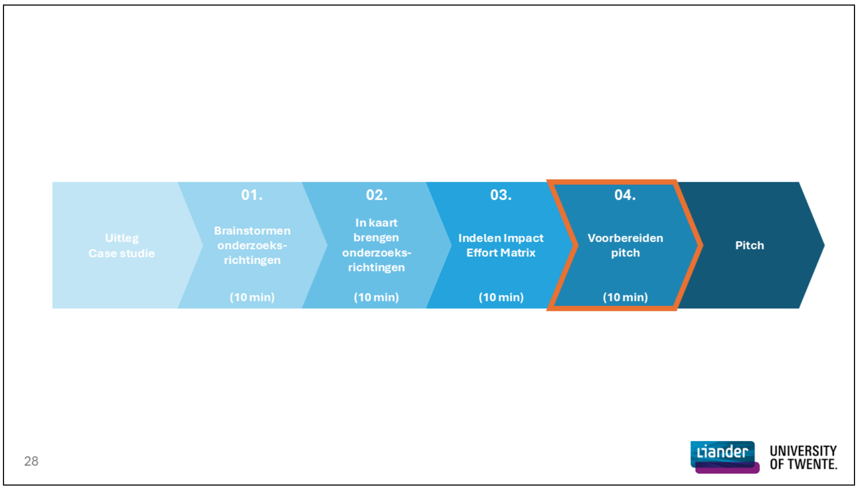

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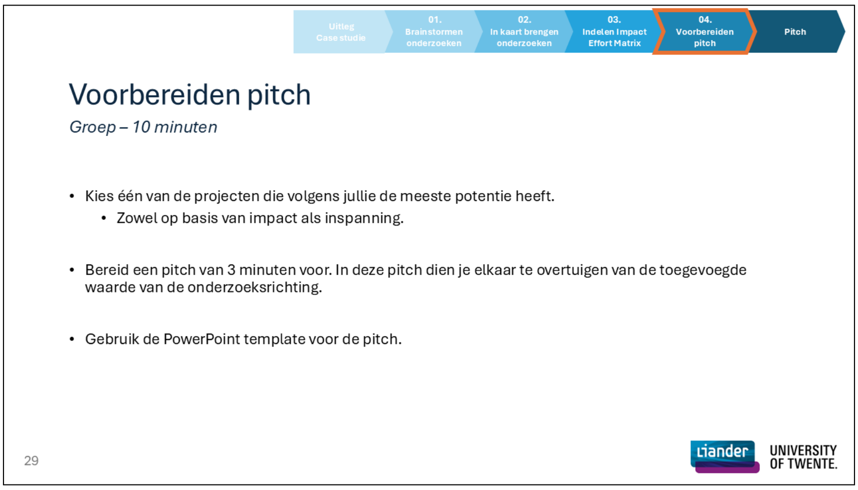

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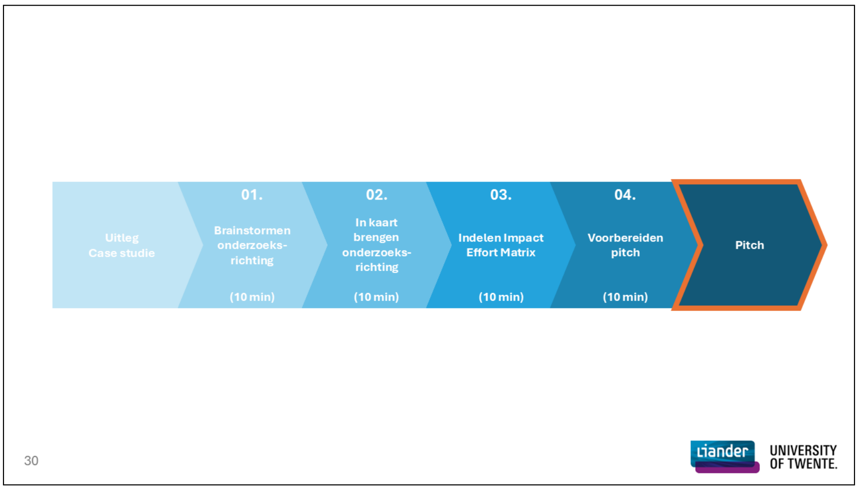

