MSc Business Information Technology
Master Thesis

Enabling value creation from Enterprise Architecture: Supporting the grid operator in facilitating the energy transition

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Executive summary

In the current energy transition, the goal is to limit climate change and achieve carbon neutrality. Moreover, the energy transition aims to reduce the dependency on scarce fossil fuels. This is done with the implementation of variable renewable energy sources to supply electricity and large scale electrification in primarily the heating and transportation sector. These developments result in an increase in the need for transportation capacity in the distribution grid. The conventional electricity grid cannot facilitate this, and has become increasingly congested. DSOs are not keeping up with upgrading the grid fast enough and are failing to fulfill their mission to satisfy customers in their energy need, while facilitating the energy transition.

To prevent congestion and satisfy customers in their energy need, DSOs need to develop capabilities to actively manage their grid. Many of these capabilities are related to increasing the flexibility in the grid, specifically to implementing demand response measures. Flexibility can be increased in many ways, one of the most effective options being the implementation of flexible connection agreements with customers, made available by flexibility products. To successfully operate the flexibility products, and realize the necessary capabilities, many new business processes, data and applications are needed. This increases the complexity within the DSO, and its IT landscape. Enterprise architecture can be used as a tool to offer the DSO the holistic image that combines business and IT aspects, aligns these, and help guiding the organization through acquiring the required capabilities. Currently, the DSO is unsure how it can optimally use EA to achieve the desired organizational benefits. Moreover, it is unknown how EA can optimally contribute to the development of flexibility products, needed to increase the grid utilization.

This research utilized an exploratory literature review to thoroughly examine both topics of the energy transition and Enterprise Architecture. First, several energy transition consequences for DSOs were presented, including the required new capabilities that DSOs have to develop. Second, reviewing the topic of EA showed insight in the EA purpose, its benefits, and an overview of artifacts. A systematic literature review was conducted to specifically examine the use of EA within DSOs. The review resulted in the inclusion of 16 studies, which highlighted a rapid rise in the complexity of the electrical power systems and the related IT of DSOs, affecting business, information, and application architecture levels. To acquire more information about the use of EA within a DSO, a case study was executed at DSO Alliander. Expert interviews were conducted with the architects as well as with architecture users, which resulted in the identification of an unclear EA process as well as several bottlenecks in the development of flexibility products, EA is currently not supporting this process.

To create insight in the process from EA creation through to organizational benefits, this research presents an EA benefit realization framework, highlighting the importance of an EA artifact that provides an appropriate EA service to realize a benefit mechanism. This research aimed to improve the EA process quality construct by proposing 4 architecture (purpose) levels, which have been matched with suitable EA artifact categories. An EA process model was designed to graphically represent these artifacts on the different levels, highlighting the importance of the interactions between the artifacts. To improve the development of flexibility products, this research presents how EA can contribute to the PLM. A product reference capability map was designed to provide insight in product related capabilities, useful to optimize the resource portfolio. The designed artifacts have been validated with expert interviews, involving architecture creators, architecture users and external architects. The validation resulted in refinements of the designed artifacts, ensuring correctness and usefulness of the artifacts.

With the design of the EA benefit realization framework, EA process model, and product reference capability map, this research makes significant contributions to both science as practice. Therefore, helping the DSO to improve their overall enterprise architecture value creation, and specifically tailoring EA to support the development of flexibility products, optimizing the DSOs grid utilization.

Keywords: Energy transition, Enterprise Architecture, Distribution System Operator, Flexibility, Demand response

Foreword

In front of you lies my thesis, written to conclude the last part of the master Business Information Technology. After achieving a bachelor's degree in Electrical Engineering and Industrial Engineering & Management, this degree offered me the perfect combination of business and technology, of which my field of interest lies exactly in the middle. I was quickly drawn to the subject of the energy transition, as the consequences of grid congestion are becoming an increasing societal issue, reaching more and more individuals and companies, and becoming a standard issue in the newspapers. I wanted to make my contribution to the energy transition.

Alliander offered me the opportunity to make this contribution. Without mentioning an explicit problem they wanted me to focus on, this company offered me the context and expertise to conduct my research. I did this by focusing on the entire enterprise architecture function in the organization. This discipline interested me since it promotes the use of appropriate IT to achieve business purposes. Since then, I am on my journey to find out how the enterprise architecture can optimally contribute to the energy transition.

Writing this thesis has been a journey of highs and lows. Navigating a rapidly changing organization, facing numerous challenges, and balancing the diverse and often conflicting perspectives of various stakeholders made it a challenge to keep my eyes on a target. Although challenging, this made my research super instructive. In my first employment interview, I said to my Alliander supervisor that I want to make real impact. Looking back, I think I've made proper scientific and practical contributions with my research, but also, I think this research is far from a true done, as new questions keep rising every day. I'm hoping this research will be embraced by the DSO, and will make its contribution to the energy transition, to a better world.

This thesis would not have been the way it is without the help of some important people. First of all, I want to thank my company supervisor Prince Singh, your mentorship provided me with valuable support, input and feedback throughout my entire research, your scientific background helped me enormously to properly conduct and document my research. I want to thank Hans Moonen for his valuable insights, especially in investigating the problem and scoping the research. I also want to thank Luís Ferreira Pires for giving me meaningful reflections and providing me with extensive feedback on the thesis. Furthermore, I would like to thank every Alliander employee that I spoke to, your insights have been incredibly helpful. On a personal note, I want to thank my family, girlfriend, friends and roommates for supporting me. Your energy and support helped me enormously to relax and laugh during the evenings and weekends.

With this thesis, I mark the end of my time as student. I am looking forward to true 'adult life', and all the opportunities that that may bring. *Graduation is just the beginning*

Tijs Berkenbosch
Enschede, June 2025

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Chapter 1

Introduction

This first chapter presents the introduction of the research, which includes the definition and context of the problem. Based on this problem, the chapter presents the research objective and defines the research questions. Consequently, the research scope and the used methodology are also presented in this chapter.

1.1 Problem statement

The energy transition poses several challenges to distribution service operators (DSOs). They are confronted with high penetration of variable and decentralized renewable energy sources as well as electrification within the transportation and heating sector. This increases the overall demand for energy transportation and primarily increases power peaks in the distribution grid. The electricity grid is not capable of transporting these amounts of energy, the grid is becoming increasingly congested. Assets are being overloaded and the risk for blackouts is increasing. DSOs are responsible for the operation of the distribution grid, therefore their mission is to satisfy customers in their energy need and to facilitate the energy transition. To fulfill this mission, grid congestion issues have to be solved.

Next to expanding the physical grid capacity, grid congestion can be solved by increasing flexibility in the distribution grid. This could help spread the energy load of customers and increase the grid utilization. However, implementing flexibility measures requires the DSO to (re)design business processes and acquire new (IT) capabilities. DSOs rapidly have to develop these capabilities to decrease the list of customers waiting for an electricity connection, which is causing major economic losses, but also to decrease the risk of a total blackout.

Enterprise architectures (EA) can add substantial value in addressing these challenges for DSOs. It can provide a structured approach to align business processes, information flows, applications and needed technology with the strategic goal of implementing flexibility into the distribution grid. Enterprise architecture can help identifying necessary capabilities and establishing a clear roadmap for achieving them. However, as a result of the rapidly changing internal and external environment of the DSO, as a result of the energy transition, the DSO is unsure how EA can be appropriately created and used to create the most value for the organization. This results in challenges to effectively deploy EA, and limits the ability of EA to create business and IT value, therefore not optimally guiding the DSO in acquiring the required capabilities.

This research addresses the topic of enterprise architecture, and how it can be used as a tool to help the DSO in preventing grid congestion through increasing the flexibility in the grid. Eventually supporting the DSO to facilitate the energy transition.

1.2 Problem context

This study has been conducted in collaboration with Alliander N.V., which is a major Dutch distribution system operator (DSO). With more than 10.000 employees, Alliander is at the forefront of facilitating the energy transition toward a sustainable, carbon-neutral future. Alliander is the operator of distribution electricity grid in large parts of the Netherlands and responsible for ensuring the delivery of power to 3,3 million households and businesses. Alliander has a big role in transforming and upgrading existing infrastructure to support the growing integration of renewable energy sources like solar and wind power. With the rise of decentralized electricity production, Alliander is innovating to enable flexible, smarter grids capable of managing increasing and more variable energy flows. Driven by these challenges as a result of the energy transition, the organization is growing rapidly with around 200 employees monthly, to upgrade the infrastructure and develop innovations [1].

1.3 Objective

This research aims to assess how DSOs can improve their enterprise architectures to ensure that EA creates organizational value, and supports the DSO in the energy transition. Based on this assessment, and the identified organizational need to increase the flexibility in the distribution grid, in this research we developed a tailored EA artifact that supports the DSO in the development of their flexibility products.

This main objective is decomposed into sub-objectives. These sub-objectives have been linked to the different research questions, jointly forming the main objective and main research question. The sub-objectives are shown in Table 1.1.

Table 1.1: Research objectives and corresponding research methods

DSRM	RQ.	Objectives	Problem type	Research method	Ch.
Problem	RQ1	Acquire an overview of the consequences of the energy transition and how DSOs need to change business (capabilities).	Descriptive knowledge question	Exploratory literature review	2
	RQ2	Acquire an overview of how the EA (business, data, application layers) is affected by the energy transition, assess challenges in EA value creation	Explanatory knowledge question	Exploratory & Systematic literature review & Expert interviews	3 & 4
Design	RQ3	Design a model which specifies the architecture process and manages architectural decisions.	Design problem	-	5
	RQ4	List the elements or requirements an architecture should fulfill when supporting flexibility products	Explanatory knowledge question	Expert interviews	6
	RQ5	Design a reference architecture from a flexibility product perspective and link it with capabilities, data and applications	Design problem	-	6.5
Validation	RQ6	Validate the designed artifacts with experts	Descriptive knowledge question	Case study & Expert interviews	7
	RQ7	Provide guidelines on how DSOs have to change EA to better contribute to facilitating the energy transition	Design problem	-	8.5

1.4 Scope

The Smart Grid Architecture Model (SGAM), which is a framework to describe and analyze smart grid systems in a structured way, is used to properly scope this research. SGAM consists of three main dimensions: domains, zones, and interoperability layers. The domains represent different parts of the electrical energy conversion chain, zones reflect the hierarchical levels of information management and control, ranging from the process level (e.g., sensors and actuators) up to the enterprise level (e.g., business planning and management). The interoperability layers address different aspects of system integration, such as business, function, information, communication, and component layers. The SGAM framework is further described in Figure 3.1.1.

By mapping this research onto SGAM, the scope can be defined clearly, indicated by the highlighted green area in Figure 1.1. The dotted line around this area represents the continuous interaction with other zones and domains, since they are highly interrelated with each other. The working area of the DSO itself is broader and also indicated in Figure 1.1 with the grey area.

As can be seen in Figure 1.1, the scope includes the domain electricity distribution (low/medium voltage grid), which is the primary activity of DSOs. The domains distributed energy resources (DER) and end-user facilities are also included, because these are the domains that are 'connected' to the distribution. Generation and transmission domains are out of scope, as this is the responsibility of other stakeholders. The zone enterprise is taken as primary scope because this zone represents the organizational processes within the DSO. The operation zone is also in scope, this zone includes DSOs systems and data, required to execute the processes. Station, field and process zones are out of scope because they represent local field level assets and data, which is too geographically dependent, which is too specific for this research. The zone market is out of scope, although DSOs trade on these markets, they are not responsible for the market

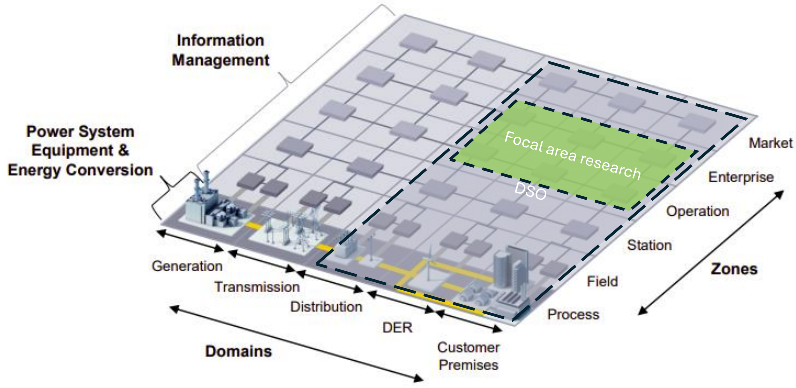


Figure 1.1: Scope of research indicated in green SGAM section

platforms themselves. Moreover, this research will focus on products that the DSO can use to improve flexibility, which is currently preferred to realize with individual customer agreements then via market offers. Regarding the interoperability dimensions the study focuses on the business, function and information layer.

The data that has been acquired in this research is about the energy landscape and (distribution) grid of a part of the Netherlands. Because DSOs in the Netherlands are a member of 'Netbeheer Nederland', which is an association that stimulates collaboration between grid operators, and because DSOs in the Netherlands operate in the same regulatory framework, this study is generalizable for DSOs in the Netherlands. Primary business activities and capabilities of DSOs throughout Europe are roughly the same, the energy transition poses the same challenges on them. Main differences between different DSOs in Europe are expected to lie in organizational structures and regulatory frameworks they operate in. These aspects should be reconsidered before generalizing the outcomes to other DSOs.

The research covers the first three phases of the DSRM by Wieringa [2]. The problem investigation, treatment design and treatment validation are reported in this thesis.

1.5 Research questions

The main research question of this thesis is:

RQ: How can distribution system operators improve their enterprise architecture to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

To answer the main research question, several sub questions have been formulated:

RQ1. What challenges does the energy transition bring to distribution system operators?

RQ2. How are the energy transition challenges reflected on the (enterprise) architecture of DSOs?

RQ3. How can the DSO ensure it creates value with enterprise architecture?

RQ4. How can enterprise architecture enhance the development of flexibility products?

RQ5. How can an enterprise architecture be designed that helps the DSO in the development of flexibility products?

RQ6. Can the artifact help DSOs in increasing the flexibility in the distribution grid?

RQ7. What further enterprise architecture related changes are required to successfully support increasing the grid flexibility?

1.6 Research methodology

To answer the main research question, a research methodology has been chosen. Since the main RQ is an improvement and design question, the Design Science Research Methodology (DSRM) from Wieringa has been employed [2]. According to his methodology, design problems have a context and stakeholder goals and call for an artifact such that the interactions of ($artifact \times context$) help stakeholders to achieve their goals. The design problem for this thesis can be described by using the DSRM template:

Improve	the development of flexibility products
By (re)designing	enterprise architecture processes and artifacts
That	are aligned with the organization and supports product developers
In order to	Enable EA to support the DSO in facilitating the energy transition

Figure 1.2 shows that the DSRM-methodology is a rational problem-solving process executed in three phases. The DSRM-methodology starts with the problem investigation, this phase specifies what phenomena must be improved and why. Moreover, this phase addresses the knowledge questions, required to design an appropriate artifact. For answering the defined knowledge questions (RQ1 and RQ2), a foundation of existing knowledge is acquired by combining exploratory and systematic literature reviews (SLR), as well as practical knowledge gathered in a case study, by collecting data through expert interviews.

The second phase, artifacts are designed that could treat the problem. This pase (including RQ3, RQ4 and RQ5) proposes three different artifacts, collaboratively helping the stakeholders to achieve their goal: (1) an EA benefit realization framework, (2) an EA process model and (3) a product reference capability map.

In the treatment validation phase, artifacts are validated, which assesses if the artifacts have the desired effect on the problem. For the validation, several expert interviews have been conducted, both with architecture creators, and the architecture users, which ensured a holistic validation of the artifacts. Also, trade-off and sensitivity questions were answered, assessing the artifact effects in different contexts. Table 1.1 shows how the DSRM methodology is applied to the research questions. The DSRM methodology also includes the treatment implementation and implementation evaluation, these two phases are out of scope for this research.

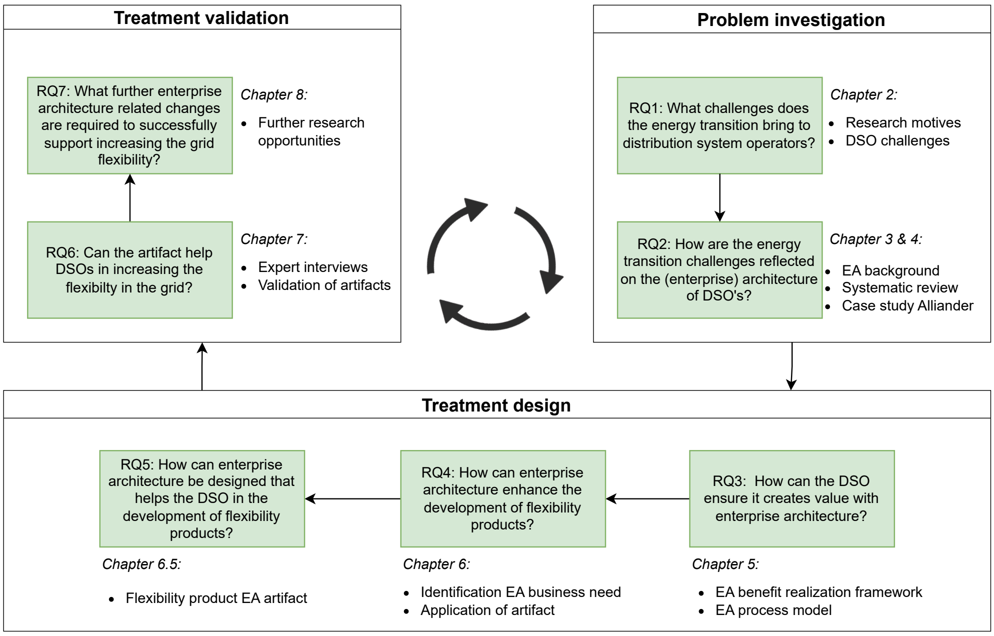


Figure 1.2: DSRM methodology applied in this research

1.7 Report outline

The structure of this master thesis is visualized in Figure 1.2, where the different research questions are placed in the three DSRM phases. Figure 1.2 shows that the problem investigation of this thesis is based on the five research questions answered in an initial research, of which the findings answer the first two research questions.

This document has been further structured as follows. Chapter 2 explains the energy transition and the implications for DSOs. Chapter 3 gives the background information about EA, complemented with a systematic literature review about EA in DSOs. Chapter 4 describes the results of a case study at Alliander, including expert interviews, thereby concluding the problem investigation. Chapter 5 describes the design of a benefit realization framework and an EA process model. Chapter 6 describes the design of an artifact to help the DSO in the development of flexibility products. Chapter 7 presents the outcomes of the validation of the designed artifacts. Finally, Chapter 8 presents the conclusions of this research and identifies topics for future work.

Chapter 2

The energy transition and its implications for DSOs

Before answering the research question, which aims to contribute to the energy transition, this chapter gives a background overview of the energy transition. This is the main motive for executing this research, it mechanisms therefore should be known. The second part of this chapter addresses the effects of the energy transition for distribution system operators. This chapter provides the necessary background knowledge to understand the changing environment of the DSO, and what it should do to keep facilitating the energy transition.

2.1 The energy transition

A major structural change in the way energy is supplied and consumed is needed to limit climate change and deal with fossil fuel scarcity. The concept of energy transition is explained according to the golden circle model, which was used because it empathizes the main motives behind the energy transition (the 'why' aspect) and therefore proves the relevance and purpose of this research. By acquiring this overview of high level goals, supplemented with how and what aspects, a solid insight in the changing context of this research is gathered [3].

2.1.1 Purpose

The primary objective of the current energy transition is to limit climate change and achieve carbon neutrality [4, 5, 6, 7]. This is needed to achieve net-zero emissions and limit global warming to 1.5℃ by 2050 (agreed on in the EU green deal [8]). To achieve this, a sustainable, efficient, competitive and secure energy system needs to be developed [4]. Currently, a transition to sustainable energy is underway by implementing renewable energy sources and phasing out fossil fuels, reducing emissions and climate impact.

Several secondary factors stimulate the current energy transition. First, the supply of non-renewable energy sources such as fossil fuel is scarce. These sources can become depleted and cause shortage [5]. Second, these sources are mostly imported and thus cause a big dependence on another country. Society became aware of this in the global oil crisis in 1970 [4, 6]. Energy price fluctuations caused by recent geopolitical tensions in the middle east made society and governments even more aware of this dependence and underscore the importance of energy security

[7]. Third, air or water pollution from these energy sources also cause many adverse health effects and harms ecosystems [5].

The goal of the renewable energy transition is therefore to become sustainable and reduce emissions, diversify the energy portfolio and reduce the dependence on finite and geopolitically sensitive energy resources.

2.1.2 Approach

Technological developments are the enablers of the current energy transition. Efficiency improvements and cost reductions in renewable energy production make renewable energy sources more attractive than non-renewable sources [5, 6, 7]. The levelized costs of energy (LCOE) is a measure of the net present costs of energy generation, and can be used to compare energy generation methods [9]. It is calculated by dividing the sum of the costs of lifetime by the sum of the total energy produced in the lifetime. For many renewable energy sources, the LCOE is lower then fossil fuels. For instance, in 2010 the onshore wind production was 23% more expensive then the global weighted average LCOE of fossil fuels, but in 2023 was 67% less expensive compared to fossil fuels [10]. This is mainly due to efficiency and costs improvements of wind turbines.

The objective of becoming climate neutral and the decrease of the pricing (and LCOE) of mostly photovoltaic panels (PV) and wind turbines, caused a rapid increase in their deployment [6, 10]. Also governmental policies such as feed-in tariffs have been developed to simulate the deployment of renewable energy generation [11]. The current deployment status of renewable energy differs much between per countries. Globally, around 18,5% of the energy production is renewable [12]. The global yearly addition of renewable power capacity increases yearly and thus the total installed capacity grows exponentially. In 2023 a total of 473 GW of new renewable power sources has been installed [10]. In the Netherlands, currently 50% of electricity (not energy) is produced by renewable sources [13].

To further reduce emission, action plans have been developed to increase the electrification in the heating and transport sector, with the implementation of heat pumps and electric vehicles (EV) [14].

Figure 2.1 shows on the left part that large scale electricity is generated and transported, this transmission is the responsibility of the transmission system operator (TSO). They maintain the high voltage electricity grid. In Europe, the transmission grid of countries is connected and form the 'synchronous grid of continental Europe'. The European Network of Transmission System Operators for Electricity (ENTSO-E) manages this [15]. The right part of Figure 2.1 shows that the energy is locally distributed, this is the responsibility of the distribution system operator (DSO), they maintain the medium and low voltage grid and deliver electricity to the end user. From an electricity perspective, this TSO and DSO are the two main actors responsible for facilitating and enabling the energy transition. New market arrangements have led to the role of aggregator, which is party that groups together and manages flexible loads of multiple grid users [16, 17].

Historically, electricity distribution was simple and based on the principle of large-scale centralized generation and unidirectional transportation towards consumers. However, the increasing deployment of renewable energy has transformed this dynamic. Consumers now often produce electricity as well, becoming prosumers with technologies like rooftop solar panels, which made electricity flows more variable and bidirectional [4, 6, 19], as can be seen in Figure 2.1. These changes must be accompanied by key enablers as grid expansion and energy storage [10, 20] as well as demand response, smart grids, new business models and market arrangements[6, 19]

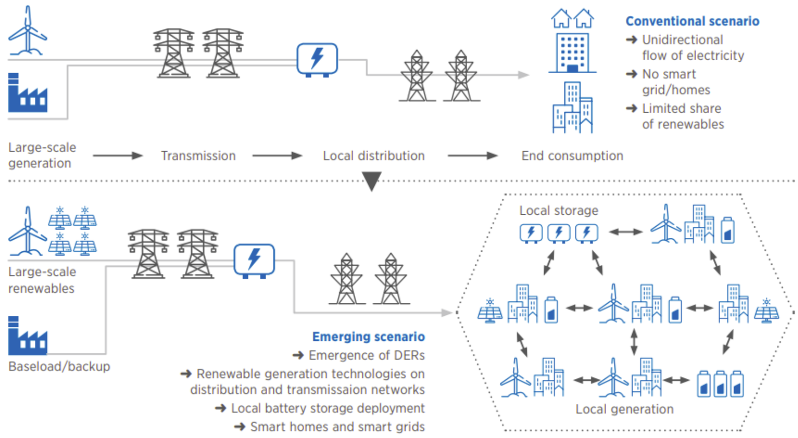


Figure 2.1: Changing power system [18]

2.1.3 Definition

An energy transition is historically defined as the shift from one dominant energy resource – or set or resources – to another [4]. This transition involves a transformation in the energy technology as well as several socio-economic developments. Energy transitions are driven by a combination of technological innovation, market dynamics, policy arrangements and cultural factors[4].

Energy transitions in the past have been complex and long-dawn processes that could take centuries, as it depended on the switch in fuels and technologies for multiple energy services in many sectors [21, 22, 23]. An example of a previous energy transition is the industrial revolution where energy from wood and other biomass was replaced with coal and later oil. A review of 14 past transitions indicated that, for a new energy source to become dominant, the energy services it provided had been cheaper than the original energy source [21]. This happens when a new source can generate power at a lower LCOE and this is called grid parity [9].

On the contrary, the studies did indicate that many of the services provided by the new energy source were initially more expensive than those from the incumbent source, the new energy source or its related technology, offered benefits (e.g. ease of use, flexibility and cleanness, or exclusivity, novelty and status) that consumers were willing to pay for [21]. Long-term scaling up the new technology offered substantial cost improvements through economies of scale effects and caused the technology to achieve grid parity and become dominant [7, 22].

Energy transitions, in which new technological combinations enabled entirely new or vastly improved traditional services at greater energy efficiency and falling costs, caused self re-enforcing positive feedback loops where energy demand and supply co-evolve, with innovations mutually enhancing each other [22]. Energy transitions are therefore often associated with an increase of total energy consumption [24], since the switch in primary energy source does not directly lead to a decline of the energy used from the now secondary source. Therefore, previous energy transitions could sometimes more accurately be described as energy additions rather than transitions [25].

Energy transitions have often been associated with periods of rapid economic growth [26] and transformations in economic structure and activity [23].

2.1.4 Glance into the future

The future energy landscape is dependent on decisions made by the European Union and other governmental bodies, such as the Dutch national government. 'Netbeheer Nederland' distinguished four scenarios that describe how the future energy system for European countries (perspective of The Netherlands) could look like towards 2050 [27], which are shown in Table 2.1

Scenario	**Characteristics**
National leadership	Government leads market High penetration of renewables No import/export
European integration	European supply/demand management Energy demanding industry becomes sustainable
Decentral initiatives	Energy demanding industry leaves Many regional collaborations to balance energy
International trade	Worldwide energy trade Energy demanding industry leaves

Table 2.1: Energy landscape of the future scenario's [27]

The future electricity demand and supply – and thus the needed infrastructure – is dependent on which scenario will manifest itself. This determines, for instance, to what extend energy intensive industry will leave or to what extend industry becomes sustainable. However, regardless of the scenario, electricity consumption in the EU will increase, primarily due to the further deployment of heat pumps (+50 million before 2030) and electric vehicles (+70 million before 2030)[28]. The rise of artificial intelligence (AI) and the associated increase in data centers is also expected to drastically increase electricity demand [29].

Next to this, the number of variable renewable energy (VRE) sources is expected to increase [10, 27, 30, 31, 32], ultimately moving towards a primarily sustainable energy system in 2050. Percentages vary a lot between countries but globally 65 to 80 percent of global power generation will be produced by low carbon sources [29]. A report of AMO (on behalf of all Dutch DSOs) about the energy landscape in 2050 in The Netherlands, confirms an electricity supply almost totally generated by renewables (wind and solar primarily) [33]. This requires a shift in how energy is consumed, from demand-based, to supply-based [27].

More electricity production and consumption requires the power grid to be upgraded. The traditional distribution grid can only transmit power, while the modern smart grid is able to store, communicate and make decisions. This grid aims to integrate the actions of all users – producers, consumers and prosumers – in order to efficiently deliver sustainable, economic and secure electricity, powered by information technology [19, 34, 35].

2.1.5 Energy transition motivation modeling

To summarize the motivation for the energy transition, as described in this chapter, the main drivers, goals and outcomes are shown in an Archimate model, shown in Figure 2.2. Archimate is a standard notation developed to represent Enterprise Architecture views. In this model the goal to limit global warming and to become climate neutral plays a central role, and is supported by policies from EU and national government bodies. The increase in VRE and electrification show to have the most impact in achieving this.

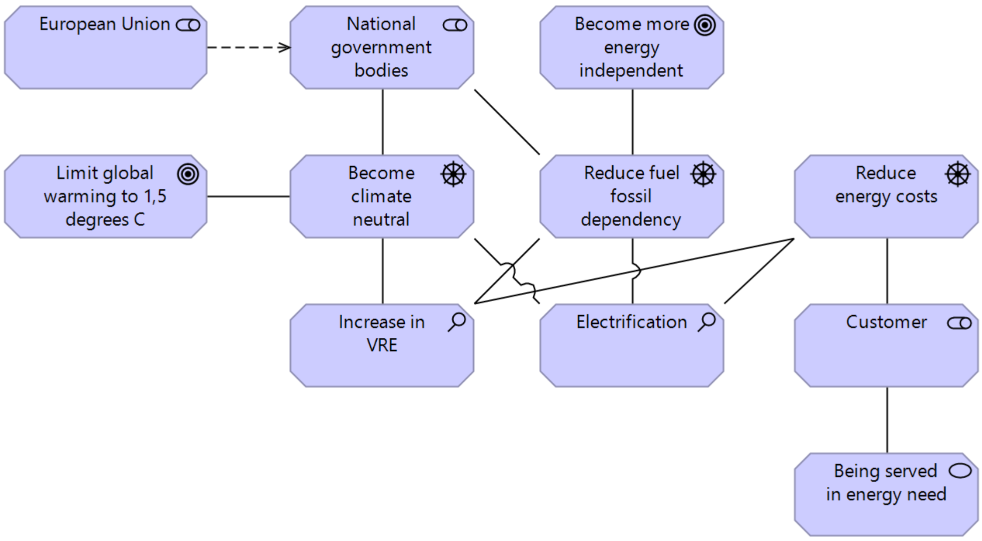


Figure 2.2: Energy transition motivation in Archimate

2.2 Challenges for distribution system operators

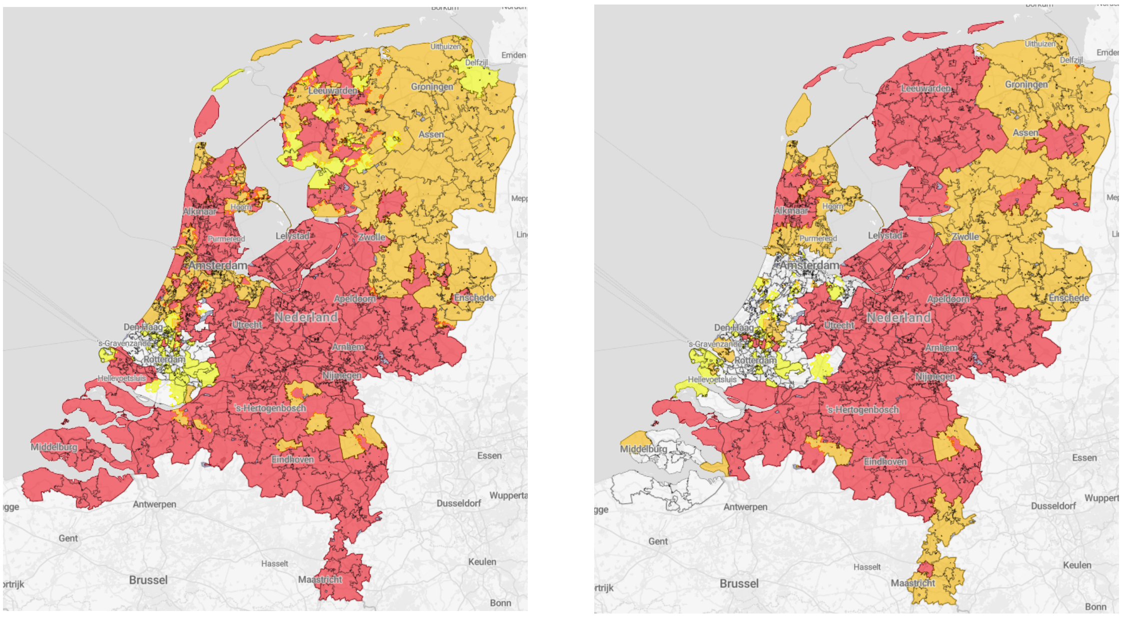
The increase of renewable energy deployment and electrification increase the total electricity capacity, but also make power peaks more significant, because typically these sources require or produce energy at certain moments of the day. These developments make the power flows less predictable and lead to an increase of the need for transportation capacity between the electricity supply and demand (customer).

The conventional electricity grid is often not able to transport the increasing (peak) amounts of energy, so grid congestion occurs [1, 16, 19, 32, 36, 37]. In Europe, grid congestion is becoming an increasingly frequent issue, mostly caused by renewable generation peaks and load peaks [36]. In many EU countries with a lower penetration of renewable power generation and EV, congestion is not yet an issue. However, also for them grid congestion can rapidly become an issue in certain zones as these penetration numbers increase [36]. DSOs should be prepared to be faced with a major increase in a very short time. For example, in Latvia, the connection request for solar energy rose with 1425% in 2021 [37].

Because of grid congestion, customers cannot get access to electricity and a substantial amount of renewable electricity is at risk of being wasted. It is estimated that in 2040 up to 310 TWh of renewable energy could be curtailed because of grid congestion, which equals half the electricity production from wind and solar in the EU in 2022 [30]. The easiest solution to solve grid congestion and allow further developments in the energy transition is to reinforce the physical capacity of the grid. Over 7 million km of electricity networks in the EU need to be renewed until 2050, which corresponds to two-thirds of network in place today [28]. However, this is a process that takes decades and is extremely costly [18, 38].

2.2.1 Situation in the Netherlands

Grid congestion in the Netherlands has reached a severity where there is a waiting list to be able to get access to the electricity grid [1]. Grid operators have done congestion management investigations to assess the currently available flexibility in the grid and how this can be used to shorten the waiting list. In the meantime, a lot of investments are being done to expand the grid. However, it is expected that grid congestion problems are not solved before 2032 [39]. According to a recent research from Ecorys and the Boston Consulting Group, the annual economic loss because of grid congestion ranges between 10 and 40 billion euros [40]. Figure 2.3 shows the available capacity on the grid in the Netherlands, where Figure 2.3a shows the availability of new demand connections and Figure 2.3b shows the availability of power delivery to the grid and is thus only applicable to prosumers and producers. In Figure 2.3, red areas indicate that no new grid connections are possible, orange areas indicate that no new connections available but congestion management investigations are in progress to try to find capacity for new connections, yellow areas indicate limited available capacity, white areas indicate missing data.



(a) Demand

(b) Supply

Figure 2.3: Congestion map the Netherlands (01/11/2024) [41]

The 'Landelijk Actieprogramma Netcongestie' is a national initiative in the Netherlands aimed at tackling grid congestion. The program brings together the government, grid operators, and other stakeholders to (1.) expand grid infrastructure, (2.) improve utilization of the current electricity grid and implement smart technologies to manage electricity demand and (3.) Improve data collection. Its goal is to ensure a reliable and flexible electricity network to support the growing demand for renewable energy and electrification in the Dutch enery transition [42].

2.2.2 Implications for DSOs

To enable the energy transition and solve the named challenges of congestion, transmission service operators (TSO) and distribution system operators (DSO) need to develop new capabilities. Historically, the role of these system operators was merely the development of grids and maintaining them through asset management. Nowadays, they need to actively operate the grid, execute congestion management and tackle peak load management [17, 18, 31, 37, 43].

The future activities and needed capabilities of DSOs are only partly predictable. It is known that, to meet future demands, DSOs need to establish capabilities to manage and utilize data as a basis for operational decisions [44]. They also need advanced forecasting methods and improved

IT solutions [43]. Also, they need to better collaborate with TSOs [17, 45]. There are also major uncertainties related to the electricity grid ecosystem such as regulatory changes to tariff schemes and market roles [46]. Vokony [47] created a business capability map that shows future business activities of DSOs, which is shown in Figure 2.4. New capabilities lie predominantly in the active network management. The energy transition also poses new business opportunities for DSOs, as their expertise in energy solutions becomes more and more valuable to different actors (e.g. municipalities) [47].

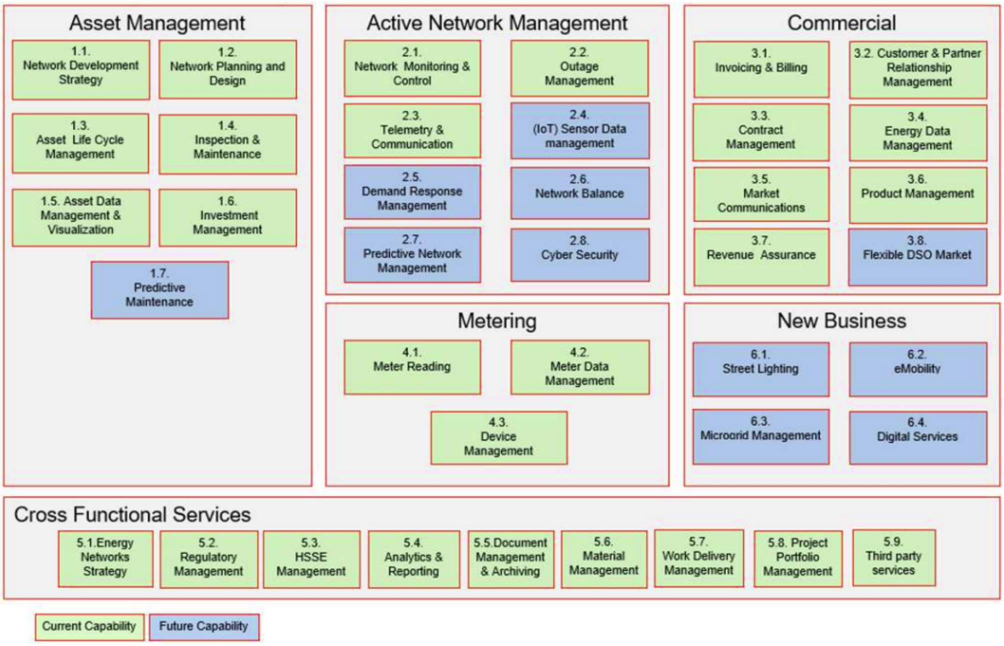


Figure 2.4: Business capability map for DSOs [47]

Analyzing data gathered from 56 DSOs in 22 EU member countries resulted in the identification of multiple challenges that DSOs are confronted with [32]. Table 2.2 summarizes all these changes, complemented with other challenges found in this literature review. Historically known DSO challenges, such as grid reliability, are excluded, these challenges are not related to the energy transition explicitly. The challenges should not be seen as individual challenges and are interrelated with each other.

Table 2.2: New challenges posed on DSOs

Change	Source
Increasing flexibility in the distribution grid	[16, 17, 20, 27, 28, 30, 32, 35, 37, 43, 47, 48, 49]
Increased importance of TSO-DSO collaboration	[17, 32, 37, 45, 49]
Supply and demand forecasting	[32, 35, 43, 44, 47]
Data management (cloud, interoperability)	[28, 32, 35, 37, 47, 49]
Smart metering deployment & infrastructure	[28, 32]
Increased (e.g. SCADA) IT system capabilities for station and load control	[32, 47]
Grid expansion	[28, 29, 32, 35, 37]
Cybersecurity	[28, 47]
GIS and mapping systems	[28]
Predictive maintenance	[47]

DSOs are heavy infrastructure actors and regulated entities that depend on the proper framework conditions to deliver [37]. For the 56 DSOs three primary barriers have been identified that hinders them in becoming more active and engaged with the needed capabilities [32]. The findings correspond with the challenges the DSO-Entity identified in a report representing every European DSO [37].

- **Regulation does not provide appropriate incentives for innovation.** This includes counter productive subsidies or tariff structures and laws. For instance, the possibility for DSOs to own and operate energy storage (art. 36 of EU Directive 2019/944) which prevents the deployment of storage as a grid management tool.
- **Lack of qualified personnel.** Specifically in the adoption of digital transformation capabilities.
- **Regulatory uncertainty and instability.** DSOs need government bodies to make consistent decisions about the future, for instance, choosing a definitive energy landscape scenario as discussed in Section 2.1.4.

Table 2.2 shows that, implementing flexibility is considered important in most literature [16, 17, 20, 27, 28, 30, 32, 35, 37, 43, 47, 48, 49]. DSOs are now increasing flexibility in distribution networks, this could increase grid capacity utilization, decrease power peaks and enable a higher integration of renewable energy, reducing the need for expensive grid expansion [16, 17, 20, 27, 30, 32, 43, 48]. Currently, there is little storage capacity available in the power grid so demand and generation must be perfectly matched and continuously managed to avoid frequency or voltage instabilities [50]. Balancing the generation of electricity has become increasingly difficult because the energy production from renewable sources cannot be controlled and is weather-dependent, which is not fully predictable and does not match with energy demand [20, 34, 48]. Flexibility in the distribution grid can be used to better align supply and demand and shift the power peaks caused by renewable energy sources or loads [14, 48], as shown in Figure 2.5. A variable generation-based grid of the future must include generation that can start, stop and ramp rapidly, accompanied with deployable reserves [48].

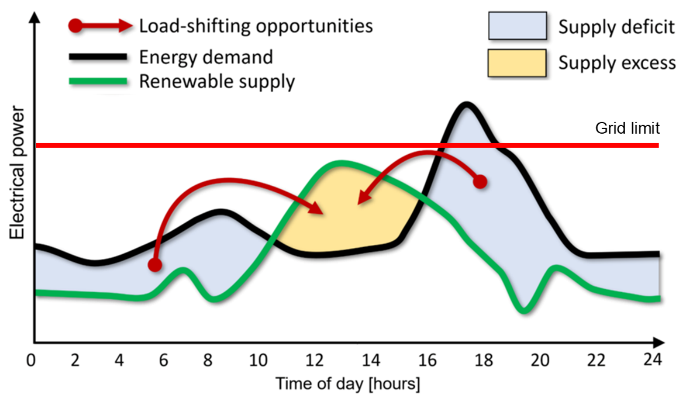


Figure 2.5: Objective of flexibility (adopted from [51])

2.2.3 Implementing flexibility

Increasing flexibility in the distribution grid require DSOs to implement (technical) solutions that need to be accompanied by organizational changes. Several flexibility measures can be implemented to make the traditional grid a more smart grid, which can maximize the alignment of supply and demand of energy and prevents congestion. Two aspects of flexibility can be addressed [31]:

1. Demand response: measures taken by active and engaged prosumers to manage their electricity usage in response to real-time information.
2. Demand-side management: measures taken by utilities (DSO and TSO) to ensure an even supply of energy.

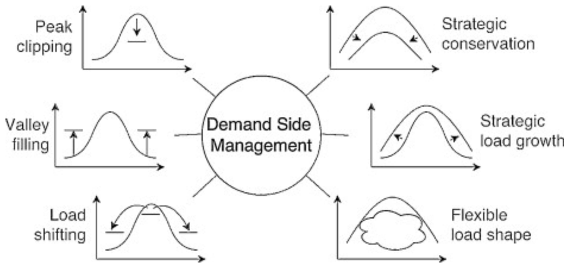


Figure 2.6: Load shaping techniques [34]

The main objective of flexible demands is to reduce the power peaks in the distribution grid, and thus prevents congestion, as shown in Figure 2.5. This can be done by encouraging users to consume less power during peak times or to shift energy use to off-peak hours to flatten the demand curve, an example can be seen in Figure 2.6. In the case of a high integration of renewable sources it is desirable to follow the generation pattern, and thus weather patterns [17, 34, 48].

Demand response

With the use of a demand response product, a connected party (a DSOs customer), can change its electricity load or production magnitude from its normal or current consumption pattern in response to a variety of conditions. This is most suited to loads that can be time-shifted to later periods without serious consequence, for example charging an electric vehicle [17].

Energy tariff (Time of Use) Users are obligated to pay for the amount of energy they consume. Often the price of energy is fixed, which means that the user pays the same price regardless of what the load in the distribution grid was at the moment of user's consumption. This design only provide incentives to consume less total energy. Energy/ToU tariffs make the energy price dependent on the load on the distribution grid, which should encourage users to shift their consumption to moments with a low grid utilization instead of a moment where the grid is congested. This could lead to load shifting [16, 49, 52].

Capacity tariff A capacity tariff assumes the price of the energy to be based on the maximal achieved power, providing incentives to the end user to keep the peak consumption as low as possible. A peak tariff is a variant of the capacity tariff where the price is the peak load caused by end user's consumption multiplied by the tariff. The tariff could be constant or depend on the size of the peak load. The user's payment is based on a capacity class to which the peak load belongs [16, 49, 52]. This could also lead to load shifting.

Flexibility market A flexibility market is a platform where flexibility in consumption or production is a product and can be traded both by a DSO and a TSO. All the grid operators trying to solve a congestion or imbalance problem and all devices with flexible consumption that could solve grid problems compete against each other in one market [16, 31]. For example, on this market a DSO can ask a big consumer if it can limit its consumption during a certain time period, for which it will be financially compensated. In the Netherlands the grid operators platform for congestion solutions GOPACS platform has been developed and is used as a flexibility market [52].

Capacity limited contracts (CLC) A CLC is an agreement between the DSO and a customer, in which the connected customer commits to reducing their electricity take-off or feed-in during peak times in exchange for a fee, thereby helping to mitigate grid congestion. The fee is calculated based on the customer's missed generation or consumption. This contract can be applied to an individual customer, but also to multiple customers, as can be the case in energy hubs. The group of customers will then be given a collective capacity limit that can be reduced during peak times. CLC's can be fixed – where a customer needs to reduce transport capacity during certain pre-agreed periods – or dynamic, where the capacity limitation is only activated by the grid operator if it expects congestion to occur [32, 52].

Energy hubs (microgrids)

Microgrids have been proposed as one solution for integrating VRE into the power system and balancing supply-demand alignment. Microgrids are local grids to supply electricity to local consumers. A microgrid energy system may include local power generation. Within a larger power distribution system, the microgrids could be operated as a component of the larger grid system to balance voltage fluctuations. During disturbances, they can be isolated from the larger system (island mode) to secure the energy supply in its own area [19, 20].

An energy hub is a practical implementation of microgrids in the Dutch electricity system. An energy hub is a local junction in an integrated energy system, where supply and demand are efficiently managed and aligned between parties. Energy hubs have the potential to reduce the peak load on the electricity net since aligning the local demand and supply investments in the infrastructure can be minimized. However, groups of companies and/or residents have to collaborate to align this. Digitalization including AI and algorithms are an important factor in energy hubs. Currently there are approximately 100 energy hubs on industry parks in the Netherlands, however, 'Topsector Energie' (a Dutch initiative to innovate the energy system) identified 1200 opportunities for energy hubs [53, 54]. Energy hubs and microgrid are examples of area's where self consumption is encouraged.

Increasing self consumption

Encouraging self consumption should lead to a reduction in the need for transportation capacity. With current feed-in-tariffs in place there is less incentive to self-consume the power because the energy can be sold [17]. If feed-in-tariffs decrease then the self-consumption economic model for distributed solar power becomes more profitable, where power that is self-generated and self-consumed, for example through a local battery, has more economic value to the consumer than power that is sold to the grid [20].

Energy storage

Battery storage can be used to time-shift the delivery of power and reduce peaks on the electricity grid. This is done by storing locally produced energy in a period of grid congestion or in a period with more supply then demand. This energy is then released in a period with lower grid utilization and higher demand [17, 38]. Examples are home batteries and community batteries, but also flywheels, hydrogen or thermal storage [17, 20]. A lot of research is being done into the topic of vehicle-to-grid (V2G) as a possibility to use the batteries of electric cars to offer flexibility on the electricity grid. V2G scheduling can dramatically smooth out fluctuations in power loads[19, 32, 50]. Energy storage is suitable for the grid of the future because of their rapid response time and high power ramping rate [20], which were essential aspects of the grid of the future according to [48]. Energy storage can also solve renewable energy curtailment, with storage the production can continue while being disconnected from the grid [20].