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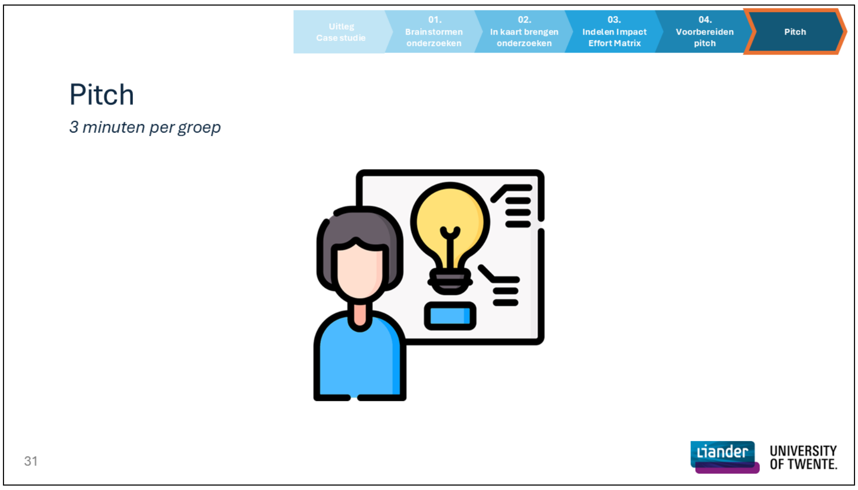


Figure D.32: Slide

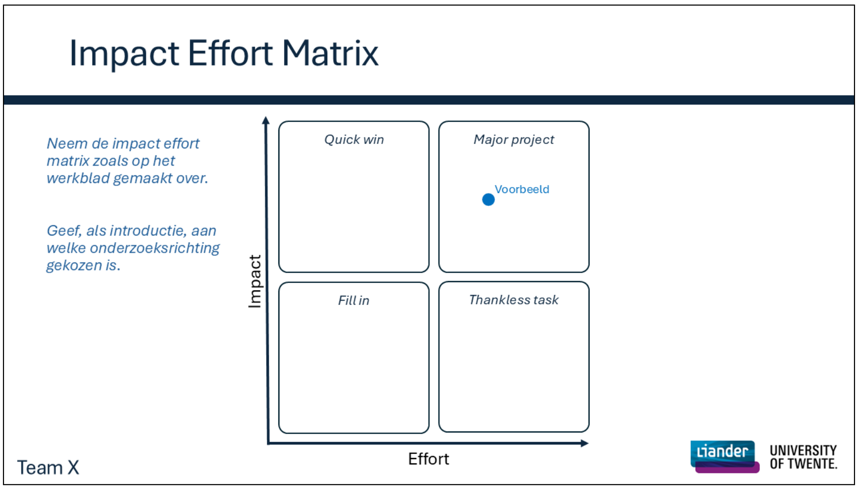
Figure D.33: Slide

Figure D.34: Slide

Figure D.35: Slide

Figure D.36: Slide

D.3 PowerPoint pitch template



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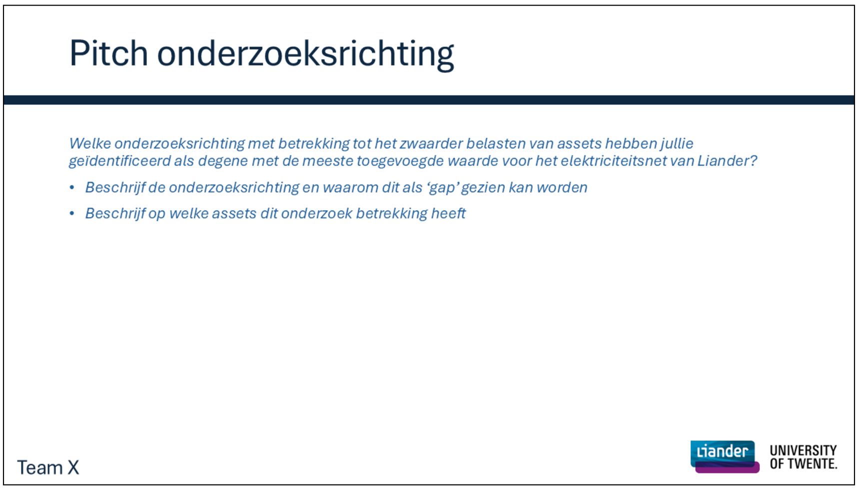