Virtual power plant (VPP)

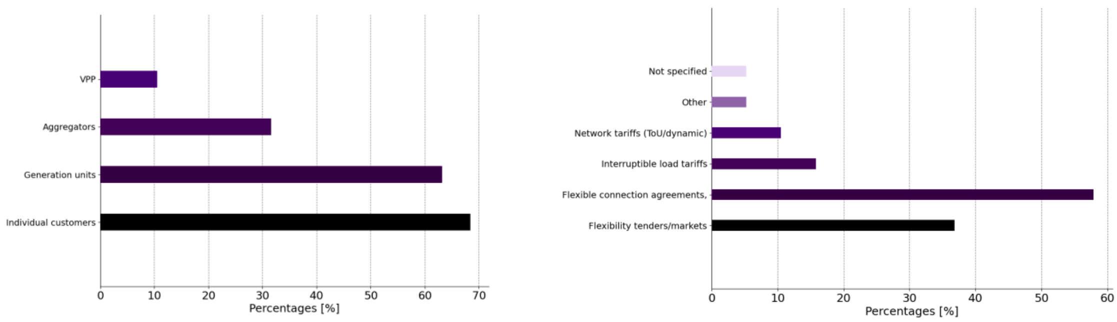
A virtual power plant is a combination of distributed energy resources bundled together, such as distributed generation, storage, demand response, and electric vehicles, which all may be individually small and geographically disparately located. Connected together via smart-grid links, with control and accounting systems, this virtual block of resources can become a dispatchable resource to the grid, can provide ancillary services, or can be used in local power networks and markets [17].

Supply-side flexibility

The balance in the electric system is traditionally managed on the supply side. This is done with measures or technologies through which the output of power generation can be influenced. As described in Section 2.2.2 this has become increasingly difficult with the implementation of renewable energy sources. These sources cannot be ramped up as traditional power plants could. Variable renewable sources can be curtailed (limiting the power output) but this is not desirable because of energy losses [20]. It is therefore preferred to solve grid congestion on the demand side.

Current usage of flexibility within DSOs

The degree in which DSOs have implemented flexibility into the grid differs much per DSO. A survey among 56 DSOs in 22 EU member countries showed that only 34% of the DSOs procured flexibility. Figure 2.7 shows the results of this survey, Figure 2.7a shows that most of the DSOs use flexibility offered by individual customers, primarily industry. Figure 2.7b shows that most DSOs access this flexibility through flexible connection agreements.



(a) Flexibility providers

(b) Options to access flexibility

Figure 2.7: Percentage of DSOs using flexibility measures [32]

Earlier initiatives have been executed to help DSOs in implementing flexibility. The EU project UNITED-GRID tried to support DSOs in the transition towards an active system operator by providing a toolbox of market frameworks and technical solutions (including measures mentioned in Section 2.2.3) to serve needs and opportunities for DSOs in their electricity grids [55].

2.2.4 Organizational challenges

All these measures to actively manage the distribution grid and reduce grid congestion will not only require accelerated investment in (technological) innovation and digitalization, but also upgrading internal processes and tools, and a shift in the cultural mindset of the DSO [43]. The changes within DSO organizations can be divided into four categories, as shown in Table 2.3, identified by interviewing 10 grid company managers [44]. The identified organizational challenges correspond with the challenges mentioned in Section 2.2.2.

Table 2.3: Changes within DSOs [44]

Change category	**Subcategories**
Consolidation, Responsibility, and Regulation	New DSO roles Flexibility market Changing tariff structures
Consumer Expectations	New customer demands Electrification
Digitalization	Smart meters Automated processes System integrations Data quality
Power Grid Demands	Grid expansion Aging grid

For companies in the power grid industry to survive the next decade, it seems insufficient to have the management capability “to effectively coordinate and redeploy internal and external competences”. Rather, it is essential for them to be able to establish competences that enable them to follow ever-faster technology shifts and regulatory changes, while maintaining high up-time in supply of power. Currently, DSOs perceive that the rate of change in technology is faster than the rate of internal change [44].

DSOs have to develop new organizational capabilities to keep up with facilitating the energy transition and in undergoing the four identified change categories listed in Table 2.3. The capabilities need to be organic and have to support operational capabilities. Reegard [46] identified four capabilities DSOs need to overcome the challenges from Table 2.3. These capabilities are placed into a typical capability stack of a DSO in Figure 2.8:

1. Analytics: Facilitate data driven decision making
2. Collaboration: Involve relevant stakeholders at the right time
3. Innovation: Identify new business opportunities and leverage organizational developments
4. Influence: Change, develop and customize framework conditions to business opportunities

The exact organizational challenges faced are different for every DSO because of the large difference in organizational structure, technical differences in the networks, and different regulatory frameworks among the European DSOs [43]. The DSO organization has to assess its future readiness based on technical, market and policy indicators. These indicators are vital to identify the areas of development that the DSOs should focus on. Based on this, DSOs can identify investment needs (such as flexibility measures shown in Section 2.2.3).

DSOs need to become more agile and react to market developments when needed. Two business models are proposed to utilize the full potential of all the implemented smart grid solutions: (1.) he DSO as a service provider, and (2.) the DSO as a market platform operator. These models would entail a shift where DSOs become service operators [43] and market facilitators [49]. The

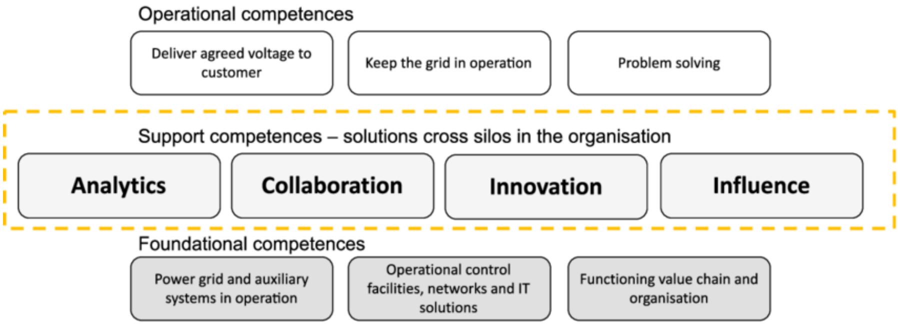


Figure 2.8: Capability stack model [46]

energy transition therefore provides an opportunity for DSOs to transform some of their activities from a legislated environment with obligations to a customer-centric, service-based approach [47].

2.2.5 DSOs role in energy transition modeling

To summarize the the implications of the energy transition for DSOs, an Archimate model has been developed. The model, shown in Figure 2.9, is an extension of the motivation model (Figure 2.2) with the DSO role, assessments and outcomes. Figure 2.9 shows the two primary goals of the DSO: (1.) to facilitate the energy transition and (2.) to serve customers in their energy need. These goals can be realized by becoming an active system operator, which has many compositions. Executing these compositions reduces grid congestion and thus an increased amount of customers being served in their energy need.

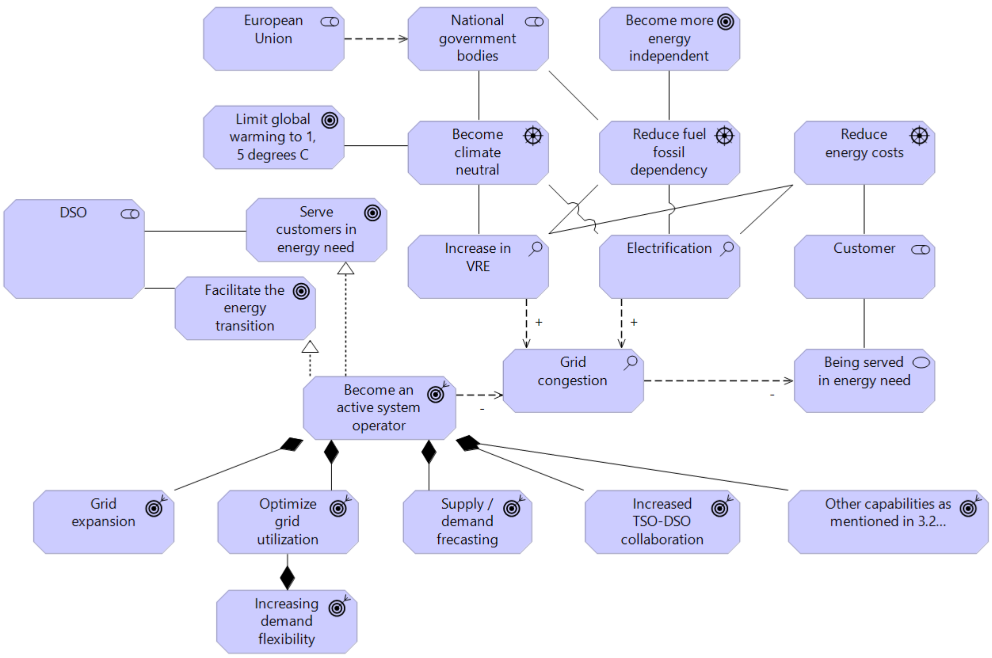


Figure 2.9: Energy transition reflected on the DSO archimate motivational model

Chapter 3

Enterprise architecture for DSOs

This chapter explains the role of Enterprise Architecture in organizations Section 3.1 provides a solid theoretical background about EA, covering vital elements as EA processes, artifacts and the benefits it yields. Section 3.2, reports on a systematic literature review conducted to assess the state of the art literature about the usage of EA within DSOs in the energy transition.

3.1 Enterprise Architecture

This section presents the results of an exploratory literature review conducted about Enterprise Architecture and its role and purpose within organizations.

Enterprise Architecture (EA) by most accepted definition is:

'A coherent whole of principles, methods, and models that are used in the design and realization of an enterprise's organizational structure, business processes, information systems, and infrastructure' [56].

EA captures the essentials of the business, IT and its evolution. An appropriate Enterprise Architecture provides the insight needed to balance the organizational requirements and facilitates the translation from corporate strategy to daily operations [56]. Business and IT improvement often takes place in silos, without comprehensively considering the organizational viewpoint and transformation as a whole (the holistic picture seen as the 'glue' of the transformation is missing) [57]. EA is a strategic planning and governance instrument in guiding the integral organization through a planned course of development, or in guiding through a changing environment [57, 58, 59].

EA can be seen as a blueprint that ensures that all components of an enterprise, such as business capabilities, IT infrastructure, applications and data are interconnected and optimized to support the organizational strategy. According to The Open Group Architecture framework (TOGAF) 'the purpose of EA is to optimize across the enterprise the often fragmented legacy of processes (both manual and automated) into an integrated environment that is responsive to change and supportive of the delivery of the business strategy' [60].

Traditionally, EA primarily descriped the current and future state of the enterprise-wide IT architecture, where business descriptions only provided input. EA was driven by technology and business standardization, systems engineering, and IT asset utilization. Currently, Enterprise Architecture is no longer understood as an isolated responsibility of the IT department, as EA must align with the organization's strategy planning and strategy implementation processes to achieve its full potential [61]. In an organization, EA should therefore be positioned between business strategy and IT [59].

In order to achieve organizational benefits with Enterprise Architecture, several aspects should be taken into consideration. The literature about Enterprise Architecture benefit realization presents three key themes [62], which are shown in Figure 3.1.

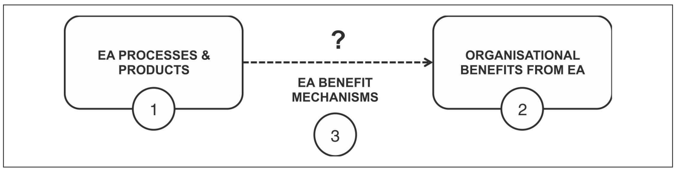


Figure 3.1: Three themes responsible for EA benefit realization [62]

1. **EA processes & products:** involves what EA consists of, including its activities and EA deliverables, described in: Frameworks, EA purpose and responsibilities and Artifacts. This can also be referred to as the **EA capability**, being the 'extent to which the EA team effectively and efficiently produces and provides IT decision-makers with relevant, timely, high-quality information and advice pertaining to the EA vision, current state, and/or roadmap' [62].

2. **Organizational benefits:** involves the expected outcomes from the EA, described in Benefits.

3. **EA benefit mechanisms:** focuses on how the causal relationship between 1 and 2, i.e., how EA activities lead to organizational benefits, described in Benefit realization.

The following sections will explain the key aspects contributing in achieving organizational benefits with EA, in order to efficiently use it in this research for increasing grid flexibility.

3.1.1 Frameworks

Frameworks structure architecture description techniques by identifying and relating different architectural viewpoints and the modeling techniques associated with them. Two popular frameworks are used in Enterprise Architecture and relevant to the working area of DSOs

TOGAF

The Open Group Architecture Framework (TOGAF) is a domain-independent framework used for designing, planning, implementing and governing an Enterprise Architecture. It is an open standard and consists of several techniques and best-practices to support the Architecture Development Method (ADM). The TOGAF ADM is a step-by-step approach to develop and manage Enterprise Architectures, defined by 8 phases, as can be seen in Figure 3.2. The ADM starts with the strategy and & motivation preliminary and phase A. In this phase the architecture capabilities are established and the scope is defined. In phases B, C and D the business, application and technology architecture are developed, respectively, in phase E until H, the implementation and migration takes place, including all the necessary steps to move the organization from the as-is to the to-be architecture.

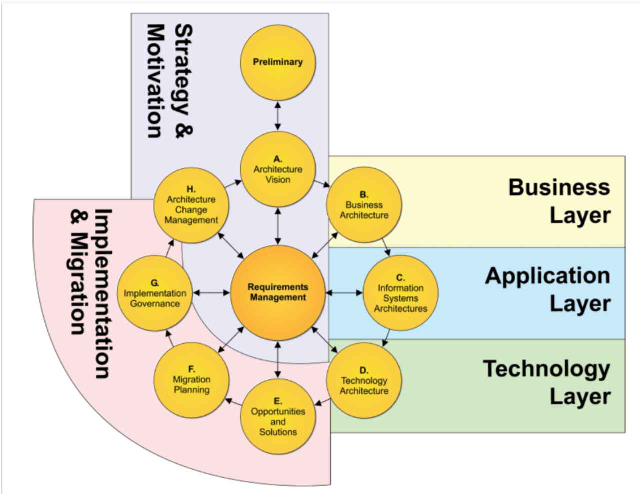


Figure 3.2: TOGAF [60]

Smart Grid Architecture Model

The Smart Grid Architecture Model (SGAM) – shown in Figure 3.3 – is a domain dependent framework that provides a structured approach for developing Smart Grid architectures [63]. In addition to providing a high-level framework for representing Smart Grid solutions, SGAM enables to identify interoperability issues in systems under design. Thus, available standards and standardization gaps for each solution can be easily represented in this framework.

SGAM allows establishing clear relationships between five interoperability layers, five smart grid domains and six different zones that represent the hierarchical levels of power system management. All the different items are explained in Appendix B [63, 64]. SGAM has been created

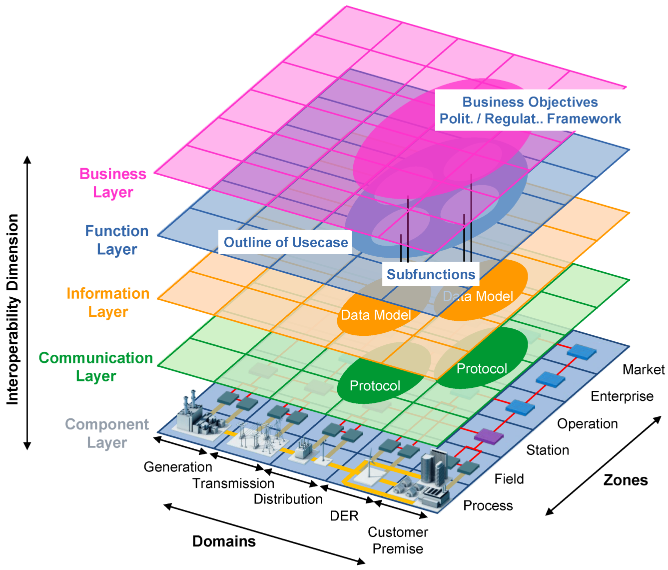


Figure 3.3: Smart Grid Architecture Model [63]

for the purpose of identifying gaps in existing and future standardization. However, the model has already outgrown its original purpose of allocating standards to various Smart Grid systems and interfaces as it was envisioned. Cost–benefit analysis, security analysis, technical debt analysis and maturity levels of organizations can be visualized using SGAM [65]. SGAM can be used to help DSOs face the challenges of the energy transition [64, 65, 66]. The very purpose of SGAM application is to share information among projects that implement similar use cases based on different technical solutions [67].

3.1.2 EA purpose and responsibilities

According to TOGAF [68] there are four broad purposes of EA capability, which are shown in Table 3.1.

Table 3.1: EA purpose characteristics [69]

Purpose	**Explanation**	**Breadth**	**Level of detail**	**Timeframe**
Architecture to Support Strategy	Provides target architecture and roadmaps to guide strategic change initiatives across multiple programs and portfolios.	No pattern. Some Strategy will have a broad impact while others will cover a narrow subject.	Not very detailed.	Target: 3–10 years.
Architecture to Support Portfolio	Supports the alignment, governance, and coordination of multiple projects within a single portfolio to deliver cross-functional change.	Will cover single subjects (the Portfolio).	Typically not very detailed.	Target: 2–5 years.
Architecture to Support Project	Clarifies project objectives, ensures architectural compliance, and supports alignment with broader initiatives within a single project context	Narrow breadth, typically discrete Projects within a Portfolio.	Typically detailed.	Target: less than 2 years.
Architecture to Support Solution Delivery	Defines the architecture for how a solution will be designed, built, and governed during delivery, focusing on detailed constraints and implementation guidance.	Typically, very narrow breadth.	Most detailed EA.	Target: less than 2 years.

Literature does not agree on a uniformly refined set of responsibilities for the EA function. Poort [70] deconstructed the role of architects into a set of five responsibilities, which covers most of the responsibilities mentioned in other literature [56, 71]. These five responsibilities can help organizations assess how well they are crafting architecture (and their architecture maturity) and where they can improve. This set of responsibilities needs to be complemented with *EA conformance*, which is typically the responsibility of other members in the organization who are affected by EA products. They have to provide feedback to EA products and decisions [71]. The model is shown in Figure 3.4, and their elements are briefly explained below:

1. **Understanding context:** Ensuring effective stakeholder communication and involvement in architectural design and managing architectural context knowledge.

2. **Making decisions:** Treating architectural decisions as primary deliverables, prioritizing them based on business impact, justifying and documenting them, making well-timed decisions, and decentralizing decision-making when appropriate.

3. **Modeling:** Creating and maintaining visual models of both the system's context and solution to show boundaries and dependencies as well as stakeholders concerns.

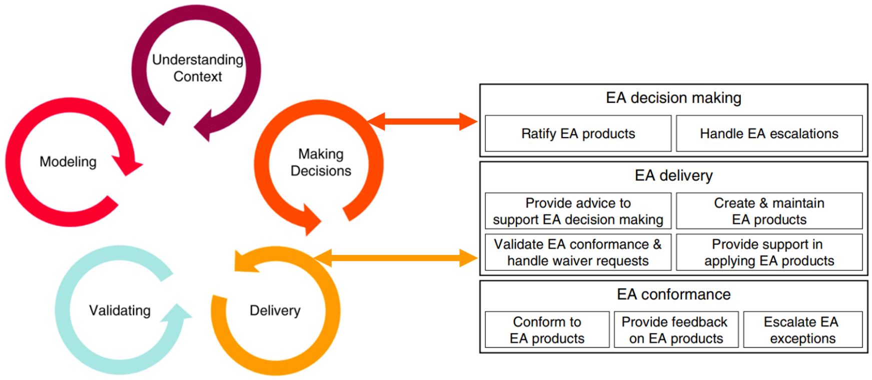


Figure 3.4: Architecture responsibilities (adopted from [70] and [71])

4. **Validation:** Ensuring that architectural designs fulfill stakeholder needs by validating them before implementation, with appropriate trade-offs based on business criticality, complexity, and risk.

5. **EA delivery:** Recognizing the architectural runway in product planning, managing architectural debt, anticipating future events that could impact the architecture and delivering products, as mentioned in Section 3.1.4.

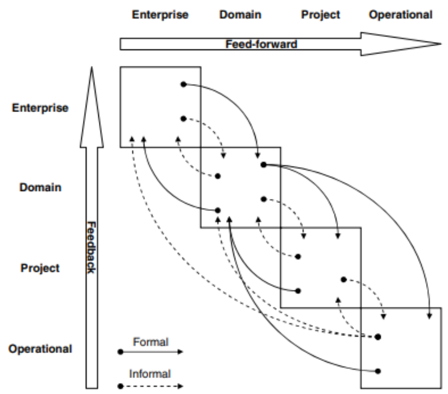
6. **EA conformance:** Recognizing the importance of sticking to architectural decisions, receiving and providing feedback to different EA levels, linked to the intention to use the EA rather than its product quality.

3.1.3 EA function and process

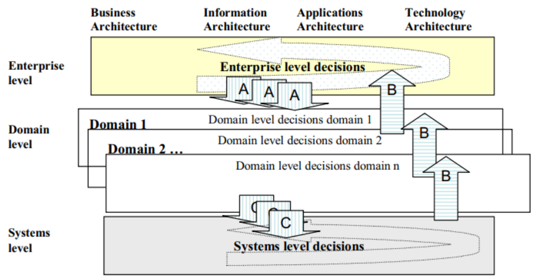
These responsibilities are carried by the architecture function within an organization. The EA function is defined as: 'the organizational functions, roles and bodies involved with creating, maintaining, ratifying, enforcing, and observing Enterprise Architecture decision-making – established in the Enterprise Architecture and EA policy – interacting through formal (governance) and informal (collaboration) processes at enterprise, domain, project, and operational levels' [71]. In carrying these responsibilities, the architecture function should serve a regulative, instructive and informative role [59, 72].

EA products are designed with varying dimensions and for different organizational levels to help stakeholders in decision making. Typical abstraction levels include the enterprise, domain and solution/system level [73], where the latter can be separated into project and operational level [71]. These levels allow the EA product to be designed for corresponding decision (abstraction) levels of stakeholders, and thus to identify and manage architectural decisions required on these levels. EA functions should be formed accordingly, this ensures various roles representing the potentially conflicting interests that occur at different organizational levels [71]. This shows that the entire EA function must be properly integrated into the overall organizational and governance structures in order to be effective [71].

Figure 3.5 shows two EA process models, with information flows between the EA levels. In Appendix D, the defined activities and responsibilities as proposed by Raadt and Vliet [71] on the different levels are shown. According to Raadt and Vliet, an organization will only apply EA effectively when there is effective formal and informal interplay between the members of the EA delivery function and the stakeholders responsible for EA decision making and EA conformance. Moreover, the entire EA function must be properly integrated into the overall organizational and governance structures in order to be effective.



(a) EA process showing formal and informal feedback and feed-forward loops between EA levels [71]



(b) EA process showing enterprise level decisions (A), decisions from parallel domains to systems (C), and upstream feedback (B) [73]

Figure 3.5: EA process models

TOGAF also provides an example set of roles that are considered valuable in the evolution and governance of the architecture within organizations. These roles support effective decision making at different abstraction levels with corresponding levels of influence and impact [74]. Figure 3.6 shows the various roles, in which enterprise architects are experienced professionals responsible for creating, leading and delivering significant technical and business change across an enterprise [74]. They initiate, drive, and own major pieces of work, interfacing strategic levels, with accountability for overall business service delivery through information systems.

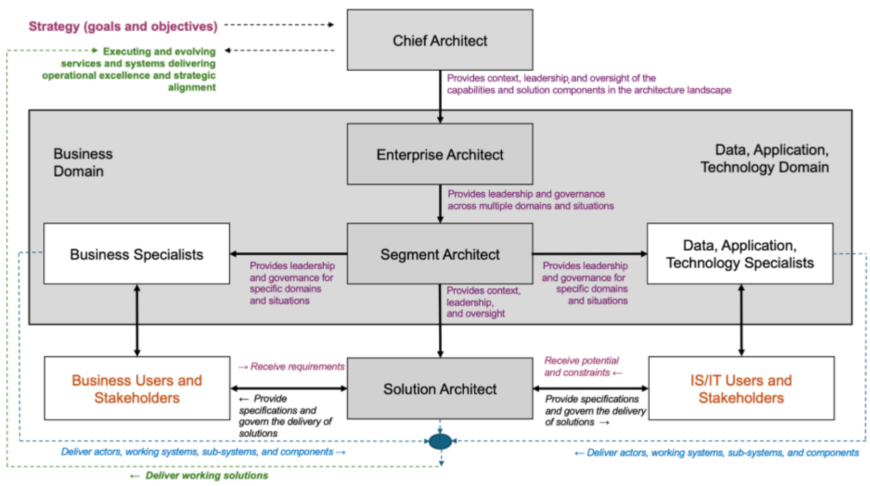


Figure 3.6: TOGAF Enterprise Architecture role division [74]

A segment is a coherent grouping of capabilities for management and control purposes, usually managed as portfolio. Typical segments for architecture landscapes with IT systems are called the business, data, application and technology domain. Segment architects evolve and govern capabilities within a segment to achieve goals. Segment architects are responsible to create the conditions for creation, integration and evolution of processes and systems within a segment. They have to ensure technical/business specialists and solution architects deliver the desired solutions contributing to the desired business services [74].