Figure D.38: Slide

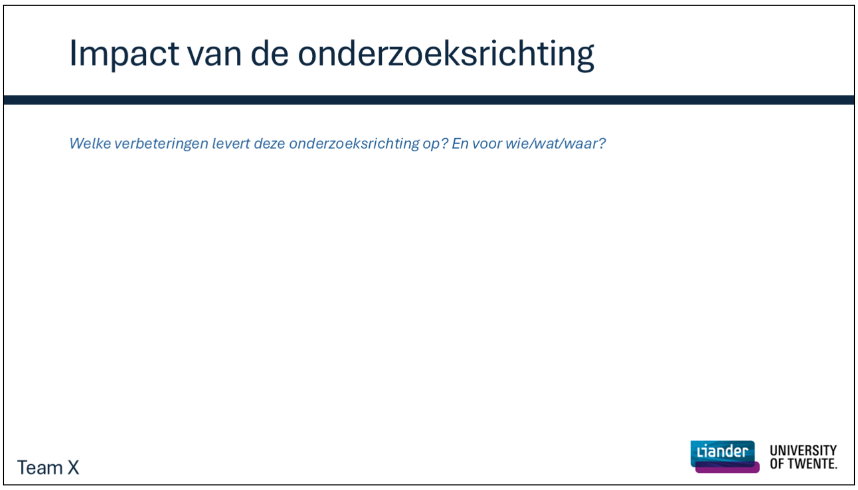

Figure D.39: Slide

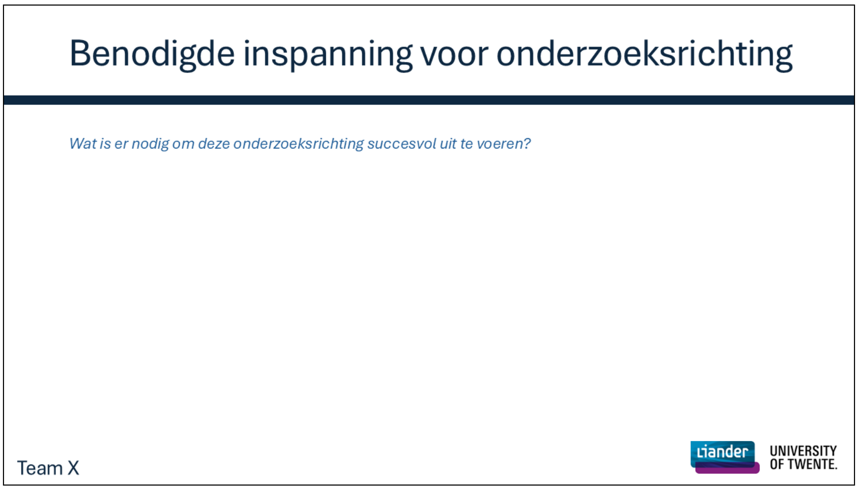

Figure D.40: Slide

E SURVEY

E.1 Survey questions

Below, the survey questions are presented. During the workshop the questions were asked in Dutch, as shown on the left-hand side. On the right-hand side, the questions and possible answers have been translated into English.

Question 1

De asset taxonomie heeft een duidelijke en logische structuur.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy has a clear and logical structure.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 2

De asset taxonomie geeft op een effectieve manier overzicht in de bestaande initiatieven.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy effectively provides an overview of existing initiatives and policy documents related to capacity enhancement of existing assets.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 3

De asset taxonomie ondersteunt het bepalen van de impact van een initiatief op het elektriciteitsnet.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy supports determining the impact of an initiative on enhancing the capacity of the electricity grid.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 4, statement 1

De asset taxonomie faciliteert samenwerking tussen verschillende initiatieven.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy facilitates collaboration between various initiatives.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 4, statement 2

De asset taxonomie faciliteert het vermijden van overbodigheden/dubbel werk met betrekking tot initiatieven.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy facilitates avoiding redundancies within initiatives.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 4, statement 3

De asset taxonomie faciliteert het identificeren van tekortkomingen tussen bestaande projecten.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy facilitates identifying gaps between existing initiatives.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 4, statement 4

De asset taxonomie faciliteert het stellen van prioriteiten binnen bestaande en/of nieuwe initiatieven.

1. Volledig mee oneens
2. Oneens
3. Neutraal
4. Eens
5. Volledig mee eens

The asset taxonomy facilitates setting priorities within existing and/or new initiatives.

1. Strongly disagree
2. Disagree
3. Neutral
4. Agree
5. Strongly agree

Question 5

Vind je de asset taxonomie een nuttig hulpmiddel voor strategische besluitvorming bij het zwaarder belasten van assets in het elektriciteitsnet? En waarom?
Open vraag

Do you find the asset taxonomy a useful tool for strategic decision-making within the capacity enhancement of assets in the electricity grid?
Open question

Question 6

Wat zijn de drie sleutelwoorden die het eerste in je opkomen wanneer je denkt aan de asset taxonomie? Geef één sleutelwoord per antwoord.
Open vraag - Wordcloud

What are the three key words that first come to mind when you think of the asset taxonomy. Provide one keyword per answer.
Open question - Wordcloud

E.2 Survey results

Here, for question 1 to 4 (each statement separately) of the survey, the results are presented in the form of bar charts. The raw data used to generate these charts can be found in Table E.3.

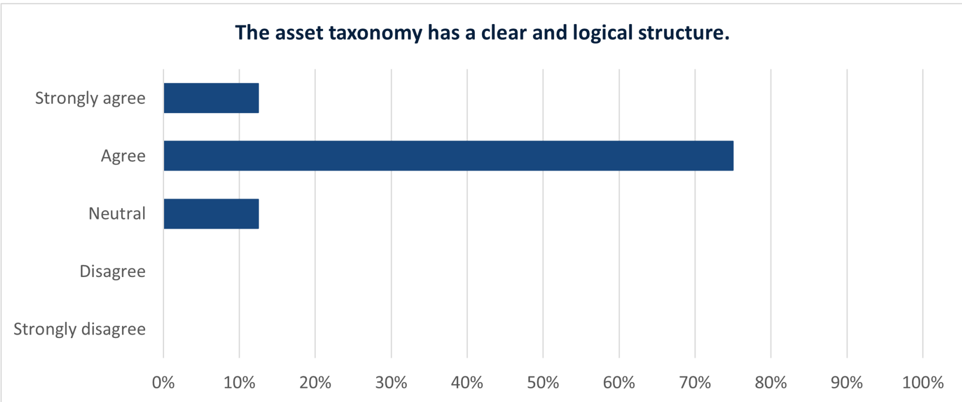

Figure E.1: Results question 1

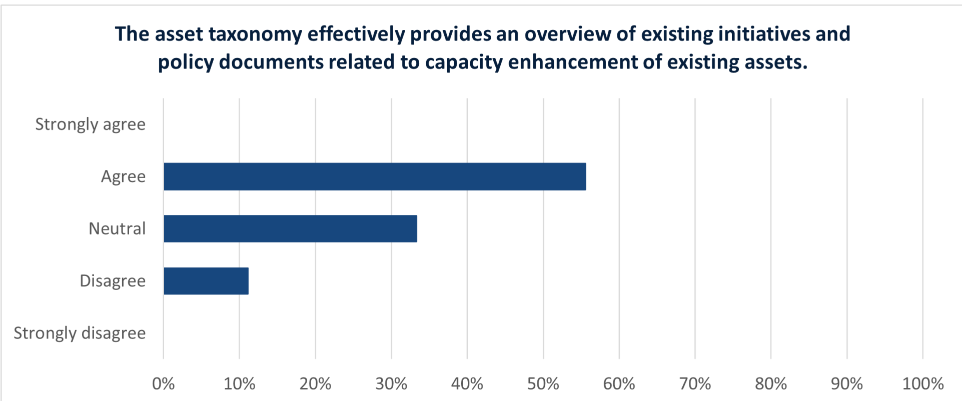

Figure E.2: Results question 2

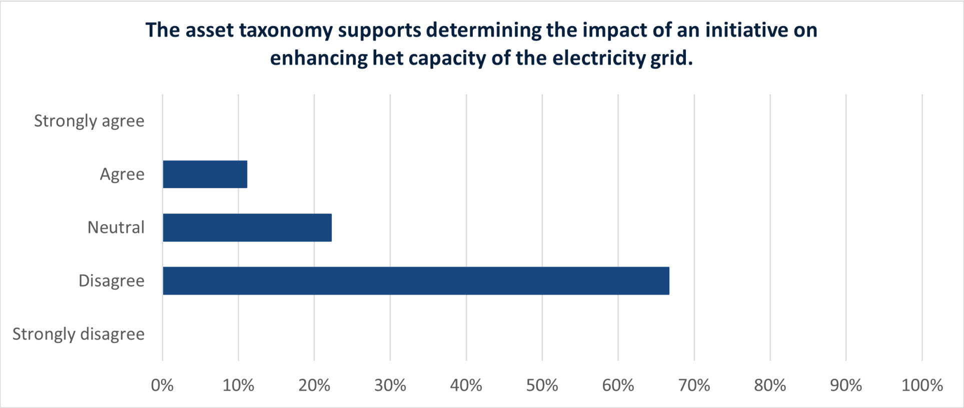

Figure E.3: Results question 3

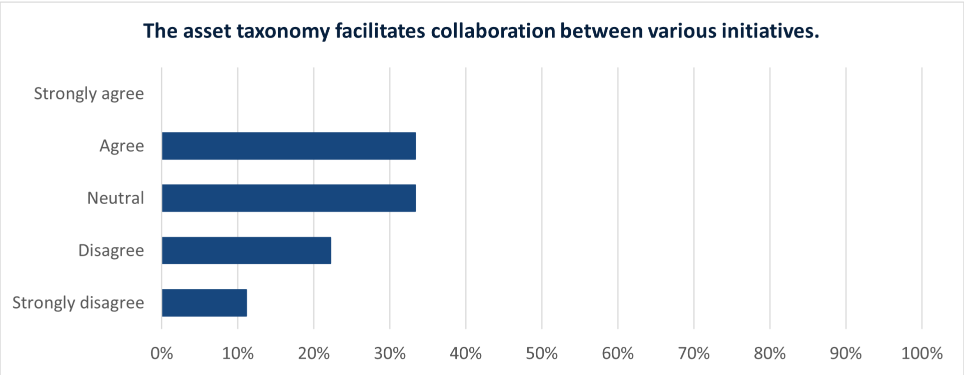

Figure E.4: Results question 4, statement 1