Solution architects shape and govern the solutions needed based on specific requirements, delivering specified service levels within time frames. This architectural role specifies systems and components needed for a solution and their interoperability. Their prime responsibility is to create the collaborative conditions for the specification, creation and integration of a solution, ensuring the effective delivery of systems [74].

3.1.4 Artifacts

Enterprise Architecture is a process as well as a product [59]. The process includes the direction and support in the design and management of the EA to support the organizational transformation. EA products are the outputs of these EA processes, such as documentation and services. Documentation includes architectural models, standards, principles, and other knowledge items describing the organization's *EA dimensions*. Typically these dimensions are business, information, application, and technology, as seen in e.g. the TOGAF framework [60, 73]. EA products are usually distinguished according to their time reference [72]:

1. **As-is architecture:** the currently implemented operational environment.
2. **To-be architecture:** the desired future state.
3. **Roadmap:** the transformation path from the as-is to the to-be architecture.
4. **EA principles:** guidelines and rationales for the development and evaluation of EA.

However, 'architecture' product is still a vague term, referring to a broad range of artifacts that may be produced. There is no recognized set of deliverables defined for EA that its practitioners agree on, which makes it difficult to differentiate EA artifacts or see relations between them [75]. In Appendix A, a set of different types of EA artifacts are described according to the TOGAF standard [76]. This list is complemented with outcomes of research on EA artifacts produced and used in organizations which are considered to have a mature EA capability [77, 78]. Such a list of artifacts can serve as a dictionary to find a suitable artifact for a desired purpose [78].

All EA artifacts can be classified based on their conceptual differences and similarities into six consistent groups, describing their role in an EA practice [75, 77, 78]. These classifications are shown in Table 3.2. It can be seen that every artifact type has a different purpose, and there are relationships between the identified artifact types.

Different stakeholder groups make decisions with a different level of abstraction. The EA products therefore have to be designed for different *EA levels* of abstraction (often called viewpoints) for varying (stakeholder) needs [57, 59, 73, 75]. Enterprise Architecture products are generally enterprise-wide, which offers business managers information which accurately matches their level of abstraction in order for them to make decisions about the business, but also about technology investments. Architecture can also be scoped to include only certain enterprise elements (e.g., domain, business unit and/or technology).

These products and processes are supported by EA infrastructure, which includes governance aspects (e.g., EA decision making), frameworks, tooling and reference architectures. Also EA services, which includes the communication and collaboration interfaces of the EA processes

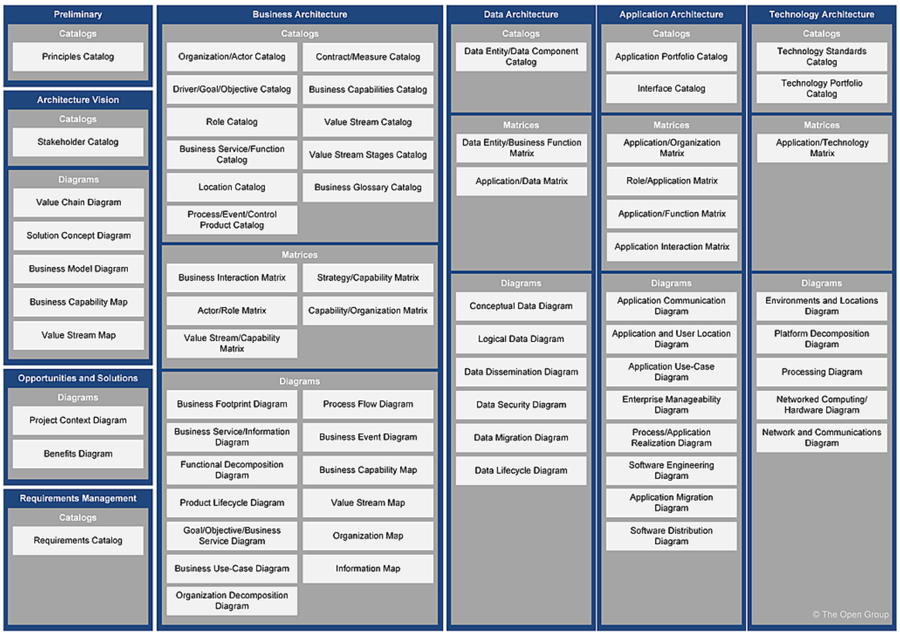


Figure 3.7: EA artifacts according to TOGAF [60]

toward EA stakeholders [72], are vital to support the EA products. A large enterprise with a mature architecture capability is expected to have an EA repository to facilitates these artifacts, which should include EA products but complemented with governance logs, reference libraries and information about used standards. A description of the architecture meta model, which describes the organizational application of EA frameworks and development, and a description of the architecture capability itself, including processes to govern the EA [79], should also be included.

Stakeholders can have two perspectives on EA (products): (a) they can be contributing, for instance by being involved in the creation of EA products, being involved in meetings about EA governance or by providing mandate and general support; or (b), they can be benefiting, by using the EA products and consuming its services [72].

3.1.5 Benefits

Many organizations lack a foundation supporting their strategy. Indicated by senior executives stating that different organizational parts give different answers to the same question, the business lacking agility, struggles with meeting new regulations and IT bottlenecks. These are indicators that an organization will benefit from EA [80]. Literature shows dozens of organizational benefits caused by Enterprise Architecture. The most important and commonly cited benefits according to Tamm et al. [59] are:

- Increased responsiveness and guidance to change
- Improved decision making and risk management
- Improved communication and collaboration
- Reduced IT costs, more effective IT use

Table 3.2: Summary of the six roles of EA artifacts [75]

Role	Information	Usage	Purpose	Relationships
Considerations	Global conceptual rules and fundamental considerations important for business and relevant for IT	Developed collaboratively by senior business leaders and architects and then used to influence all architectural decisions	Help achieve the agreement on basic principles, values, directions and aims	Influence Standards, Visions and Outlines
Standards	Global technical rules, norms, patterns and best practices relevant for IT systems	Developed collaboratively by architects and technical subject-matter experts and used to shape architectures of all IT initiatives	Help achieve technical consistency, technological homogeneity and regulatory compliance	Shape Outlines and Designs
Visions	High-level conceptual descriptions of an organization from the business perspective	Developed collaboratively by senior business leaders and architects and then used to guide IT investments, identify, prioritize and launch new IT initiatives	Help achieve the alignment between IT investments and long-term business outcomes	Initiate new Outlines
Landscapes	High-level technical descriptions of the organizational IT landscape	Developed and maintained by architects and used to rationalize the IT landscape, manage the lifecycle of IT assets and plan new IT initiatives	Help understand, analyze and modify the structure of the IT landscape	Provide the environment for Outlines and Designs
Outlines	High-level descriptions of specific IT initiatives understandable to business leaders	Developed collaboratively by architects and business leaders and then used to evaluate, approve and fund specific IT initiatives	Help estimate the overall business impact and value of proposed IT initiatives	Provide the basis for Designs
Designs	Detailed technical and functional descriptions of specific IT projects actionable for project teams	Developed collaboratively by architects, project teams and business representatives and then used by project teams to implement IT projects	Help implement approved IT projects according to business and architectural requirements	Cause updates of Landscapes

- Business-IT alignment

Especially for organizations in change (e.g., digital transformation), EA can be a useful tool. EA offers the organization a unified and holistic view, which allows different teams (organizational silos) to better understand the impact of their initiatives, which allows a more precise scoping of projects. Stakeholder management is therefore an essential aspect of EA, both for acquiring input for the architecture, but also for identifying conflicting objectives [79]. This could lead to improved stakeholder satisfaction within organizations [81]. Architectures can also help organizations identify their capabilities, and to what extend they are sufficient to execute business, and to acquire sustainable competitive advantage [81, 82]. Furthermore, EA could improve business agility and value delivery [82], which also contributes to competitive differentiation [62].

The holistic view offered by EA also provides benefits from a technical point of view. EA could improve interoperability between different IT systems, prevent inconsistency in data, and prevent duplicity – which happens when two or more systems contain the same data or perform the same function or goal [61, 83]. Therefore, EA can help an organization to optimize their operating platform and its related IT landscape [59].

EA benefits manifest in two different ways: some benefits flow from the EA directly, and other benefits can only be achieved through the implementation of the EA plans [57, 59]. This means the process and use of EA can immediately contribute to the improved understanding of the organization and its components, thus providing a basis for more informed decision-making and development by giving, for instance, a clear overall view of a specific subject area, its components, and interrelations [57]. EA also has more indirect implications, achieved through the implementation of the EA plans. As the EA is used to guide development activities, it may, over time, improve the organizational IT platform and reduce the IT costs [57, 59]

3.1.6 Benefit realization

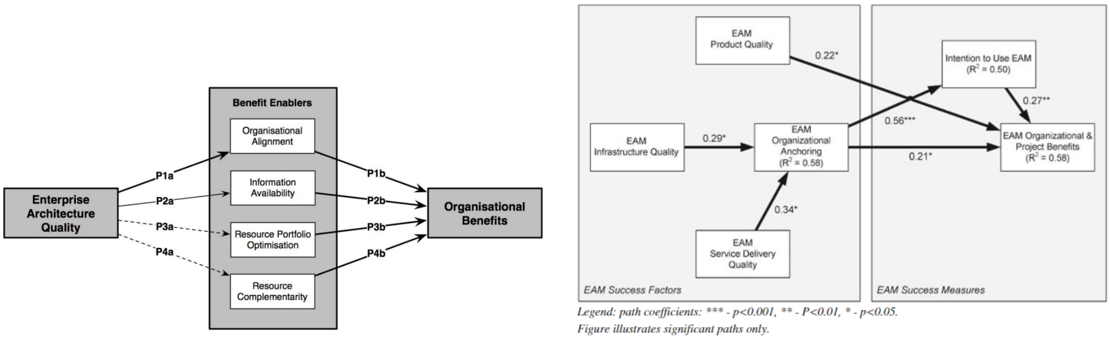
Although literature provides many EA benefits, few studies provide concrete explanations about how EA leads to organizational benefits. Large scale empirical evidence is lacking [57]. Tamm et al. [59] reviewed 50 EA benefit studies out of which only six provided empirical data. This can be explained by the focus on the hypothetical or potential benefits of EA, but not on the concretized and measured benefits. The benefits are not only difficult to measure, but also, associating them explicitly with EA is a challenge [84]. The benefits as described in Section 3.1.5 are not realized by Enterprise Architecture in itself, but through benefit enablers [59, 62, 72, 84]. Literature does not agree on a set of EA benefit enablers that explains how EA can lead to organizational benefits [84].

Tamm et al. [59] found that organizational benefits from EA are enabled by four benefit enablers, which ensure EA contributes to business success. When effectively implemented, they increase the likelihood that EA is perceived as valuable:

1. **Organizational Alignment:** the extent to which an organization's subunits share a common understanding of its strategic goals and contribute towards achieving these goals.
2. **Information Availability:** the extent of useful, high-quality information accessible to organizational decision makers.
3. **Resource Portfolio Optimization:** the extent to which an organization leverages its existing resources, invests in resources that target performance gaps, and minimizes unnecessary investments in duplicated resources.
4. **Resource Complementarity:** the extent to which the organization's resources synergistically support the pursuit of its strategic goals.

Lange, Mendling, and Recker [72] link EA benefit enablers with the EA products quality, the EA infrastructure and the EA services, as mentioned in Section 3.1.4. According to Lange, Mendling, and Recker [72] the EA product quality has a direct positive impact on the EA organizational benefits. The EA infrastructure and service quality have no direct impact on organizational benefits. however, these factors serve as important determinants of 'organizational anchoring', which is defined as the characteristics and conditions through which EA is embedded in the organization to enable, drive, and influence an organization's performance [72].

Unlike EA products, which can be employed at the project level with limited understanding of EA, the infrastructure and service quality appear to act as hygiene factors; while they are necessary to support a deep organizational anchoring, their presence alone does not ensure the realization of organizational benefits with EA [72]. Other findings included the importance of an organizations intention to use EA. Together with organizational anchoring, intention to use EA are central mediators in explaining the EA organizational and project benefits [72]. All direct and indirect variables contributing to EA organizational benefits according to these two studies are visually represented in Figure 3.8.



(a) Tamm et al. [59]

(b) Lange, Mendling, and Recker [72]

Figure 3.8: EA benefit models

Niemi and Pekkola [84] concluded that available literature on EA benefit realization is fragmented and partly conflicting. No existing EA benefit realization model fully captures the complex phenomenon of EA benefit realization. In an attempt to harmonize different EA benefit realization models, an analysis was done of existing models, including but not limited to the models shown in Figure 3.8. The study resulted in the model shown in Figure 3.9.

Figure 3.9 recently (2022) has been validated based on multiple case studies by Tamm, Seddon, and Shanks [62]. The EA communication quality (driver of intention to use [72] (Figure 3.8b), and results use [84] (Figure 3.9)), product quality and process quality were confirmed to be the most important variables in EA quality, empathizing the importance of EA as a service [62]. These three variables will therefore be taken as the primary determining the success of the EA capability within a company (= EA processes & products in Figure 3.1). According to this model, EA benefits are realized through three benefit mechanisms, which refers to the processes or actions through which EA delivers its benefits:

5. **Improving IT Decision-Making**: EA enhances decision-making by providing structured processes, objective information, and educating decision-makers on effective IT investment practices.

6. **Enhancing IT Project Delivery**: EA improves project coordination through contextual awareness and accelerates projects by providing standards.

7. **Optimizing the IT Platform**: EA aligns the IT platform with business needs, increasing flexibility and improving resource utilization and complementarity.

3.1.7 Trends

Enterprise Architecture is a constantly evolving discipline, shaped by social progress, technological advances and learning outcomes [85], but also by advances in business models and legal frameworks [58]. The focus of EA research has shifted from understanding EA to managing EA. Gampfer et al. [85] identified several trends that will be of increasing importance in the EA discipline based on scientific literature. These trends include cloud computing, adaptive and agile methods, sustainability, internet of things and big data.

To gather a more complete view of EA trends in practice, the findings from the Gartner hype cycle are also taken into account. These trends are based on surveys and expert judgment. The results of the Gartner hype cycle for Enterprise Architecture are shown in Figure 3.10. From this figure three themes can be derived [86], followed with innovations in this theme:

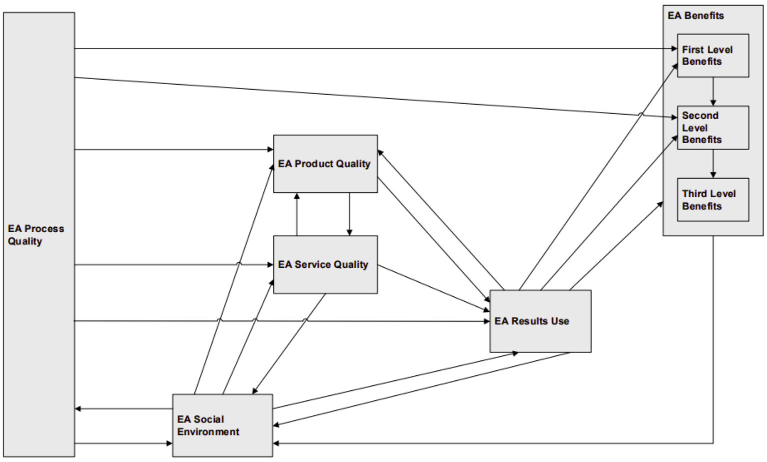


Figure 3.9: Overview of constructs interacting in the EA benefit realization process [84]

1. **Advanced business architecture:** customer journey, value stream mapping, business capability modeling, organization digital twin.
2. **Adoption of AI capabilities:** generative AI, AI reference architecture, augmented architecture.
3. **Franchise digital delivery:** platform engineering, innovation management, product architecture, minimum viable architecture.

The vision of an EA is shifting from the traditional EA, which is modeled as a framework-centered, tool-driven, technology-centric and business-constraint, to a digital architecture, which includes the latest digital capabilities such the shown trends shown above and, e.g., service-oriented architecture [58].

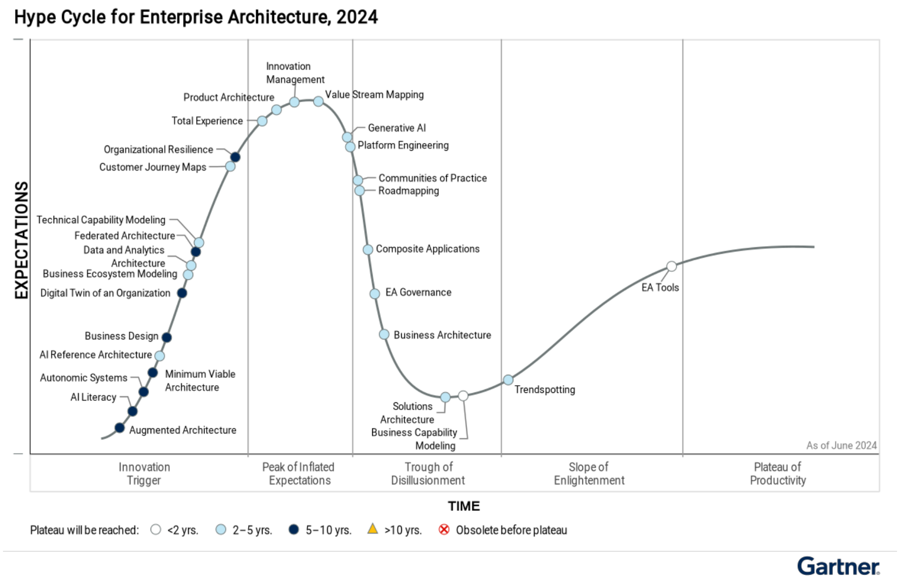


Figure 3.10: Enterprise Architecture hype cycle [86]

3.2 Systematic literature review: EA for a DSO

To gather the state of the art knowledge about the implications of the energy transition on architectures of DSOs, a systematic literature review was applied. This method was chosen because it gives a comprehensive overview of all the available evidence on this specific topic. This systematic literature review (SLR) aims to fulfill the following objective:

Acquire and analyze the state of the art knowledge about the use of architectures in distribution system operators in the energy transition

3.2.1 Methodology

To find as many studies relating to the research question as possible, an unbiased search strategy has been followed. This study has been undertaken as a systematic literature review based on the original guidelines as proposed by Kitchenham [87]. Kichtenham defines three stages of the SLR: planning, conducting and reporting the review. To ensure most relevant literature was found, snowballing was applied to the screened papers. This was done according to the guidelines of Wohlin [88].

To ensure the SLR is valuable, a transparent, complete, and accurate account of why the review was done, what was done, and what was found has to be written. The process of the SLR was therefore documented in a flow diagram according to the PRISMA guidelines [89]. Jabref was used as reference manager in the process.

Data sources

To avoid bias in the selection of papers, multiple data sources were queried with the same search string [87], namely ACM, IEEE, Web of Science and Scopus. These four data sources are chosen because of their relevance to the field of engineering, EA and IT. Also they are peer-reviewed libraries and are considered the largest, therefore most of the available publications about the RQ were expected to be found.

Inclusion and exclusion criteria

Several criteria were designed to ensure that the selected studies answer the research questions in a valid way and are relevant to the RQ.

- The publication date is within the period from 2010 to 2024 (2010 being the 'start' of the energy transition and the year results from now are often compared with).
- Only peer-reviewed studies.
- Only studies that are published in the English language.

Search query

This review requires acquiring relevant studies about the following key concepts: distribution system operators, Enterprise Architecture and energy transition. These keywords were chosen because they represent the stakeholder, artifact and context for this research. Respectively, for these key terms synonyms were sought to create an appropriate search query to finds all relevant literature. All used terms synonyms are shown in Table 3.3.

Distribution system operator	Enterprise Architecture	Energy transition
Grid operator	Smart grid architecture	Smart grid
Network operator	TOGAF	Smart energy system
System operator	IT architecture	Energy management
Distribution network operator	Digital architecture	Demand side management
DSO	Information systems architecture	Demand response
	Application architecture	Flexibility
	Business architecture	Intelligent grid
	Process architecture	
	Communication architecture	
	Information architecture	
	Data architecture	

Table 3.3: Synonyms key concepts

The search query strings were designed according to the syntax of each library. The queries are shown in Appendix C.

Quality criteria

A set of quality criteria were defined to determine whether or not a paper should be included in the study:

1. The paper covers the application of (enterprise) architecture within DSOs
2. The paper is applicable to the business processes of DSOs and not only to technologies
3. The study is transferable to other (DSO) stakeholder (organizations)
4. The paper provides practical insights for DSOs

3.2.2 Included and excluded studies

The process of the SLR process is represented by the PRISMA flow diagram in Figure 3.11. A total of 255 papers have been retrieved from the 4 databases. 72 duplicates have been removed. 183 papers have been screened. This screening included reading the title of the paper and scanning the abstract. The screening resulted in the exclusion of 137 papers.

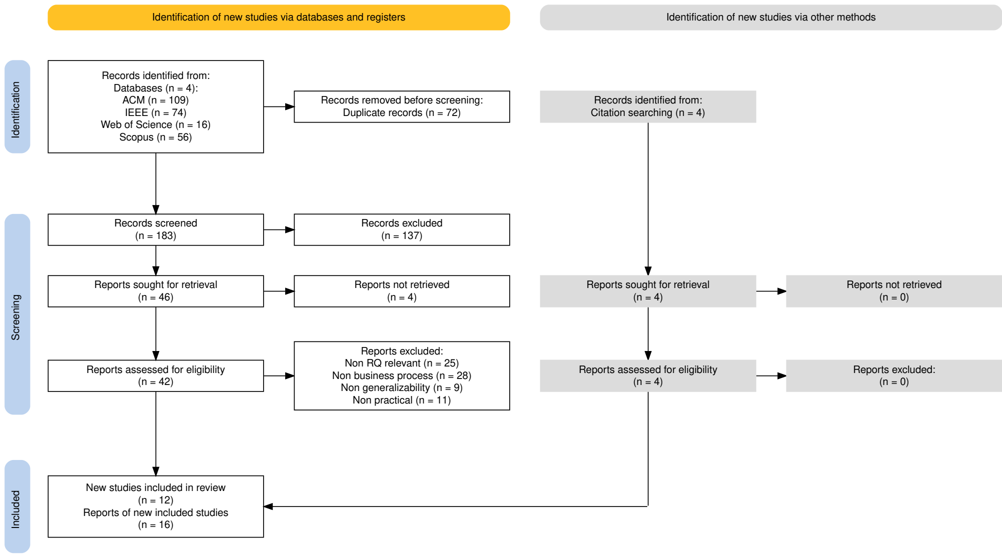


Figure 3.11: PRISMA flow diagram

After the screening, 46 papers remained to be further assessed for their suitability in this study. After removing 4 non retrievable studies, each of the 42 papers have been assessed using the 4 quality criteria. The results of this assessment is listed in Appendix C, in which Y indicates passing the quality criteria, and N means failing the criteria. There were 12 studies for which four Y's were found, thus satisfying all quality criteria. Snowballing in the retrieved papers resulted in 4 more studies that were included, also shown in Appendix C.

3.2.3 Results

Many of the selected studies agree that the complexity in electrical power systems and the related (IT) processes and systems is increasing [90, 91, 92, 93, 94, 95, 96, 97, 98]. Tools are needed to facilitate the management of these processes and systems on different levels and from different stakeholders' viewpoints [90]. As described in Section 3.1, Enterprise Architecture can be valuable tool in handling this complexity.

However, only one study explicitly mentions *Enterprise* Architecture for DSO organizations. Seghiri [93] summarizes similarities between TOGAF and SGAM and how they can be used to model architectures from different stakeholder perspectives, which is needed to handle the complexity and to separate concerns. The study empathizes why simulating EA in the context of smart grids is crucial, as they are in continuous change. Changes can be in the context of regulatory frameworks, emergence of new partners and heterogeneous interactions with customers through smart meters and smart phones. Executable EA is necessary for modeling validation and analysis [93].

Business

The main changes on the business architecture layer is the implementation of processes related to managing the available capacity within the grid. Almost all studies mention the importance of the implementation of flexibility and active demands into the distribution grid [91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101], which corresponds with the findings from the exploratory literature review in Section 2.2.2 and 2.2.3. However, only in [92, 94, 95, 97, 98, 99] flexibility is explicitly mentioned as a measure to relieve congestion, but in other cases it is mentioned as a measure to match supply and demand to achieve financial benefit [100]. Only one study explicitly links congestion and flexibility with the high level motivation of the energy transition [97], providing a complete overview of business operation impacts, shown in Figure 3.12.

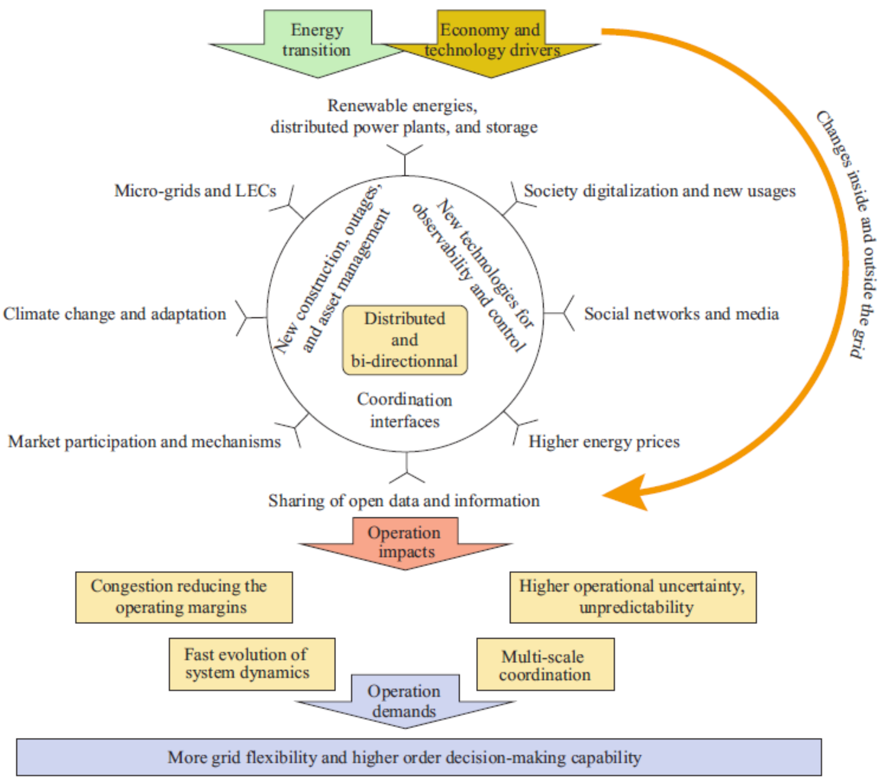


Figure 3.12: New operational needs caused by the energy transition [97]

On a business level, flexibility measures not only affect DSOs. Active demands (customers offering flexibility) have their business processes deeply affected by offering flexibility. For instance, they need to be able to shut off heavy machienery or entire processes on request of the DSO. Therefore, increasing flexibility in the grid has an impact on the business processes of multiple stakeholders [93].

Information

From an information/data architecture point of view, a big increase in information flows and data can be observed. Studies mention an increase in communication to and from the distribution grid, increased information exchange with new stakeholders (e.g., wind farm owners), and communication with smart meters [93, 96]. The information exchange needs to conform with new European regulations and directives, the importance of conforming to these standards is increasing [95]. The IEC 61850 series of standards provides fundamental device-level data models information exchange requirements and protocols. The Common Information Model (CIM) standard provides system-level information models and information exchange messages needed for proper system integration [67, 90, 94, 95, 96, 98, 102]. OpenADR is also worth mentioning, which standardizes demand response (flexibility) measures [95, 99].

Multiple studies mention the increase of information flows between DSOs and their customers

[93, 96, 97]. However, the increased required information flows within the DSO organization to support active network management and flexibility implementation (as mentioned in Section 2.2.4) is mentioned in none of the selected studies.

Application

Multiple selected studies agree that the smart grid of the future requires new services and functions, and thus new application capabilities [94, 96, 98]. These capabilities include: distributed renewable management [94, 96], energy storage management [96], demand response management [94, 96], advanced voltage and var control [96] andm advanced forecasting and analytics[94, 96, 98].

Complex application architectures for smart grid control require system design principles to be used efficiently. Strasser [94] states that important principles are multiagent systems, service-oriented architecture, holonic control architectures and the use of standards to ensure interoperability. These principles could help in the design of an effective and responsive IT landscape [97]. Many of the studies see the increasing importance of cybersecurity, which should make systems resilient to cyber attacks [91, 94, 95, 97, 98, 99, 100, 102, 103].

Example architectures

Three real world case studies have been mentioned where architecture helped to develop and/or implement smart grid solutions, all of these used SGAM as a foundation. The studies mention the challenge to handle the complexity of distributed systems, especially if they provide critical infrastructures, as is the case for smart grids. The broadly accepted concept of Model Driven Engineering (MDE) was used to analyze, decompose and develop the smart grid related systems, focusing on structuring the requirements instead of the exact implementation. The projects include: (1) INTEGRA, which focused on the secure and stable operation of various interconnected Smart Grid systems, a Model-Driven Architecture (MDA) approach to re-engineer and analyze existing systems, aligning with the Smart Grid Architecture Model (SGAM) [90]. (2) The DISCERN project aimed to provide a common view on smart grid projects and compared implemented solutions by DSOs in terms of cost-effectiveness and performance [67, 90]. (3) A case study about the management of an electric vehicles fleet showed the complexity of a smart grid project on business, information and application layer of multiple stakeholders, including DSOs [93].

The selected studies show several smart grid architectures to manage and implement smart grid solutions, including flexibility measures. However, no studies revealed the application of Enterprise Architecture within DSOs.

Chapter 4

Enterprise architecture and flexibility products within Alliander

This chapter presents a case study, which has been conducted to acquire an overview of how an actual DSO is managing the challenges of the energy transition and to assess the role of Enterprise Architecture in this. This case study has been conducted at Alliander, which was therefore taken as use-case for a generic DSO. Later in this research, architecture experts from other DSOs are interviewed to ensure generalizability of this research (presented in Section 7.4). In this chapter, Section 4.1 analyzes the Alliander organization, including the ongoing changes in response to the energy transition. Specifically, the Enterprise Architecture function and the extent in which EA is supporting the development of flexibility products is investigated in more detail. In Section 4.2 and Section 4.3, the reporting out of the interviews with architects and with flexibility product developers (architecture users) is presented, respectively.

4.1 Case study overview

This section presents the analysis of the Alliander organization in more detail, specifically how this DSO handles the increase of flexibility in the grid. The Enterprise Architecture function in the organization was also analyzed, which was done based on internal documents.

4.1.1 Organization

The Alliander organization consists out of several different departments, with their own responsibilities and capabilities (e.g., customer intake, asset management). These departments used to work as organizational silos, in which little collaboration was needed between departments. Departments consists of one or more agile release trains (ART), which are teams that work together to deliver (often IT) solutions, with the goal to provide a service to the business. One of these departments is 'system operations', which is responsible for actively operating the electricity grid and to solve capacity and congestion issues in the grid.

The energy transition challenges the DSO to acquire many new capabilities (including the capabilities shown in Section 2.2.3), which requires these silos to collaborate. This is in line with the organizational changes presented in Section 2.2.4, in which was proposed that collaboration becomes an increasingly important organizational capability of the DSO. In response to these challenges, Alliander is currently developing value chains, in which the organizational silos work together in end to end processes, aiming to improve the internal efficiency and the value delivered to the customer. The value chains are currently being formed and (strategic) plans are being written, so the scope and activities inside a value chain are subject to change. However, it is clear that value chains will become dominant and leading in the organization, and will become dominant in dividing the work among the different organizational departments. Value chains are formed to realize the following seven strategic pillars of the organization:

1. Excellent management: Optimizing maintenance and improving customer service.
2. Reducing demand for transmission capacity.
3. **Improving grid utilization (Beter Benutten Net)**.
4. Scaling up grid expansion.
5. Sharing data and developing new market services.
6. Developing infrastructure for heat and sustainable gasses.
7. Creating future proof foundations.

One of these strategic pillars is 'Beter Benutten Net' (BBN), for which a dedicated value chain has been established. The objective of this value chain is to maximize the capacity utilization of the existing electricity grid, while maintaining grid safety. Increasing the utilization of the existing electricity grid is primarily done with (1) implementing technical solutions (e.g., changing grid configurations); and (2) increasing the flexibility in the grid (e.g., flexibility measures as described in Section 2.2.3). The primary key performance indicator (KPI) of this value chain is grid utilization (%), which can be translated into a customer-oriented goal (# helped customers), and a grid oriented goal (unlocked capacity (P). The end goal of this value chain is to contribute to the primary goal of serving customers in their energy need, whilst facilitating the energy transition.

The BBN value chain consist of several processes that together utilize a workflow that helps a customer in getting a sufficient grid connection. This process flow currently includes: (1) customer intake, (2) fitting the customer in the grid, (3) contracting the customer, and (4) operating the customer to prevent grid congestion. Different organizational departments realize different processes within this value chain. Within the BBN value chain four so called 'strategic themes' were identified, which together support the value chain in realizing its targets. These strategic themes can be seen as change initiatives; by working on these themes the BBN value chain can be more successful. The strategic themes are shown below:

- **Sweating the assets:** re-assess the asset limits and increase them to allow increased power flows through the assets.
- **Diversification of transportation right and tariffs:** increase the range of possible (non-firm) connection agreements (flexibility products) and work on incentives that lead to a better spreading of grid load.
- **Real time system operations:** work towards a system that manages congestion real time instead of based on forecasts.
- **Grid digitalization:** digitalize the grid by increasing measurements to acquire a total overview of all the power flows in the entire distribution grid.

4.1.2 Architecture

In order to get an overview of the role of (Enterprise) Architecture within the company, and how this role is affected by the energy transition, we analyzed the as-is state of the architecture within Alliander and BBN. Based on this analysis, a treatment could be designed that improves the EA, as is the objective of this research. The analysis was based on information gathered from internal sources, and later complemented with input acquired from expert interviews in Section 4.2.

Function and organization

Within Alliander, currently five architecture roles are defined, which are briefly explained below:

- **Enterprise Architecture:** responsible for developing and maintaining an overarching architectural vision and strategy for the entire organization. They form the architecture leadership team.
- **Solution architecture:** responsible for defining, transferring and securing the architecture of one or more business solutions in an ART. This ensures solutions fit with the intended (business) purpose, in line with established requirements.
- **Business architecture:** responsible for creating overview and insight through consistent and unambiguous capture of (the link between) value chains, capabilities, business solutions, processes and the organization.
- **Data architecture:** responsible for understanding and interpreting information needs and the structuring, attribution (organization and application) and governance of the data needed to do so.
- **Security architecture:** responsible for designing and implementing security measures to ensure the confidentiality, integrity and availability of systems and data.

The architecture function in Alliander is organized based on the organizational departments with their ARTs. Every ART consists of one but often more solution architects and one enterprise architect. A (group of) solution architect(s) is therefore assigned to one ART and an enterprise architect is assigned to multiple ARTs, covering one or more departments.

Enterprise Architecture creates a 'helicopter view' across organizational departments, including the realization of capabilities in these departments (and the ART). The enterprise architects aim to develop and govern the overarching architectural vision and strategy for the organization. They are responsible for the architectural principles and guidelines, developing a target architecture on strategic level and the consistency between different architecture initiatives. Enterprise architects collaborate with solution architects, since solution architects are responsible for designing one or more business solutions within the department.

The business architecture function was established only recently. These architects, together with data and security architects, are not specifically assigned to somewhere in the organization, since business architecture currently primarily focus on complex projects. Business architects are responsible for the design of architecture artifacts using the BizzDesign tool.

For the Beter Benutten Net value chain, a dedicated architecture group called 'BBN architecture' was established to align the relevant capabilities and their solutions. Their initial mission is to develop an information architecture that spans the entire scope of the BBN value chain. Currently, this is the only value chain with a dedicated architecture team. The specific roles and responsibilities within this team are currently being defined.

Realization of capabilities

The capabilities defined within Alliander are based on NBility ('NetBeheerder business capability'), developed by DSOs in the Netherlands, including Alliander. NBility has been created to simplify and streamline working together within the utility sector (DSO and TSO), and with the suppliers/advisors. NBility consists of a capability model, a related business object model and a value stream model, shown in Appendix E.

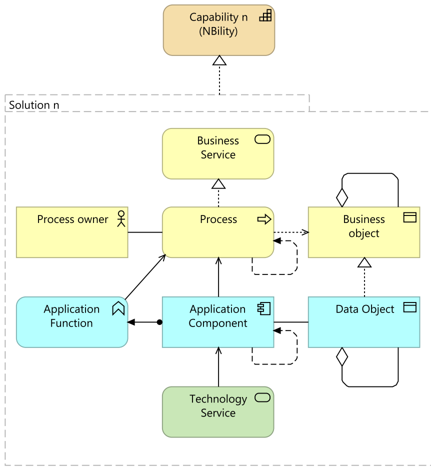


Figure 4.1: Business solution metamodel within Alliander

Within Alliander, a decision was made to define the realization of the capabilities in business solutions. The architectural deliverables of solution architects in departments are defined accordingly. Business solutions realize capabilities and describe *how* Alliander does things based on the existing capabilities. A business solution itself is defined as the combination of people, processes, systems and controls that work together to achieve certain business goals. A business solution is developed as a mechanism to cluster the (IT) landscape of the company, helping the organization acquire a structured overview of how capabilities are realized. The metamodel of a business solution within Alliander is shown in Figure 4.1. The different architecture roles contribute in different ways to the business solutions: (1) enterprise architects identify the business solutions, (2) solution architects fill in the business solution and (3) business architects create a harmonized central model of the business solutions.

4.1.3 Flexibility products

Increasing the flexibility in the distribution grid is essential for the DSO to facilitate the energy transition. Together with grid reinforcements and technical solutions, increasing the flexibility in the grid is a measure to minimize grid congestion and the associated risks of power outages.

Traditionally, DSOs, including Alliander, offered their customers firm contracts, which are contracts in which the customer and the DSO agree on a capacity that the customer is not allowed to exceed. This capacity is often based on a customers maximum expected power usage, which is often only used during specific moments of the day (or year). However, the DSO has to guarantee it can deliver the customer this capacity 24/7. This leads to an inefficient use, and low utilization, of the current electricity grid. The firm contracts result in calculations showing a grid asset (e.g., a cable or transformer) has no leftover capacity available to connect a customer, while the asset, based on actual power usage, would have enough capacity available for a majority of the time.

With actively managing the true capacity in the grid, its utilization can increase and new customers could be connected, whilst preventing congestion. To manage the capacity in the distribution grid, the DSO needs to manage its customers actively, and has to be able to influence the electricity demand or supply from the customer. This can be realized by offering the customer a non-firm, flexibility product, instead of a firm product. A flexibility product (= demand response product) is an agreement between a DSO and a customer (or a representative of multiple customers) that allows the DSO to actively manage the electricity demand or supply from the customer.

Alliander is currently developing several flexibility products, and some of them are already being operated. With these flexibility products, Alliander is currently assessing all customers on the waiting list to find a suitable product for every customer. However, the number of customers contracted with these flexibility products is below target, meaning that there are not enough flexibility products that can be activated to prevent grid congestion. To improve existing, or develop new flexibility products that meets the customers needs better, in order to connect the customer with a sufficient connection and increase the grid utilization.

Product lifecycle management

The flexibility products are developed and operated according to the product lifecycle management process. This process is defined within Alliander to optimize the product portfolio and ensure the products match with the customer demand. Next to that, it structures the different phases a product must undergo in order for the product to be successfully used in the organization, and ensures it can be implemented effectively. The PLM process steps are shown in Figure 4.2, and briefly explained below:

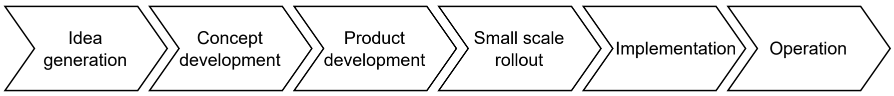


Figure 4.2: Product Lifecycle Management process defined for flexibility products at Alliander

1. **Idea Generation:** ideas are being generated about a new flexibility product, including how this product should operate.
2. **Concept Development:** a proof of concept of the product is designed, and the impact in terms of time and capacity on the entire value chain is assessed, as if the product were to be developed. This impact may, for instance, arise from the development of required IT capabilities, or modifications of business processes.
3. **Product Development:** the product is developed, primarily according to the product policy document. The processes for the small-scale rollout are defined.
4. **Small-Scale Rollout:** outlined product processes are validated with a small number of customers, involving a limited number of employees.
5. **Implementation:** IT capabilities and business processes are implemented. This phase is not always necessary, as there are products with small volumes where automation or scaling up is not required.
6. **Operation:** the product is used in the BBN value chain to offer to customers.

Product overview

A wide range of flexibility products are currently being developed at Alliander, each contributing to increasing the flexibility in the distribution grid. Some products are offered to customers directly, while others are not. The exact product specifications are evolving rapidly, reflecting the fast-paced nature of innovation in this area. Flexibility products vary in terms of their activation timescales, where some products offer near real time flexibility and some products offer flexibility that can be utilized one or two days in advance, requiring the DSO to rely more on energy forecasts. An overview of available flexibility products is shown in Table 4.1.

Table 4.1: Overview of flexibility products currently developed by Alliander

Name	**Explanation**	**PLM-phase**
ATR	After congestion issues have been solved, customers get back their 24/7 transportation contract. This ATR product contracts them based on their desired profile (capacity required per moment of day), instead of a firm capacity.	1
NFA	The available residual capacity in the power grid, is made available day-ahead among customers who have contracted flexible transmission capacity.	1
Groeps-TO	With a group of connections, the contracted power is shared to optimize the energy usage and generation between a group of customers.	3
Groeps-CBC	Capacity reduction contract for groups of customers (e.g., an industrial site). Let them share the responsibility to deliver flexibility to the grid.	4
NBL	'Netbewust laden' is a product to optimally assign capacity to groups of car charging points, reducing their assigned capacity when the grid is congested.	4
BPC	Bidding obligation contract for redispatch contract. Customers get a power connection but are obliged to provide flexibility if needed (handling through the earlier described market platform GOPACS).	4
CBC-A	A demand response product in which a connected party provides flexibility in feeding or consuming electricity for predetermined periods of time.	5
CBC-T	A demand-response product in which a connected party, during pre-agreed fixed moments, limits the use of transport capacity.	6
Redispatch	Redispatch is an intra-day demand response product for redistribution of energy by altering the generation and/or load pattern. Bids and offers for redistribution are matched on a bidding platform like GOPACS.	6

Flexibility products focus for this research

In order to properly focus EA on the development of flexibility products in this research, the development of flexibility products was defined. First, the ambiguous term 'operation' should be clarified, since this process step is defined in BBN as well as PLM, with significant other meanings. The operation process in the BBN value chain refers to operating the product linked to a customer, as a measure to relieve congestion (i.e., deploying the product on a day to day scale). The operation process in the last phase of the PLM refers to the product being 'consumed' in the organization, meaning the BBN value chain can offer this product to a customer. In other words, the operation process in the PLM includes all processes from customer intake to customer ending in the BBN value chain.

The latter is exactly the scope of the BBN architecture team, which aims to align all the processes needed in the process from a customer intake, to customer operation, based on a flexibility product (as shown in Figure 4.3). However, before this product can be used in BBN, it has to be developed, as can be seen in Figure 4.2. The BBN architecture is currently being developed in the BBN architecture group. This research therefore focuses on how architecture can contribute to the development of flexibility products (PLM stage 1-5), which is done to avoid conflicting the scope of this research with work currently being done for the BBN architecture.

4.1.4 BBN and PLM summary model

In order to visually represent the elements explained in this case study, an Archimate model was designed, shown in Figure 4.3. The model shows the BBN value chain, including the different process steps explained before. It also shows the four most important departments that realize the processes within the value chain. The model can be seen that the outcome of the value chain is an increased grid utilization, realized through the four strategic themes. Figure 4.3 also shows the PLM process, realizing flexibility products associated to BBN. Several Alliander departments are assigned to the PLM process to deliver their input. This Archimate model can be seen as the Alliander realization view of the optimizing grid utilization outcome in Figure 2.9.

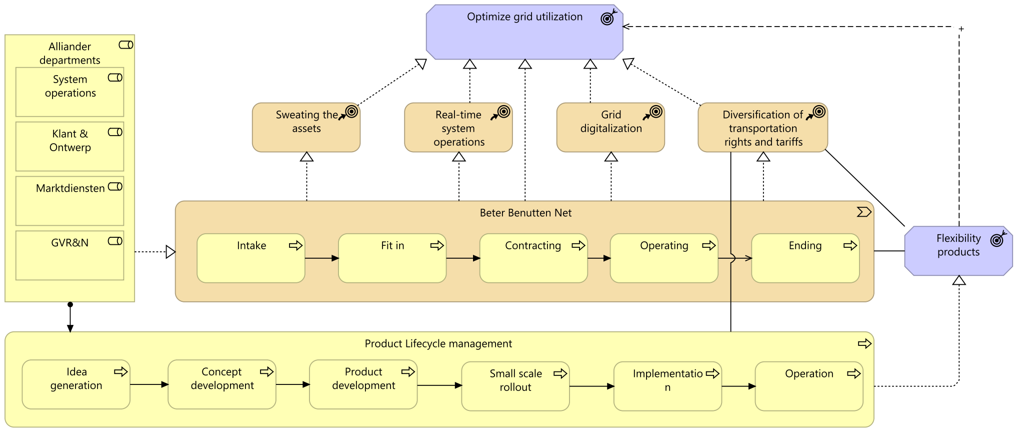


Figure 4.3: Relations between PLM and BBN

4.2 Expert interviews with architects

To acquire more insight in the current state of EA within the company, and how this is impacted by the energy transition and the accompanied organizational changes mentioned before, a set of interviews with architects were conducted. These interviews aim to reveal how EA is currently supporting flexibility products, in order for later stages in this research to identify improvement opportunities. This first set of interviews was conducted to acquire an overview from the perspective of the EA creators.

4.2.1 Methodology

Qualitative interviews are essentially goal-oriented conversations with an informal character [104]. This first set of interviews was executed semi-structured. Semi-structured interviews are guided by a topic list that outlines key themes and potential sub-questions. This format ensures consistency across the interviews while still allowing for the emergence of unexpected insights. This method suits with the purpose of the interview, since the interviews need to uncover all relevant aspects about EA in the organization. This interview methodology offers adaptability and allows the interviewer to focus on relevant topics, skip questions when appropriate, and tailor the conversation to each participant [104]. This is useful to adapt the conversation to the focus area of an architect. The template with the questions used to guide the interviews is shown in Appendix F.

Interviewees were selected out of the different architecture functions in the company. Data and security architects were not included because this type of architecture is not relevant for the scope of this research. The interviewees represent the primary architecture disciplines within Alliander, and cover all architectural disciplines involved in BBN value chain. The profile of the included interviewees is listed in Table 4.2.

Table 4.2: Selected interviewees: EA creators

Nr.	Function	Assigned to
1	Energy system architect	System operations, BBN
2	Enterprise architect	System operations
3	Solution architect	BBN
4	Solution architect	System operations
4	Enterprise architect	System operations, BBN
5	Business architect	BBN
6	Enterprise architect	Klant & Ontwerp
7	Enterprise architect	Marktdiensten, NBility
8	Business analist	BBN
9	Energy system architect	System operations, BBN
10	Manager Enterprise Architecture	EA

4.2.2 Outcomes

During the interviews, notes were taken of the answers to the questions. The key outcomes from the interviews are described in this section. The outcomes of the interviews are categorized in two separate themes. (1) how the architecture function is positioned in the organization and (2) how architecture is currently supporting flexibility products.

The architecture process

The interviews identified that some of the roles and responsibilities of the different architecture functions have become unclear. The organization moving towards value chains has introduced the concept of a value chain architecture group for BBN. However, this architecture is not (yet) recognized as an official architecture function, and is not incorperated in the architecture operating model and governance of the organization. Moreover, this new architecture group does not have defined responsibilities and deliverables.

As earlier described, EA used to create a helicopter view over organizational departments. However, the introduction of multiple new value chains will start to change the way of working. Interviewees were asked if this implies that a helicopter view over the value chains will be needed in order to acquire an overview of the required capabilities per value chain, and avoid architectural pitfalls such as data inconsistency and duplication between different value chains. Architects do not share a common opinion on this topic. Some architects indicate that the organizational shift towards value chains does not impact the EA function, since it is just an organizational structure to deliver value to the customer. They state that EA focuses on capabilities, and the development of these capabilities is not impacted by working in value chains. Other architects think it requires the focus of EA to become value chain overarching instead of department overarching.

All architects recognize the importance of architecture in realizing the value chains. However, several architects doubt whether the EA benefits are fully realized within the organization. Architects indicate to be unaware of the benefit mechanisms of EA, and to which organizational benefits they try to contribute. Some architects are not satisfied with the architectural repositories and almost all interviewees indicate that it can be difficult to find and provide information, because information is 'scattered around many sources'.