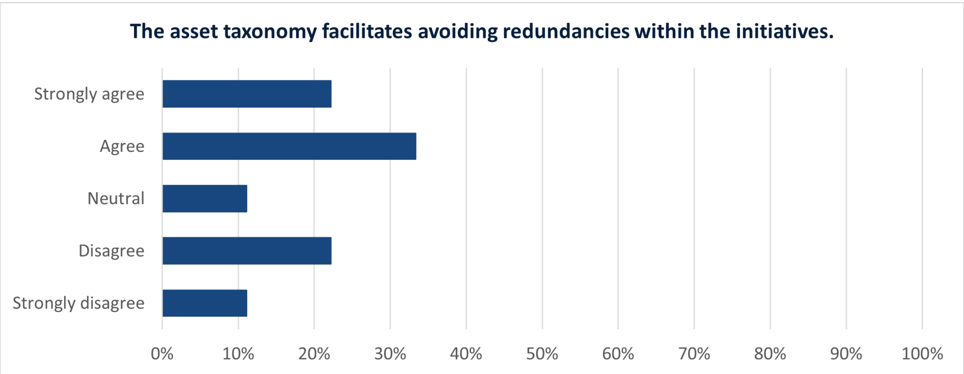

Figure E.5: Results question 4, statement 2

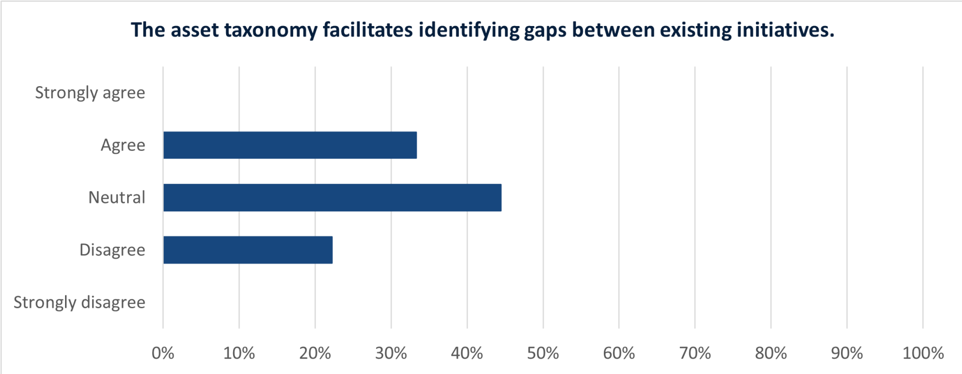

Figure E.6: Results question 4, statement 3

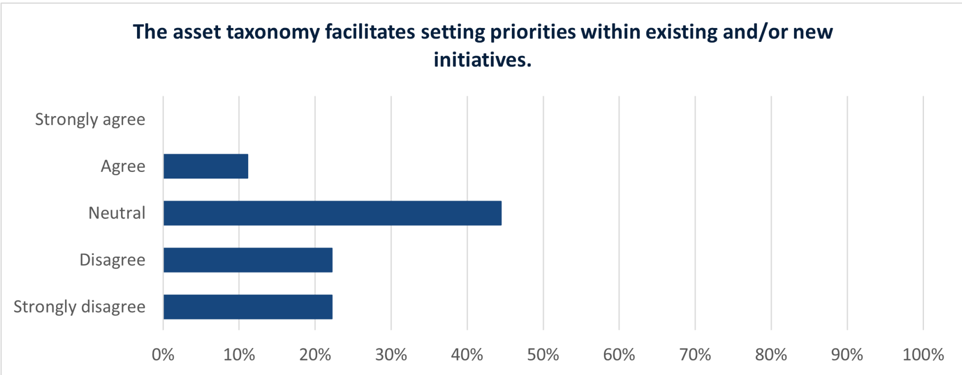

Figure E.7: Results question 4, statement 4

In the first column of Table E.1, the original responses to the fifth question of the survey are presented. In the second column these responses have been translated to English. The translation has been carried out as literal as possible.

Table E.1: Answers as given to question 5, including translation to English

Dutch response	English translation
Ja, het geeft een systematisch (hoog)overzicht van de initiatieven die lopen en mogelijke "gaps". Het is alleen lastig om afhankelijkheden tussen initiatieven weer te geven in de taxonomie.	Yes, it provides a systematic (high-level) overview of ongoing initiatives and possible "gaps." However, it is difficult to represent dependencies between initiatives in the taxonomy.
Ja, geeft inzicht in de gaten in beleidsvorming.	Yes, it gives insight into the gaps within policy-making.
Ja, het is handig om een nieuw initiatief in het framework van het bestaande te zetten. Maar op zichzelf staand bevat het denk ik niet genoeg informatie over impact/prioriteit.	Yes, it is useful to place a new initiative within the framework of the existing one. However, on its own, I think it does not contain enough information about impact/priority.