Architects explain that within a specific value chain the business processes and solutions (e.g., applications) from different organizational departments need to be aligned in order to create an efficient and aligned end-to-end process which produces more customer value. Architecture could contribute to this alignment, however, architects indicate the importance of avoiding organizational departments and their ARTs to work according to different architectural guidelines or standards created in different value chains. This implies that, architecture on a value chain could be valuable, but Architects indicate that they have been looking into the organization of the EA function, but that an optimal solution has not yet been found.

Capabilities and solutions

In the design of the architectural artifacts, experts indicate to use the NBility standard, used to see the different capabilities in the organization. In the NBility model, capabilities are treated individually, however, an architect involved in the creation of the NBility model indicated that these capabilities are actually heavily dependent on each other. An exact mapping of the dependencies between these capabilities has not yet been made. Some interviewees indicate that the NBility model does not fully cover all the required capabilities needed in the DSO. Moreover, interviewees indicate that the maturity of the architecture representation of business solutions is not at its desired state. Currently, solutions are being documented and linked with the capabilities. Interviewees indicate that this is 'work in process'.

EA benefits

The EA quality constructs found in the literature review were shown to some of the interviewees. They were asked what for them would be an important construct to focus on to improve the EA quality. Although sometimes not explicitly mentioned, most of the responses of interviewees related to the EA process quality.

The literature review identifie a set of 7 EA benefit mechanisms (Section 3.1.6), of which four focused on business and three on IT elements. Architects involved in the BBN value chain were asked which of the 7 benefit mechanisms they primarily aim to achieve. All architects in the BBN value chain indicate that organizational alignment is the primary benefit mechanism they want to achieve. Solution architects in the company indicate to be more focused on the IT benefit mechanisms.

Architecture for flexibility products

Interviewees have been asked about the availability of EA artifacts that show a flexibility product and its relations with, e.g., business processes, data and applications. Interviewees indicate that these architectural viewpoints are not available. However, they do agree that these architectural artifacts would be useful. When asked for reasons, interviewees indicate that flexibility products are still a relatively new concept, and they are unsure what and how architecture can contribute to these flexibility products.

The BBN architects indicate that they are currently developing architecture primarily for the operation of flexibility products. The effective operation of these flexibility products is the aim of the BBN value chain. BBN architecture is therefore defining desired business services delivered by different departments, and how these services should be aligned in an end-to-end process. In a later stage, they will assess currently available business services and address the found gaps. These are the business services that should be developed in order to efficiently increase the grid utilization.

4.3 Expert interviews with architecture users

A second round of expert interviews was conducted with stakeholders that should benefit from EA.. Since this research aims to improve the EA support in the development of flexibility products, the interviews were executed with stakeholders involved in the PLM process, as these are the stakeholders that should benefit from the EA in this research. The purpose of the interviews is to assess the information needs and pain points of stakeholders in the PLM process. Based on this information, it was investigated how architecture can better contribute to the development of flexibility products in later stages of the research.

4.3.1 Methodology

This series of interviews was also conducted semi-structured. This interview protocol was chosen to steer the interview towards specific topics related to EA support in the PLM. Because the interviewees were not expected to have knowledge about EA, the interview should focus on aspects that are related to architecture, preventing usage of architecture jargon. The semi structured interview protocol would still allow the conversation to dive deeper into relevant topics raised by the interviewee [104], that can later be used to assess how EA can contribute to the PLM.

A careful selection of interviewees was made, ensuring interviewees were selected that cover multiple flexibility products, necessary to ensure a diverse perspective on the PLM process. The profile of the selected interviewees are shown in Table 4.3. The director of the value chain BBN is also interviewed, who, being a key architecture user, has more than 17 years of experience in the company, and can contribute to this research by giving valuable insights in the way of working in the organization, also related to flexibility products. The interview template to guide the interview is shown in Appendix F.

Table 4.3: Selected interviewees: EA users

Nr.	Function	Assigned to
1	Epic owner	System operations
2	Value chain director	BBN
3	Consultant product development	Asset & Product management
4	Senior productmanager	Asset & Product management
5	Senior productmanager	Asset & Product management
6	Productmanager	Asset & Product management

4.3.2 Outcomes

During the interviews, notes were taken of the interviewee responses to the questions. The key insights from the interviews are described in this section.

PLM process

First, interviewees were asked to explain the PLM process, as described in Section 4.1.3 in more detail, specifically how they assess which IT or business aspects have to improve in order to be able to operate a product in the organization. Interviewees indicated that this is a process in which multiple experts from organizational departments are assigned to a multidisciplinary team. This team then carefully assesses the designed product policy and the required functionalities. The team manually assesses which capabilities need to be improved, and whose responsibility this is. The required capabilities are derived from the policy document, which is designed in one of the first stages of the PLM. This document describes the characteristics of a product, defining how the product should function.

The required capabilities to operate a product are usually separated into business and IT aspects. IT aspects are translated into epics, which is a building block of multiple user stories. This epic is then prioritized in the department and eventually assigned to a DevOps team. This team will then develop the required functionality. Business aspects are also developed, which could include the design of processes or trainings.

Interviewees have been asked which application or tools are used in the PLM process. They indicate that there is not yet a PLM tool within the organization. However, a recent tender has been issued to acquire a software tool which can support the organization in the development of the products. This tool is expected be available within a year.

Product capabilities

Interviewees were asked whether they have an overview of required capabilities related to specific flexibility products. They indicate that there is no clear view of all the different capabilities related to a flexibility product. Differences are observed in the availability of information per organizational department or product. Interviewees indicate some departments have a clear overview of their capabilities related to the operation of a flexibility product, other departments lack departments this overview. Interviewees agree that there is no department overarching view that shows a flexibility product and its related capabilities (often called building blocks by the interviewees). This corresponds with the interview outcomes with architects, who indicated there is no architecture available specifically for supporting a flexibility product.

The interviewees explain that they have just started an initiative which they think could be related to architecture of a flexibility product. They indicate that a brainstorm session had taken place in which a first draft was created of all the building blocks related to a flexibility product. However, this is not worked out at the required level of detail.

Bottlenecks

Interviewees were asked to define the biggest bottleneck in the PLM process. Multiple interviewees indicated that it is often a struggle to find responsible departments for product developments. In addition, departments have their own roadmap of how they want to develop their processes or IT. Interviewees experienced that the capability development required for flexibility products is not always considered top priority. One interviewee also mentioned that the multidisciplinary team is not always well-equipped with sufficient support from the different departments.

Interviewees indicate that the development of a product is executed individually per product, which is observed to cause inefficiencies. For instance, little consideration is taken in the already available 'recyclable' product capabilities (because of a lack in insight). PLM stakeholders also indicate the policy document is often a lengthy document, and difficult to translate these documents into actions. There is no insight in the extent to which different policy documents show similarities or differences, which prevents products to utilize already existing capabilities.

Finally, the value chain director addressed the urgency of the problem in the interview. It would be desired to focus this research on the development of a flexibility product that is not yet in operation. In order to speed up its development and increase its effectiveness. This could rapidly reduce the list of customers currently waiting for an electricity connection.

Chapter 5

A model for DSO Enterprise Architecture creation

Based on the results from earlier chapters, this chapter presents the first part of the treatment design. To report on how this research improves EA value creation (and increase the organizational benefits), this chapter presents an EA benefit realization framework in Section 5.1. Based on this framework, Section 5.2 and Section 5.3 present an improvement of the EA process quality, resulting in the design of an EA process model, which defines how different levels in the organization can be supported with EA. Together, these sections answer RQ3, ensuring EA value creation within the DSO.

5.1 EA benefit realization framework

In the literature review on Enterprise Architecture, presented in Section 3.1, several important models were found that explain the EA benefit realization process. These models identified constructs that should be taken into consideration in order to achieve organizational benefits with Enterprise Architecture. However, these models showed little conformity between each other and do not suit the application in this research. For example, in these models the different EA quality constructs are only linked with a commonly agreed set of organizational benefits from EA (e.g., business-IT alignment), and not with strategic enterprise goals (e.g., increasing sales). Therefore, they could not be used to represent how EA can contribute to increase the flexibility in the distribution grid.

EA is a tool to support an enterprises IT landscape and aligns it with business goals, this tool in itself does not create value, but the results – realized partially with this tool – do. It are the benefit mechanisms through which the EA manifests into organizational benefits [57, 59, 62, 84]. Literature struggles to distinguish between these elements. Therefore, caution should be taken when linking an organizational benefit specifically to the outcome of EA. This corresponds with the findings from Tamm et al. [59, 62] that the EA benefit realization process is a complex phenomenon.

In order to achieve organizational benefits with EA, a framework is needed that provides insight in how EA manifests into organizational benefits, which shows the entire EA benefit realization process. With this framework, improvement opportunities for EA could be identified and it could help assess how EA can contribute to desired business outcomes. This framework could be used to, for example, help finding and developing a suitable artifact type for a desired purpose. For this research, such a framework could be used to create insight in the constructs of the EA quality, and to gather insights in how EA can be used to increase the flexibility in the grid through contributing to the flexibility product development.

5.1.1 Framework design

We designed a framework to give a complete overview the EA benefit realization process. The framework is created based on an analysis of existing benefit realization models [59, 62, 72, 84] and complemented with input gathered from experts in Alliander, presented in Section 4.2. The resulting EA benefit realization framework is shown in Figure 5.1.

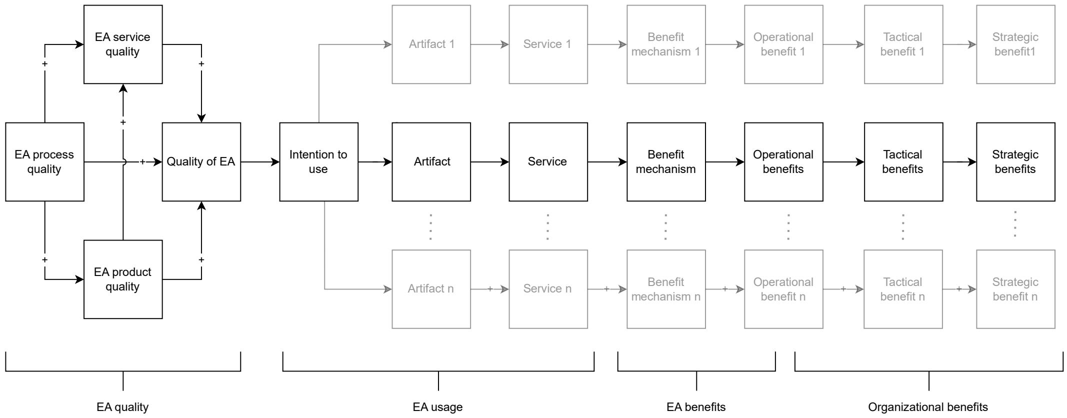


Figure 5.1: EA benefit realization framework (based on [62], [59], [72], [84] and interviews)

Figure 5.1 shows the primary EA quality variables (and thus the EA capability variables), which determines the extent to which the EA team effectively and efficiently produces and provides (IT) decision makers with relevant, timely, high quality information and advice. Therefore, the EA quality concerns the understanding of EA activities and EA deliverables [62]. Three primary variables influence the extent to which a EA is considered valuable (i.e., holds the potential to yield organizational benefits from), and influence the intention of the organization to effectively use EA. These are the EA process quality, EA service quality and the EA product quality. Other variables identified in the EA benefit realization process (e.g., EA social environment [57, 84]) were found to be less important and therefore have not been placed into the framework.

The EA usage section shows the intention to use, which represents the enterprise's willingness to use the EA, including aspects as user satisfaction and ease of use [72]. The result of the EA practice and its intention to use correspond to an n amount of EA artifacts and services. The type of artifacts and their service should match with the organizational benefits it aims to contribute to. For example, for EA to contribute to IT decision making, other artifacts and services are required when EA aims to achieve organizational alignment.

EA artifacts and services contributes to a benefit mechanism, which is the mediator explaining the link between EA quality and organizational benefits. In other words, the benefit mechanism explains how and why EA leads to organizational benefits [62]. These benefit mechanisms lead to organizational benefits. Dozens of EA benefit mechanisms are defined, a set of 7 different benefit mechanisms (4 business and 3 IT related) were selected to use in the research, shown in Section 3.1.6.

Section 3.1.6 also shows organizational benefits, being the organizational goals that EA aims to contribute to. These benefits are split into operational, tactical and strategic benefits, aligning with the KPI goal hierarchy, allowing to divide the goals into different measurable levels, as performed by many organizations [105]. EA usage not always follows every benefit, an EA decision can, for instance, provide long term strategic benefits whilst not providing direct operational benefits.

By graphically presenting the most important constructs involved in the creation of EA, and how EA is used in order to achieve organizational benefits, the framework could be used to visualize how architecture relates and contributes to the end goal of this research: assessing how EA can contribute to the energy transition, and specifically to flexibility products. The framework does not fully represent all possible interactions between elements, which is because these exact relationships are complex and are not agreed upon (see Section 3.1.6). Different studies identify different relationships in the EA benefit realization process. The framework does not represent the possibly expected feedback loops either. For example, a feedback loop between artifacts and services, and intention to use is expected, since better products and artifacts are likely to increase the intention to use them.

The degree in which organizations utilize Enterprise Architecture successfully depends on their Enterprise Architecture capability, being the ability of the EA function to provide valuable services [62]. The EA quality in Figure 5.1 shows these characteristics of EA, and therefore, can be used to assess EA success. This is proven by mapping the EA performance framework from Raadt and Vliet [71] on the EA benefit realization framework, meaning that that the designed framework also represents the performance of the EA function. The EA quality, EA usage and organizational benefits in Figure 5.1 correspond to EA efficiency, EA effectiveness and EA stakeholder satisfaction in the performance framework of [71].

5.1.2 Service mindset

EA should remains an agile service, to prevent the common criticism of EA being document-heavy, rigid and unresponsive [71]. This can be problematic as the EA function often does not have the mandate to make decisions about major IT investments. However, EA can drive business value by informing and positively influencing the decisions taken by others [62]. This process of informing and influencing decision makers is the EA service quality. For effective EA usage, the EA process should result in a personalized and interactive service that conveys the EA-related information effectively. Therefore, EA as a collection of artifacts, does not bring direct value to the DSO. Value from EA can be created by how it is used to deliver services to improve the overall performance of the organization [106].

The EA service provision is likely to be a strong driver of the intention to use EA, through its positive impact on user satisfaction [84]. The importance of the EA as a service is satisfied by placing the artifact before the service construct as can be seen in Figure 5.1, whereas the artifact is merely used as a tool to provide the EA service.

5.1.3 Enterprise Architecture responsibilities

In Section 3.1.2, six primary responsibilities of the EA function were identified. The degree to which the architecture function executes these six responsibilities effectively drives the maturity and effectiveness of the EA. The responsibilities strongly relate to the EA quality shown in Figure 5.1. To align the EA benefit realization framework with the EA responsibilities, Table 5.1 shows a mapping of the EA responsibilities onto the framework elements.

Table 5.1: EA responsibilities in relation to the benefit realization framework

Responsibility	**Framework**
Understanding context	Service quality
Making decisions	Process quality
Modeling	Product quality
Validation	Product & Service quality
Delivery	Product & Service quality
Conformance	Intention to use

5.2 The EA process

The framework shown in Figure 5.1 provided insight in the variables that can be improved in order to achieve increased organizational benefits with EA through increasing the EA performance. Three variables influenced the overall EA quality, which this research aims to improve in order to ensure EA value creation in the DSO. An analysis was performed to identify which of these three variables can be improved within the company and contributes most significantly to overall EA quality

Several reasons led this research to focus on the EA process variable, which was identified as an important variable influencing the Enterprise Architecture quality. The EA process is referring to the day-to-day operations of the EA function, including EA methodologies, frameworks, tools, organization, and stakeholder participation [84]. The decision to concentrate on the EA process quality is justified by multiple reasons, which are explained below:

1. **Key independent variable:** according to the research of Niemi and Pekkola [57, 84], EA process quality is the key independent variable that determines the success of many other variables. Other studies confirm the importance of this EA process [62, 72, 107].

2. **Interview outcomes:** in the interviews with different architects, an outcome is that there is little structure in the process in which architecture is designed in the different functions, and how these functions relate to each other was unclear.

3. **Aligning with way of working:** the organization is changing its way of working to value chains, which results in changing processes in which the architectural contribution is yet to be determined. EA should be aligned with this organizational way of working to ensure it contributes to the goals the organization aims to realize in its way of working [68, 69]

4. **Importance in organizational EA implementation:** it is essential for organizations to have a well established EA process in order to manage architectural decisions throughout the organization consistently, and ensure potentially conflicting interests that occur at different organizational levels are addressed [71, 73].

5. **Providing a holistic view on EA function:** a holistic view of the EA process is needed in order to properly identify essential points of improvement and compose an effective EA improvement plan [73].

5.2.1 EA process levels

Two primary EA process models for the management of architectural decisions within an enterprise were found, shown in Section 3.1.3. The EA process model from Pulkkinen [73] included three abstractions levels for EA, namely enterprise, domain and systems, the latter assuming that the solution is an IT system, which is not always true for a DSO, for which a solution can, for example, be a flexibility product or a business process. Raadt and Vliet [71] came to a similar conclusion and wanted to describe architecture abstraction levels more generically. Enterprise, domain, project and operational levels were defined, leaving open which types of solutions are delivered. The division between project and operational level aims to ensure the conflicts in decision making at project and operational level are properly addressed, since organizational stability on operational level and improvement projects can result in conflicting interests [71]. This matches with the operational continuity required to guarantee the reliability of the electricity grid. The EA process model from Raadt and Vliet [71] was considered valuable and was therefore taken as an inspiration and basis to improve the EA process quality in this research.

The four levels in the EA process model correspond to a large extent to the four EA purpose levels, identified in TOGAF. Table 5.2 shows a summary of the found literature on EA level division, and maps them to each other. The EA roles as identified by TOGAF were also be mapped to these EA purposes. Because the organizational benefits in the benefit realization framework were divided into operational, tactical and strategical benefits, KPIs are considered in the EA process levels.

Table 5.2: EA levels summary

Raadt and Vliet [71]	**Pulkkinen [73]**	**TOGAF [68] EA to support:**	**TOGAF EA role [74]**	**KPI level [105]**
Enterprise	Enterprise	Strategy	Enterprise architect	Strategical
Domain	Domain	Portfolio	Segment architect	Tactical
Project	Systems	Project	Segment architect	Tactical
Operational		Solution delivery	Solution architect	Operational

5.2.2 EA levels within the company

The design of the Enterprise Architecture function is often based on EA levels, which should align EA with the organizational way of working and therefore ensures the different levels can be properly supported with EA [59]. Therefore, the structure of EA functions is largely determined by the operating models adopted in the organization [108]. Moreover, according to TOGAF [68], the EA value map should be aligned with the organizations value map, ensuring that EA contributes to the business goals. For example, the business objective to reduce costs by eliminating activities that add no value can be linked with the EA objective to rationalize the portfolio.

All these reasons show the importance of properly identifying EA levels, required to design suitable EA functions in an EA process model. A model of the 'to-be' and desired organizational way of working (and thus its operating model) was needed in order to design the EA function and its process accordingly. Based on observations and outcomes of the interviews in the case study discussed in Chapter 4, four different levels in the company were identified, presented in Table 5.3. The levels represent the Alliander implementation of the levels defined in Table 5.2.

In order to better visualize the four levels shown in Table 5.3, a model was made to show how the different levels relate to each other, shown in Figure 5.2. The levels collaboratively include all the activities executed within Alliander, showing the way of working of the organization. The four identified levels are explained below.

Table 5.3: EA levels within Alliander

Raadt and Vliet [71]	**Alliander**
Enterprise	Alliander
Domain	Value chain
Project	Strategic theme
Operation	Department / ART

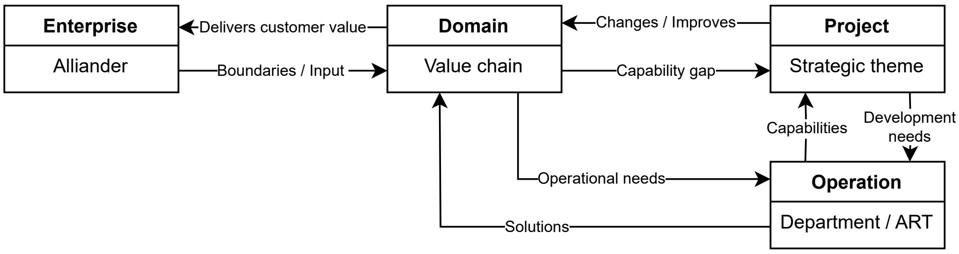


Figure 5.2: Identified EA abstraction levels and their relations

The enterprise level includes the entire DSO Alliander. In this level, the boundaries and inputs for value chains are defined. The DSO defines strategic decisions and directions that should be executed in the different value chains. Moreover, the enterprise keeps the overview over the value chains, providing the value chain with value chain overarching information. For example, a grid reinforcement as a result of activities in value chain X may lead to different calculation numbers needed in applications existing in value chain Y. This level also includes enterprise wide services (e.g., HRM, facilities, finance), used throughout the entire organization.

The domain level includes the value chains delivering customer value to the organization. It does this in end-to-end processes and with collaborations between multiple departments. The value chain requires solutions from departments to execute the process, and seeks to align all these solutions and to create an efficient end-to-end process. To continuously improve the value chain, this level communicates initiatives or capability gaps towards projects. There are multiple value chains, as described in Section 4.1. One of them is BBN, in which Alliander develops and operates the flexibility products.

The project level includes strategic themes. This level is driven by a capability gap identified in the value chain, this level aims to ensure continuous improvement and to acquire the capabilities needed to close the gap. This strategic theme therefore changes and improves the value chain. The project defines how these capabilities should be acquired and which stakeholders and departments are needed. It defines the development needs towards these operational departments, who in turn develop the needed capabilities. The project implements the solution within the operating value chain. Within BBN, four strategic themes were identified include the strategic themes, which are mentioned in Section 4.1 for the BBN value chain.

The operation level includes the departments and their ARTs, being responsible for the realization of capabilities and the development of business solutions. It does this either to a value chain directly – by delivering solutions as a response to operational needs – and to projects – by developing new capabilities used in the development of a value chain. This ensures a clear division between the department delivering solutions needed in the daily operations of the value chain, and to the project, which aims to improve this daily business.

5.2.3 Information on EA levels

After having defined the organization into the four abstraction levels as described above, the architecture functions that should support these levels can be designed. A table template had been designed to uniformly document the characteristics of the desired EA on the four levels. The elements of this table are shown and explained in Table 5.4.

Table 5.4: EA description template

Characteristic	**Definition**	
Title	EA function title	
Purpose	The purpose, that frames the depth and breadth of the EA. Divided in purposes described in Table 3.1: EA supporting strategy, portfolio, project or solution	
Decision scope	The level of influence this architecture function	
Policy level	Strategical / Tactical / Operational	
Primary stakeholders	The primary stakeholders involved in the creation of the EA product	
Primary responsibilities	The primary responsibilities of this function	
Artifacts	A summarization of deliverables of this function. Categorized into considerations, standards, visions, landscapes, outlines, designs [75] (see Section 3.1.4).	
Input (feedback)	From: stakeholder. The EA level where input is acquired from.	The content of the information or decisions that has to be conformed to, based on [71] complemented with interview outcomes.
Output (feed-forward)	To: stakeholder. The EA level where this output is consumed.	The content of the decisions and which artifact, based on [71] complemented with interview outcomes.

The EA benefit realization framework (Figure 5.1) shows that EA benefit mechanisms are realized through EA artifacts realizing an EA service. Therefore, for every EA level, we should know the artifact type that would produce most value to the business. Table 5.4 shows that EA artifacts can be categorized into six different types, a list of concrete EA artifacts for every category was shown in Appendix A. The artifacts have been linked to the different EA levels based on the results from the interviews with architects. To ensure consistency between the different EA artifacts, the relations between the different EA artifacts should also be defined.

5.3 EA process model design

This section describes the design of the EA in the identified levels. It does this by linking desired EA artifacts to the different levels, ensuring the EA products are valuable and match with the EA purpose, in order to create EA benefits. This section also specifies the necessary interactions between the EA levels, which is essential because relations were identified between different types of EA artifacts.

The identified EA levels have been described following the structure of Table 5.4. Every section starts with a high level overview of the EA purpose, as described by TOGAF. This is followed by the outcomes from the interviews and observations done in the company. Based on these outcomes, suitable EA artifacts are matched with the EA level, in order to deliver value to the business. The interactions between the different EA levels are also described.