Een beetje, het is vooral fijn voor het overzicht van de assets en waar welke initiatief plaatsvindt en dus om de 'gaps' te zien.	A little, it is mainly useful for gaining an overview of the assets and where each initiative takes place, and therefore for identifying the 'gaps'.
Ja	Yes
Deels. Het helpt zeker om een helder overzicht te hebben van alle componenten in de keten. Maar voor besluitvorming en analyses is (veel) meer informatie nodig.	Partially. It certainly helps to have a clear overview of all components in the chain. However, much more information is needed for decision-making and analysis.
Brengt wel structuur, maar blijft afhankelijk van de volledige input van eenieder. Ben bang dat het binnen Liander lastig gaat werken.	It does bring structure, but it remains dependent on everyone's full input. I fear it will be difficult to implement within Liander.
Nee, het komt voor Alliander te laat. De initiatieven zijn al in gang gezet aan de hand van de opbouw van het net. Daarnaast is de huidige taxonomie niet compleet.	No, it comes too late for Alliander. Initiatives have already been launched based on the structure of the grid. Additionally, the current taxonomy is not complete.
Zekers, geeft een samenhang tussen initiatieven. Met meerdere doorsnedes wordt de samenhang duidelijker.	Definitely, it provides coherence between initiatives. With multiple cross-sections, the interrelations become clearer.