5.3.1 Enterprise: DSO

High level description EA on enterprise level should support the enterprise strategy [69]. EA to support strategy focuses on defining a long-term vision for enterprise transformation. At this level, architecture is used to guide strategic decisions, assess the current state of the organization, and outline a target future state aligned with business goals. It supports executive planning by identifying capability gaps, defining transformation roadmaps, and influencing investment priorities. EA becomes a tool for visualizing how the enterprise must evolve over time and aligning cross-functional stakeholders around that vision [69]. The characteristics of this EA function are shown in Table 5.5.

Interview outcomes and observations Based on the interview outcomes described in Section 4.2, a shift was identified of the currently defined EA function. In order to keep the helicopter view over the entire enterprise, the focus of this function has to shift from the overview over departments and their ARTs to the overview over the value chains. Interviewees indicated that architecture on the enterprise (DSO) level should provide the holistic picture that shows interactions and integrations between value chains X and Y and ensures the alignment between them on a business, information and application point of view. It should provide insights in how activities in value chain X impact activities in value chain Y. Interviewees also indicate enterprise level architecture should be responsible for the highest level capability overview in the organization.

An important aspect gathered by input from the interviews was that it is not desired to create specific capabilities or IT solutions for a single specific value chain. This could lead to departments having to create solutions for multiple value chains, according to different architectures, which is not desired.

Artifacts The interview outcomes are used to match the appropriate artifacts to this architecture level. EA artifacts on enterprise level have to support the strategy of the DSO, as this is the purpose of this EA level. EA artifacts on enterprise level are considered generic, since they should be applicable to the entire organization. The interviewees were asked what information they needed from architecture on enterprise level, their answers could be mapped to primarily the standards and considerations category.

To prevent the departments having to work according to different architecture standards defined in different value chains, standards should be designed and defined in the highest architectural level in the organization. Therefore, the enterprise level should design the required standards artifact type, that can be used throughout the entire organization. Considerations are also a useful EA artifact type on enterprise level, they can help achieving agreement on basic principles, values and directions in order to improve the overall efficiency between business and IT. Primarily the considerations are suitable for EA to support the DSO strategy, considerations artifacts include policies, principles and architecture strategies.

Interactions The described artifacts interact with other EA artifacts on different EA levels. The standards artifacts provide technical guidelines for developing outlines and design artifacts at the project and department level. The considerations influence the development of long-term visions (primarily on the value chain level), and influence the structure of outlines for IT initiatives on department level.

Table 5.5: EA on enterprise level

Attribute	Value	
Title	Enterprise Architecture	
Purpose	EA to support strategy	
Decision scope	Entire organization, value chain overarching.	
Policy level	Strategical	
Primary stakeholders	Business leaders: C-Suite	
Primary goal	Articulate the desired future course of action for business and IT	
Artifacts	Considerations & Standards	
Input (feedback)	Value chain	EA escalations and requests
	Department	Usage of operational expert knowledge and data in decision making
Output (feed-forward)	Value chain	Validation of EA conformance & Providing support in applying EA products
	Department	Providing support in applying EA products (standards)

5.3.2 Domain: value chain

High level description EA on domain level should support the portfolio, and helps to identify projects, dependencies and synergies [69]. This level of EA translates strategy into actionable programs by organizing and prioritizing initiatives across the enterprise. At this level, architecture supports the portfolio by clustering related work, identifying dependencies and synergies, and ensuring that all initiatives contribute meaningfully to the enterprises strategy. It enables decision-makers to balance value delivery with feasibility, align resources, and manage risk. EA provides the structural clarity needed to coordinate complex transformations and ensure that investment decisions are coherent and aligned [69]. The characteristics of this EA function are shown in Table 5.6.

EA that support portfolio should be tightly integrated with portfolio planning and budget cycles. This requires the EA capability to be working well ahead of the decision-making cycle to ensure that necessary advice is available during and throughout the budget process [68].

Interview outcomes and observations As identified in Section 4.1.2, the BBN value chain is currently the only value chain with its own architecture group. These architects indicate to primarily focus on the organizational alignment benefit mechanisms. One architect made a side note that this benefit mechanism is expected to change over time, once the organization is more aligned.

Artifacts In order to contribute to the benefit mechanism of organizational alignment, and to allow EA to support the portfolio, visions are considered the right type of artifact. Visions are used to help achieve alignment between IT investments and long term business outcomes, and provides conceptual descriptions of the (long-term future of the) organization, thus helping show stakeholders the strategic direction of the company.

Landscapes are also considered a valuable artifact on domain level, since on this level the structure of the IT landscape of the company should be understood by business stakeholders. These landscapes could provide insight in applications (and their services) related to a value chain, which is necessary because these value chains need an efficient application landscape to support all the processes. The landscapes can be used to assess impacts and dependencies between processes and IT systems, which improves agility and reduce duplications.

Interactions The visions defined in a value chain initiate the creation of outlines in projects. For instance, a vision may result in the identification of missing functionality in an IT system, for which an outline needs to be created. Landscapes, provide outlines on project level and designs on operational level descriptions of the environment. On project and operational level it is important to have this overview of the environment, for instance to improve interoperability and prevent duplicity.

Table 5.6: EA on domain level

<table>
<tr><th>Characteristic</th><th colspan="2">Value</th></tr>
<tr><td>Title</td><td colspan="2">Value chain architecture</td></tr>
<tr><td>Purpose</td><td colspan="2">EA to support portfolio</td></tr>
<tr><td>Decision scope</td><td colspan="2">A single value chain, including projects and departments realizing the capabilities</td></tr>
<tr><td>Policy level</td><td colspan="2">Tactical</td></tr>
<tr><td>Primary stakeholders</td><td colspan="2">Value chain directors, portfolio managers, product managers</td></tr>
<tr><td>Primary goal</td><td colspan="2">Improve the overall quality of the IT landscape and ensure it supports business requirements, and help business leaders manage the IT.</td></tr>
<tr><td>Artifacts</td><td colspan="2">Landscapes & Visions</td></tr>
<tr><td rowspan="3">Input (feedback)</td><td>Enterprise</td><td>Conform to enterprise level EA products & Utilize the support in applying the products</td></tr>
<tr><td>Project & Department</td><td>Handle EA escalations and requests</td></tr>
<tr><td>Department</td><td>Use operational expert knowledge and data in EA decision making</td></tr>
<tr><td rowspan="3">Output (feed-forward)</td><td>Project & Department</td><td>Validation of EA conformance & Providing support in applying EA products</td></tr>
<tr><td>Department</td><td>Support in deploying and implementing solution result</td></tr>
<tr><td>Enterprise</td><td>Escalation of EA exceptions and requests</td></tr>
</table>

5.3.3 Project

High level description EA to support projects ensures that individual projects and initiatives are framed and executed in alignment with Enterprise Architecture standards and strategic goals. At this level, architects play a key role in scoping, design validation, and guiding project decisions to prevent architectural drift. EA supports integration across initiatives, promotes reuse of established patterns, and maintains consistency across the enterprise landscape. It bridges the gap between high-level design and delivery by providing architectural guidance throughout the project lifecycle [69]. The characteristics of this EA function are presented in Table 5.7.

Interview outcomes and observations In the interviews, little information is mentioned on the involvement of architecture in projects. It is unclear how architecture can contribute and add value to projects (primarily the strategic themes in Alliander). Interviewees indicated that there are many differences between projects and also in the architecture involvement in the projects, architecture artifacts or services can be delivered if needed, but are defined ad hoc.

Artifacts The outlines artifact category was found most appropriate in realizing the EA purpose to support the project. Outlines help estimating the expected business impact of proposed IT solutions in order to improve the efficiency of IT investments [78]. In the outlines, decisions are made for needed IT solutions, which could include artifacts like solution options and overviews.

Interactions The outlines on project level provide the basis for developing more detailed and technical designs on operational level. An outline can therefore be seen as inspiration for the solution design.

Table 5.7: EA on project level

Characteristic	Value	
Title	Project architecture	
Purpose	EA to support project	
Decision scope	Single project including departments delivering capabilities	
Policy level	Tactical	
Primary stakeholders	Product owners, epic owners	
Primary responsibilities	Help implement separate landscape changes	
Artifacts	Outlines	
Input (feedback)	Domain	Conform to domain level EA products & Utilize the support in applying the products
	Department	Use operational expert knowledge to run project
Output (feed-forward)	Domain	Escalation of EA exceptions and requests & rovide support in deploying result

5.3.4 Operation: department

High level description EA to support solution delivery brings architecture into the hands-on phases of building and deploying systems. This level ensures that solutions being implemented remain aligned with architecture, comply with governance, and deliver the business expectations. Architects work closely with delivery teams, offering detailed models, and oversight as systems move from design into production. EA also plays a role in operational handover and continuous improvement, ensuring that architecture delivers lasting value beyond initial implementation [69]. The characteristics of this EA function are presented in Table 5.8.

Interview outcomes and observations From the conducted interviews it became clear that, architecture on the department level is considered well established. On this level, solution architects provide development teams in ARTs with the required architecture input to design the IT. The solution architecture level is indicated to be the most technical. Therefore, the interviewees indicate to aim for primarily the IT related benefit mechanisms. From the interviews became clear that it is expected that this architecture function is not much impacted by the organizational changes.

Artifacts Designs artifacts were identified as most valuable EA artifact on operational level. This artifact type helps to build suitable IT systems according to business and architectural requirements. This improves the quality of the (IT) project delivery [78].

Interactions The implementation of solution designs leads to an update of landscapes on domain level. Other than this, design artifact are primarily affected by other artifacts. A design artifact uses technical guidelines created on enterprise level, and is based on outlines created on project level. Therefore, either direct or indirect, the design artifact is based on all other EA artifact types.

The primary interactions of the design artifact type however, are not with other EA artifacts. This type of artifact is used in teams to realize capabilities, for example, deliver IT functionalities or design processes.

Table 5.8: EA on operation level

Characteristic	Value	
Title	Solution architecture	
Purpose	EA to support solution delivery	
Decision scope	a set of (IT) solutions within a department	
Policy level	Operational	
Primary stakeholders	Development teams, product owners, epic owners	
Primary responsibilities	Help architects organize IT	
Artifacts	Designs & Outlines	
Input (feedback)	Domain	Conform to domain level EA products & Utilize the support in applying the products
	Department	Use operational expert knowledge to run project
Output (feed-forward)	Domain & Enterprise	Escalate EA exceptions and requests & Provide operational expert knowledge and data

5.3.5 EA process model

This section summarizes the elements of the four EA levels shown above in an EA process model, clarifying the desired artifacts on the EA levels, and their interactions is a DSO EA process model. To increase the usability of the EA process model, two different versions have been designed: one that describes the 'what', and another that describes the 'how', needed to create the 'what'.

Artifacts and interactions

We designed an EA process model to graphically represent the artifacts and their interactions on different levels. The EA process model, shown in Figure 5.3, shows the different types of architectural artifacts assigned to the different EA levels, therefore, presenting the content that has to be produced on the four EA levels, and the relationships between this content. Figure 5.3 therefore represents the the *what* of each EA level.

To graphically better represent (differences between) the EA artifact types, we developed a second model which takes the EA artifact categories as a basis, and draws the EA levels on them, as shown in Figure 5.4. This model could be used to explain the stakeholders the different artifact types. Figure 5.4 shows the the artifact types structured from generic to specific on the X-axis, and distinguishes artifact types between business and IT content on the Y-axis.

Processes

We designed a second EA process model to provide a graphical overview of *how* the defined EA artifacts on the different levels shown in Figure 5.3 should be realized, shown in Figure 5.5. The goal of this model is to give structure to the architecture function in creating the artifacts and services desired to create valuable EA in the DSO. The model summarizes primarily the information in- and outputs as described in the different tables shown above.

In the model of Figure 5.5, the four EA levels are shown again. In each level the primary characteristics of the EA function are repeated, including the decision scope, decision time window, stakeholders, responsibilities and artifacts. The current Alliander architecture roles observed in this level are also shown in the model. The model enables alignment between long-term strategic direction EA on enterprise level and short-term solution focused EA on the operational level, and the levels in between. With the defined feedforward and feedback loops, collaboration between the desired architecture levels in the company was defined, highlighting the importance of formal and informal interactions between EA functions to ensure effectiveness.

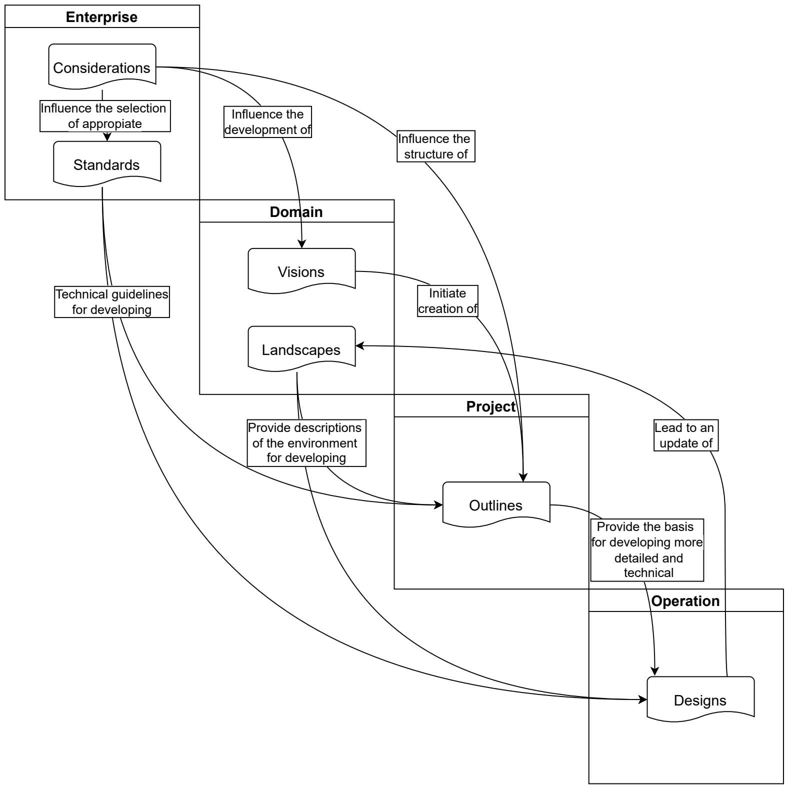


Figure 5.3: EA process model showing desired artifacts and their relations

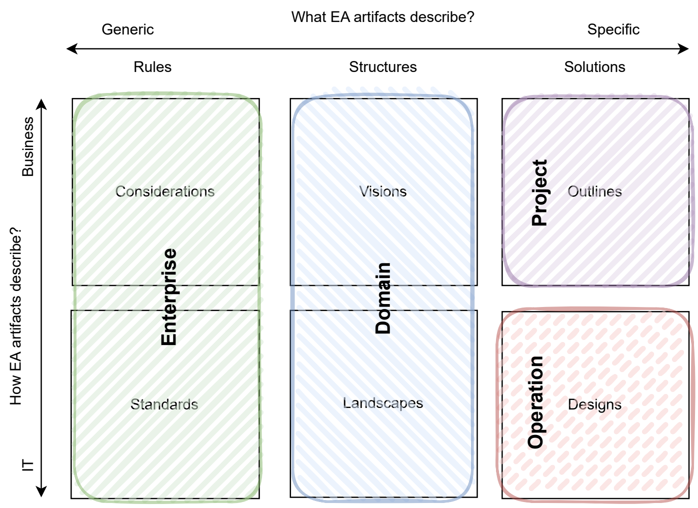


Figure 5.4: EA artifact types mapped to highlighted levels

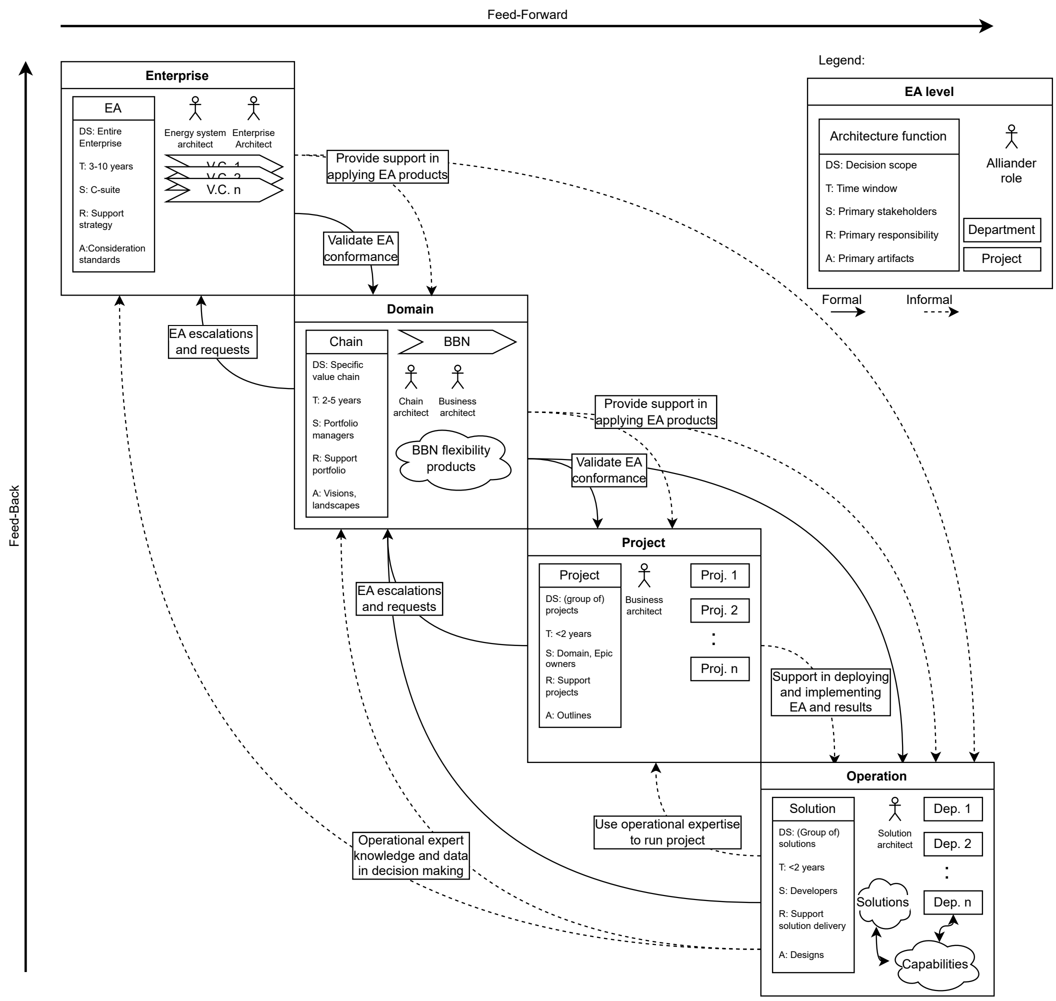


Figure 5.5: EA process model

Chapter 6

Architecture to support flexibility products

Chapter 5 shows that, on the identified domain level (specifically BBN), flexibility products are developed and operated. This chapter applies the EA benefit realization framework of Figure 5.1 to assess how EA can contribute to the development of these flexibility products, therefore answering RQ4. Accordingly, this chapter presents the design of an EA artifact that can be used in the PLM to develop flexibility products, designed to answer RQ5.

6.1 EA as a tool to develop flexibility products

The energy transition poses challenges on the DSO that are not (yet) supported by EA. One of them being EA supporting the development of flexibility products in the BBN value chain. Until now, two topics have been described separately: (1) enterprise architecture and how this leads to organizational benefits and (2) how the grid utilization can be increased with flexibility products in order to facilitate the energy transition.

The EA benefit realization framework was used to assess how EA can contribute to and enhance the development of flexibility products. Figure 6.1 shows that the organizational benefits could properly be inserted into the framework, the strategic goal to contribute to the energy transition (overarching motive for this research), the tactical goal being increasing the grid utilization and the operational goal supporting the development of flexibility products.

With the organizational benefits known, the highlighted section in Figure 6.1 shows how EA can contribute to these benefits. This includes a (1) benefit mechanism, realized through an (2) EA service, supported by an (1) EA artifact. This is the benefit mechanism through which EA can contribute to the development of flexibility products. These three aspects need to be defined in order for EA to properly contribute to the development of flexibility products, which is presented in the following sections

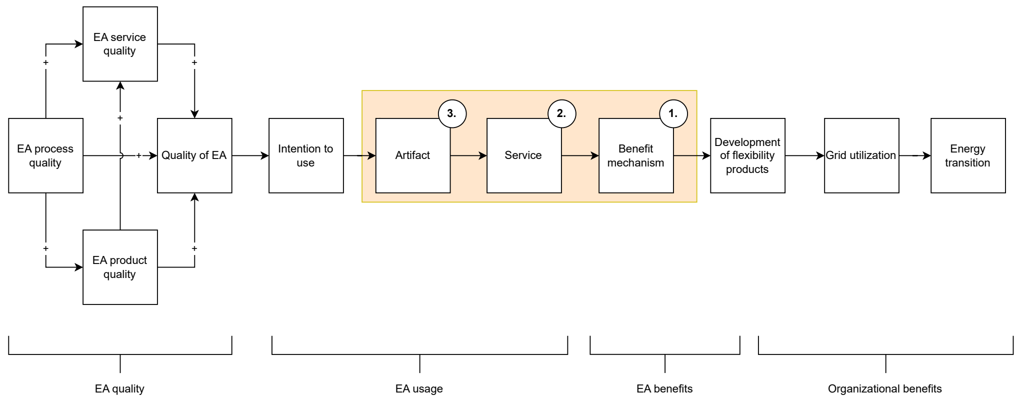


Figure 6.1: EA benefit realization framework with filled in organizational benefits

6.2 EA benefit mechanism

The benefit mechanism, which explains how EA leads to the organizational benefits, is essential to find the link between the creation of EA and its contribution to the business, namely the development of flexibility products. It should be defined before defining the EA artifact and service, because these should result in this benefit mechanism. In this research, the benefit mechanism describes the business needs in the PLM process for EA.

The selection of the most appropriate and desired benefit mechanism is based on the outcomes of the interviews with flexibility product developers, presented in Section 4.3. In these interviews, questions were asked about the needs and bottlenecks in the PLM process. The outcomes of these interviews were analyzed and compared against the 7 identified benefit mechanisms. The selected benefit mechanism is shown below, reflecting the business need for EA in the PLM process:

Resource Portfolio Optimization: *The extent to which an organization leverages its existing resources, invests in resources that target performance gaps, and minimizes unnecessary investments in duplicated resources [59].*

Four outcomes that justify this benefit mechanism are shown and explained below:

1. **Product capabilities:** there is currently limited insight in capabilities (often called 'building blocks' by the interviewees) related to flexibility products. As a result, product developers have little insight in the different 'building blocks' (e.g., IT applications, business processes, data, financial aspects, contracts) belonging to a product, making it hard to determine which of these building blocks can be improved for a specific product. Furthermore, the degree of variation and similarities in capabilities across different flexibility products is unknown. As discussed in Section 4.3, a manual assessment is necessary to determine how the required capabilities can be acquired, this is often a complex and lengthy process. Having insight in the capabilities and the underlying resource portfolio related to this flexibility product, is expected to speed up this process. The lack of insight in product capabilities results in existing resources not being utilized optimally, and hinders the opportunity to place strategic investments in resources or capabilities that could benefit multiple products.

2. **Duplicity and reusability:** Product development happens in silo's, leading to capabilities being developed or improved in response to specific needs of individual flexibility products. However, these capabilities may also be relevant for the development and operation of

other products. Due to limited insight in existing capabilities and resources related to flexibility products, there is a high risk at unnecessary duplication. Similar capabilities or resources may already exist elsewhere in the organization, linked to other (flexibility) products. There is little insight in the available reusable capabilities, resulting in capabilities being duplicated, inefficient resource utilization, and increased costs.

3. **Product information:** The identification of misalignment about product information is also led to the desire for resource portfolio optimization. The availability of information (e.g., documentation, status, usage, implementation rate) related to the flexibility products is scattered around many places. For example, the PLM is currently assessing the possibilities for software that can support the process, an overview of the product resources and information is considered a necessary prerequisite to make the PLM software useful. Such an overview could provide increased insight in the resource portfolio related to the flexibility product.

4. **Responsibilities:** An optimized resource portfolio could help solve the indicated issues around responsibilities for the development of a capability. Sometimes a required capability 'falls between' the responsibilities of different roles (operation level), and therefore takes a long time to be developed. Sometimes organizational roles take the responsibility for the development of a capability that they are not intended to be responsible for, often because of time or budget constraints or dissatisfaction at the responsible party. A more optimized resource portfolio could make this process more efficient.