As part of the survey, a wordcloud based on key words submitted by participants in response to the sixth question. Since the survey was conducted in a Dutch context, the submitted keywords were in Dutch as well. In Table E.2, the original Dutch keywords are listed in the first column. The English translation of the key words is provided in the second column. Again, the translation has been carried out as literal as possible. The third column shows the frequency of each key word, which determines its 'size' in the word cloud.

Table E.2: Input for worldcloud, question 6

Dutch term	English translation	Frequency
Overzicht	Overview	5
Structuur	Structure	2
Opbouw elektriciteitsnet	Structure electrical grid	1
Piramide	Pyramid	1
Impact	Impact	1
Assettopologie	Asset topology	1
Systematisch	Systematic	1
Niet compleet	Not complete	1
Missend	Missing	1
Beleid	Policy	1
System engineering	System Engineering	1
Techniek	Technology	1
Mapping	Mapping	1
Samenhang	Coherence	1
Commitment	Commitment	1
Alternatief	Alternative	1
Inventarisatie	Inventory	1
Assetrelaties	Asset relations	1
Lianderbreed	Liander-wide	1
Compleet	Complete	1
Data structuur	Data structure	1

Table E.3: Raw data: Question 1 to 4

Respondent	Question 1	Question 2	Question 3	Question 4, statement 1	Question 4, statement 2	Question 4, statement 3	Question 4, statement 4
1	Agree	Agree	Disagree	Agree	Strongly agree	Neutral	Disagree
2	Agree	Agree	Disagree	Disagree	Strongly agree	Agree	Strongly disagree
3	Strongly agree	Agree	Disagree	Disagree	Agree	Agree	Neutral
4	Agree	Agree	Neutral	Agree	Agree	Neutral	Disagree
5	Agree	Disagree	Agree	Neutral	Neutral	Agree	Agree
6	Agree	Neutral	Disagree	Neutral	Disagree	Neutral	Neutral
7	Agree	Neutral	Disagree	Neutral	Agree	Neutral	Neutral
8	Neutral	Neutral	Disagree	Strongly disagree	Strongly disagree	Disagree	Strongly disagree
9	N/A	Agree	Neutral	Agree	Disagree	Disagree	Neutral

Table E.4: Raw data: Question 5 and 6

Respondent	Question 5	Question 6
1	Yes, it provides a systematic (high-level) overview of ongoing initiatives and possible ”gaps.” However, it is difficult to represent dependencies between initiatives in the taxonomy.	Overview, systematic, alternative
2	Yes, it gives insight into the gaps within policy-making.	Asset topology, policy, coherence
3	A little, it is mainly useful for gaining an overview of the assets and where each initiative takes place, and therefore for identifying the ’gaps’.	Overview, mapping, asset relations
4	Yes, it is useful to place a new initiative within the framework of the existing one. However, on its own, I think it does not contain enough information about impact/priority.	Pyramid, inventory, complete
5	Yes	Impact, missing, overview
6	Partially. It certainly helps to have a clear overview of all components in the chain. However, much more information is needed for decision-making and analysis.	System Engineering, overview, data structure
7	It does bring structure, but it remains dependent on everyone’s full input. I fear it will be ifficult to implement within Liander.	Structure, commitment, Liander-wide
8	No, it comes too late for Alliander. Initiatives have already been launched based on the structure of the grid. Additionally, the current taxonomy is not complete.	Structure electrical grid, not complete
9	Definitely, it provides coherence between initiatives. With multiple cross-sections, the interrelations become clearer.	Structure, overview, technology