One of the outcomes of the first set of interviews with architects, discussed in Section 4.2, was that they are unaware how exactly EA could contribute to the development of flexibility products. This defined EA benefit mechanism makes it clear for architects how EA could have the most positive impact on the development of the flexibility products. Based on this benefit mechanism, a suitable service and artifact can be defined.

6.3 EA service

In order to realize resource portfolio optimization, an EA service has to be defined, which defines *how* EA enables the benefit mechanism. This service mindset is important and prevents EA from becoming document heavy and unresponsive. This section describes EA services that can be delivered to PLM stakeholders to help them overcome the challenges mentioned before, and to realize the benefit mechanism. Table 6.1 repeats the four most important challenges, and describes an EA service as a response to this.

Table 6.1: Business observations and their corresponding desired EA services

Challenge	**Observed in**	**Observation**	**Desired EA service**
Product capabilities	PLM & architecture interviews	No available overview of business & IT elements related to a product	Capability gap analysis, maturity assessment
Duplicity and reusability	PLM-interviews	Product development is executed per individual product, no insight in re-usability	re-usable capability overview, capability based planning
Product information	PLM & architecture interviews	Information about products is scattered around many places and sources	Provide insight in information elements related to product capabilities
Responsibilities	PLM-interviews	Problems in finding the correct responsible stakeholder for the development of a specific capability	Identifying capability owners, guide stakeholder management

Table 6.1 shows that four primary challenges were identified in the PLM, which can be contributed to with EA services. In each described EA service, the term 'capabilities' is recurring. From the interviews with architects, it became apparent that there is no overarching capability overview related to a flexibility product, and no EA artifacts or services are available that show a flexibility products and its business, data, application and technology elements. This is confirmed by the PLM stakeholders indicating that there is little overview in which capabilities relate to a flexibility product, and primarily how these capabilities are realized. This is the primary inefficiency identified in the PLM. Therefore, an EA service to solve this inefficiency should be designed.

The identified opportunities for EA services to support the development of flexibility products can be summarized as:

Identifying, prioritizing and guiding the necessary organizational and technological investments desired to enable flexibility product development

With this service, EA can help in the different phases of the PLM process to assess the maturity of the currently available capabilities, and help define the development needs (capability gaps), which should be developed in order to effectively operate the flexibility product.

6.4 EA artifact

Figure 6.1 shows that the described architecture service should be based on an architectural artifact, that substantiates the service. Since the flexibility products are developed and operated on the domain (BBN) level, the EA process model can be used to find appropriate artifact types for this level. Figure 5.3 shows that, on a domain level, visions and landscapes are considered the two most important and valuable artifact types. Therefore, in the search for an EA artifact that can support the development of flexibility products (through resource portfolio optimization), the defined six artifact types are limited to visions and landscapes, which are the EA artifacts that match the abstraction and business need of the BBN domain.

EA artifacts, can be divided in two types: primary and supporting. Primary EA-related artifacts are artifacts that directly contribute to business and IT alignment by providing descriptions relevant to the landscape structure. Supporting EA-related artifacts do not contribute to alignment directly, but facilitate the usage of primary artifacts or other aspects of an EA practice.

For this research it is be more valuable to create a supporting artifact instead of a primary artifacts, because of the quickly evolving architectural landscape within the company. Primary artifacts would contain the implementation of capabilities as defined in business solutions, which are being developed and are not yet available for all of the capabilities. For this research, it is therefore hard to determine *how* capabilities are realized, i.e., which business process, application and technology elements contribute to a capability.

With the desire to create a supporting EA artifact on domain level, the landscape artifact type is per definition not suitable. Table 3.2 shows that landscape artifacts provide technical descriptions of the organizational IT landscape, which does not match with the described supporting artifact type since these are considered more generic. This makes the vision artifact type the only remaining and appropriate artifact type to deliver the service. Visions are high level conceptual descriptions of an organization from the business perspective and are used to guide IT investments, which corresponds with the desire in the PLM as described in the EA service.

The considered artifacts found in the visions category were shown in Appendix A, which are the artifacts found in organizations with a mature EA capability, and have been proven to be effective in the EA practice [75]. From the defined EA artifacts the capability model is the most effective to support the described service and its benefit mechanism.

Capability model: *Structured graphical view of organizational business capabilities, their relationships and hierarchy [109]*

The following reasons justify the selection of this artifact:

1. **Generic:** the capabilities of DSOs in the Netherlands are defined in NBility. A capability model artifact ensures generalizability, making it useful for other DSOs.

2. **Durability:** the architectural description of business solutions in the company is heavily subjected to change and not all business solution artifacts are available. To ensure the durability of the designed artifact, the artifact type should show little change over time, which is the case with a capability model. This artifact type is considered to show the least risk to become less useful over time.

3. **Derivation possibilities:** capability models can be used as starting point for defining other vision type artifacts, such as roadmaps and process maps. In addition, Figure 4.1 shows that capabilities are realized by business solutions. Therefore, once the capabilities model is defined, they can be linked to business solutions, which in turn can be used to form landscapes artifact types.

4. **Match with EA process model:** capability maps are categorized in the visions artifact type. This type of artifact is matched with the domain EA level shown in Figure 5.3.

5. **Trend:** capability architecture models from a product point of view are recognized as an important trend in EA, with increasing evidence that this architecture types can help organizations increasing the products.

6. **Match with the desired service:** this type of artifact can be used to deliver the defined services of Section 6.3.

In the context of an EA artifact, a capability is defined as 'an ability that an organization, person or system possesses'. A capability model therefore describes abilities an organization uses to perform a function [109], in this case, operating and developing flexibility products. Business capability model can help to align IT practices and investments with business demands, especially in the communication between management and IT. Many organizations map their applications, responsibilities and processes on their business capability map, and define 'capability owners' [109].

A capability model is also useful to help business stakeholders manage IT elements, which is exactly the case in this research. In a capability model, business terms are described instead of technical terms, allowing business stakeholders to better understand IT outcomes [110]. Furthermore, a capability model provides a stable view of a business abilities, which is more specific then strategic guidelines but less volatile than business processes [110].

In the context of this research, a reference capability model instead of a capability model was designed. This ensures the model can be classified in the supporting EA artifacts category as explained above, and ensures usefulness of the model throughout multiple DSOs instead of only in the case study.

6.5 Product reference capability model design

With the selection of an appropriate EA benefit mechanism, service and artifact, the EA benefit realization framework for the development of flexibility products was completed, shown in Figure 6.2. This benefit realization framework answers RQ4 how architecture can contribute to the development of flexibility products.

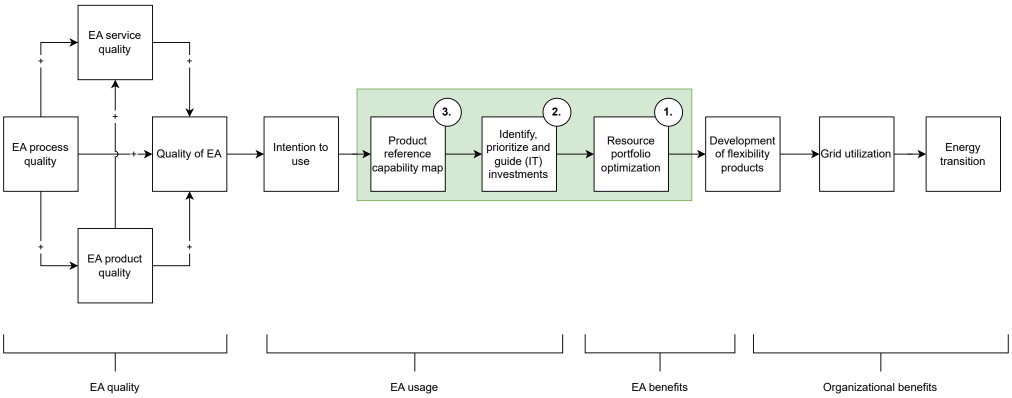


Figure 6.2: EA benefit realization framework for the development of flexibility products

Figure 6.2 shows a product reference capability model as the most suitable EA artifact to support the development of flexibility products. This artifact can provide the stakeholders in the PLM (the 'architecture benefitters') with useful information to develop the products.

6.5.1 Capability categories

In order to identify appropriate capabilities from the NBility model, a grouping of capability categories was made. The most suitable grouping of capabilities is obtained by linking the different capabilities to the BBN value chain processes. Figure 4.3 shows these different processes, where the flexibility product is used in BBN to satisfy a customer in its energy need. The product is used in the process from customer intake until customer operation, which makes it desired to categorize the capabilities according to these processes. The customer termination process step is considered out of scope, because the focus lies only on increasing the number of products sold. The following categories were defined:

1. **Customer intake:** capabilities required to handle a customer with a specific energy need.
2. **Customer matching:** capabilities required to assess how the energy need from the customer can be satisfied through the use of a flexibility product.
3. **Customer contracting:** capabilities required to offer and contract the customer a product witch optimally matches the customers energy need and grids available capacity.
4. **Customer operating:** capabilities required to operate the customer and its product to prevent grid congestion on a daily basis.
5. **Supporting:** capabilities required in the overall process of operating a flexibility product.

6.5.2 Capability selection

For the design of the capability model, the NBility capabilities are used, all NBility capabilities are shown in Appendix E. For each of the five categories described above, all capabilities in the NBility model were assessed for their relevance in this category, the result of this assessment is shown in Table 6.2. The selected capabilities were later validated with both the architects and PLM stakeholders, ensuring support from the creation as well as usage side of the model.

Table 6.2: Capabilities related to flexibility products

	Code	Description
Intake	C.1.1.2.	The ability to process and resolve customer reports, questions, and requests satisfactorily, including the entire journey from customer interest to formal request.
	C.1.1.5.	The ability to assess regional energy transport needs based on information gathered in discussions (e.g., from RES, public or business initiatives), including early interest from customers.
Match	C.1.2.3.	The ability to develop and manage products and services, including designing customer journeys and managing pricing structures.
	C.2.3.1.	The ability to assess short-term grid load, including load flow calculations, safety analysis, balancing, and contingency analysis, and incorporate results of control actions.
	C.4.2.3.	
Contract	C.1.2.1.	The ability to provide customers with product offers at the correct pricing.
	C.1.2.2.	The ability to make agreements with customers about products and services, manage performance, and maintain a contract registry, including adjusting or terminating agreements and SLAs.
Operate	C.1.3.1.	The ability to calculate a value for delivered services based on correct data (e.g., contracts, project data, usage, pricing).
	C.1.3.2.	The ability to deliver an invoice with the correct content and format to the customer.
	C.6.3.6	The ability to manage offers to grid operators for modifying production or consumption patterns at one or more connections. This includes balancing capacity, redispatch, demand response, and related bids.
	C.3.1.3	The ability to formulate and analyze alternatives to mitigate capacity and/or functionality risks in the grid, resolve bottlenecks, and determine mitigation measures. This includes scenarios, cost-benefit analysis, and value cases.
	C.2.1.3.	The ability to determine control actions on grid components to ensure energy transport and maintain balance. Includes responding to requests from other grid operators and performing emergency interventions in case of outages or technical congestion.
	C.2.1.1.	The ability to monitor the energy demand/supply balance in the network and detect bottlenecks.
	C.6.3.2.	The ability to exchange energy forecasts and nominations, e.g., with program managers.
	C.6.3.3.	The ability to establish energy exchange, including calculations of energy use (standard year), unmeasured usage, serial allocation points, assigned energy losses, and consumed market services (e.g., balancing, up- and down-regulation). Also includes delivery of data from metering parties, third parties (e.g., CPOs), and municipalities (e.g., public lighting).

6.5.3 Design of the capability model

To design a usable and complete product reference capability map, insight was needed in the necessary elements of a capability model. By exploring literature studies about capability maps, practical guidelines were found that could be used in the design of the capability model [110]. This study claims that well defined business capability maps need to fulfill four characteristics: (1) they need to be stable and independent of processes, organizational structures or technologies, (2) they describe necessary roles, (3) the capabilities should not overlap, and (4) the capabilities can be broken down into more detailed and granular capabilities and therefore show hierarchy between them. To realize a capability, the four components: roles, processes, information and tools (IT) are combined, as done in the defined business solutions.

We designed a product reference capability model based on the identified capabilities, shown in Figure 6.3. In the model, the five different capability categories are shown, in which the selected capabilities (including their business objects) are placed. The colors of the capabilities originate from the color of the capabilities within NBility, this improves usability and readability among architects within the DSOs, who are familiar with NBility. The capability model shows the primary capabilities required for the operation of a typical flexibility product, therefore, showing the capabilities that need to be developed in order to to operate this flexibility product. This capability model can give the PLM stakeholders insight in the 'building blocks' of a products, which can help them with developing the products.

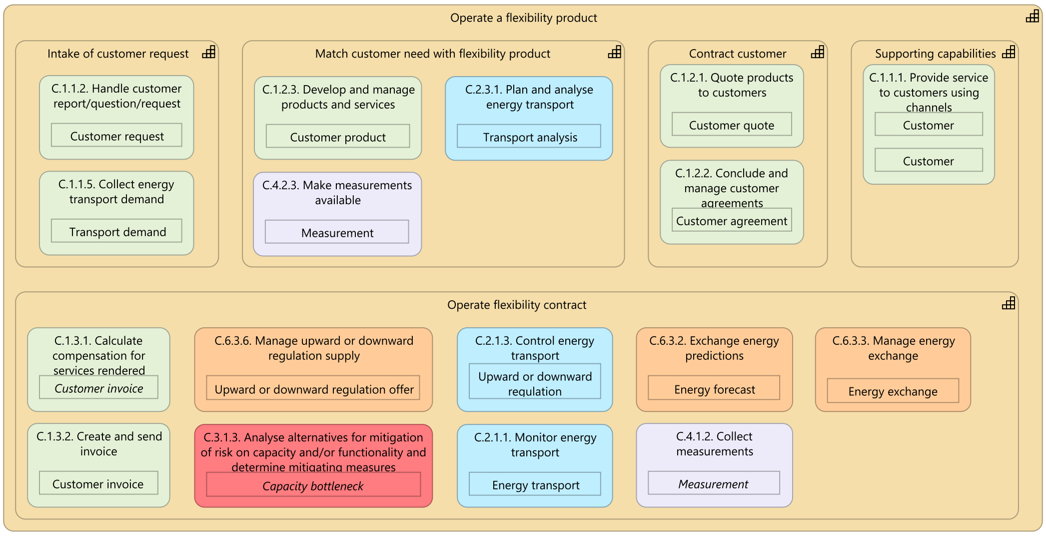


Figure 6.3: Reference capability model for flexibility products

The business capability model from Figure 6.3 satisfies three out of the four required elements for useful capability maps, no roles are indicated in this model, as there are often more than one role responsible for realizing a capability. The roles are defined in the business solutions, which can be linked to these capabilities.

6.5.4 Second capability model

In the development of the product reference capability model, one specific capability stood out, namely the C.1.2.3. capability, 'develop and manage products and services'. This capability rose the attention since it showed a potential overlap with the overarching capability shown in Figure 6.3, namely 'Operate a flexibility product'. According to the requirements, this overlap should be prevented.

In the capability model of Figure 6.3, all capabilities were shown that are involved in the operation of a typical flexibility product. These are the capabilities of which elements can be improved or developed in order to develop the flexibility product. However, given this definition of C.1.2.3., we should determine if the capability model of Figure 6.3 is correct, or that the flexibility product capabilities are better represented as being sub-capabilities of C.1.2.3..

In order to visualize this question, the capability model has been redesigned, shown in Figure 6.4. In the model can be seen that capability C.1.2.3. is removed from the customer matching capability category and enlarged, the remaining capability model remains similar and its categories are placed into the new overarching capability C.1.2.3.. This shows the possible relations between C.1.2.3. and the other capabilities, for example, in order to develop a flexibility product (C.1.2.3.) one can develop the capability to handle customer requests (C.1.1.2).

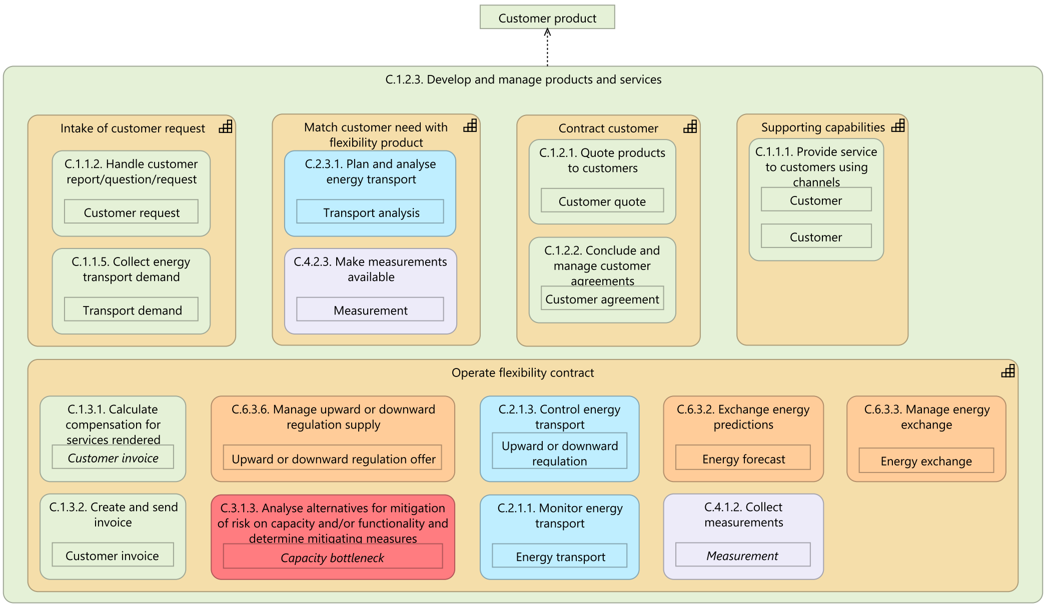


Figure 6.4: Reference capability map for flexibility products version 2

In the validation of the research these two product reference capability models were shown to the experts in order to collect their vision on this topic differentiating the two capabilities.

6.5.5 Interactions with different architectural levels

The flexibility products are operated on a domain level, for which an architectural vision artifact type was designed. However, the EA levels and their related artifacts, interact with each other, as shown in the EA process model. Therefore, for the creation of this vision artifact type, input is required from EA on other levels. In addition, the creation of this vision, is an output to be consumed on other EA levels. These interactions can be seen in the EA process models shown in Figure 5.5 and Figure 5.3, which are discussed below.

Input The creation and development of visions is influenced by considerations on an enterprise level. These considerations should be referenced in order to get an overview of existing policies, principles and strategies in the enterprise, in order to properly design a vision artifact type. Moreover, consideration artifacts and their related services can be utilized to gather insight in what the organization wants to achieve and what it wants to achieve with IT. For example, in this research a consideration artifact could be a principle indicating the extent to which the DSO wants to support flexibility products with IT or policies related to flexibility products. Both can be used as inspiration for the development of the vision, the reference capability map.

Output Visions initiate the creation of outlines on a project level. In this research, usage of the capability model may lead to the identification of immaturity of certain capabilities (e.g., missing IT functionalities). In order to develop this capability or set of capabilities, an outline has to be created which specifies how the desired maturity level of the capability will be achieved, and thus which specific solutions need to be developed. This will eventually lead to a solution design on department level.

6.5.6 Next steps: capability model use cases

The designed reference capability model for flexibility products can be used for several secondary purposes, next to supporting the defined EA services. However, most of the capability model use cases within organizations are realized only when capabilities are linked with the four capability realization elements, being business, data, application and technology elements. Based on two literature studies, more use cases were defined below in order to optimally utilize the capability map:

1. **Application lifecycle:** by heat mapping the capabilities and their related applications, insight can be gathered in the required attention to the capabilities. For example, a business capability that is supported with an application that loses software support may lead to security issues [109].

2. **Capability spanning applications:** the capability map can be used to identify applications that serve multiple capabilities, which can indicate unnecessary dependencies which act as complexity drivers [109].

3. **Cost vs capability usage:** the capability map can be used to assess the importance of capabilities, i.e., the extend the capability is used in the business. Applications with a low usage and high operating costs can be evaluated according to its need [109].

4. **Business translation:** capabilities offer a way in which business executives can gain a common understanding of their business, and which portion of the business needs attention [111].

5. **Placing investments:** With insights in the capabilities and their maturity levels, accurate investments can be made that produce the biggest impact on the enterprise [111], in this case to the flexibility product.

Chapter 7

Validation

This chapter presents the validation of the designed artifacts in this research, describing the third and final phase of the Design Science Research methodology and answering RQ6. A method to validate the artifacts is presented in Section 7.1. The validation consists of two parts: the EA process model (shown in Chapter 5) is validated in Section 7.2, and the product reference capability model (shown in Chapter 6) is validated in Section 7.3, this shows if this domain level EA artifact could contribute to the development of flexibility products. These two validations aim to evaluate whether the artifacts produce the desired effects in the problem context. Section 7.4 presents the results of the validation executed with external experts, addressing the generalizability of the research.

7.1 Validation methodology

For the validation of the designed artifacts (the treatment), a suitable methodology was chosen that allows us to assess the performance of the artifacts in the problem context. Based on the input gathered from this validation, artifacts can be redesigned if necessary, resulting in a better performing artifact.

For the validation of the artifacts, the guidelines proposed in the DSRM methodology were used. Wieringa [2] proposes a list of 3 main questions that can be answered for the validation of an artifact, which have been reformulated for usage in this research. The following questions guided the validation process:

1. **Effect questions:** Does ($artifact \times context$) produce effects?
   (a) Can the EA process model add value to EA at a DSO?
   (b) Does the EA benefit realization framework together with the EA process model help architects in defining appropriate EA services and artifacts?
   (c) Does the capability model provide sufficient support to PLM stakeholders developing the flexibility products?
   (d) How can the capability model be provided by EA to support the PLM?
2. **Trade-off questions:** Does ($alternative\ artifact \times context$) produce effects?
   (a) How do similar artifacts help structure the EA function in organizations?

(b) How can similar artifacts help DSOs developing flexibility products?

3. **Sensitivity questions:** Does ($artifact \times alternative\ context$) produce effects?

   (a) What assumptions does the design of the artifact make about its context?

   (b) Are the artifacts valuable for architects in other grid operator organizations?

Based on these questions, available validation methods were assessed. Expert opinion was chosen to validate the artifacts, since it is a valuable validation method particularly suited to early-stage evaluations of designed artifacts. This approach enables a reasoned and imaginative assessment of how an artifact might perform in real-world contexts, based on the insights from experts in the field [2]. Experts can provide critical feedback grounded on their knowledge and insights, which can be used for iterative improvement of the artifacts. In this research, expert opinion are a practical and efficient method to identify points of improvement in the artifacts. Because the research was executed within a specific DSO, experts are easily reachable and have the appropriate experience and knowledge in the fields of Enterprise Architecture and its application in DSOs.

The validation primarily focused on the effect questions, therefore, the validation assessed how the designed artifact would perform in the context they have been designed for (DSO Alliander). This is considered the most important validation type since this is the context where the need for these artifacts is identified. In a later stage of the validation, the trade-off- and sensitivity questions are also answered through interviews with external experts.

7.2 Validation of the EA process model

This section discusses the validation of the EA process model, presented in Chapter 5. This validation starts with evaluating the four identified EA levels, as defined in Section 5.2, by individually interviewing 4 experts. Subsequently, the EA process model, described in Section 5.3, is validated by individually interviewing 6 architects.

7.2.1 Validating the EA levels

Before validating the EA process model, including the design of the four levels and their interactions, the defined EA levels themselves, as shown in Section 5.2.2 had to be validated. This was done because the design of the EA process model is based on these four levels. If the experts would not agree on the identified levels, the rest of the EA process model had to be redesigned.

In order to correctly validate the identification of the levels, stakeholders were selected that could critically reflect on the identified organizational levels. These stakeholders had to be informed and involved in the organizational changes and challenges identified in Section 4.1, and should also have a thorough insight and overview of the desired way of working in the organization. Table 7.1 shows the four selected experts involved in the validation of the EA levels, all these experts were earlier interviewed in the problem investigation

Table 7.1: Experts selected in the validation of the EA levels

Nr.	Function.	Experience
1	Value chain director	16 years
2	Business architect	3 years
3	Energy system architect	10 years
4	Enterprise architect	12 years

For this validation, the experts were first shown and briefly explained the EA levels, as identified in the literature review. This allowed the experts to learn the definitions of the EA levels. After this, the experts were explained that this research aims to link these four levels to 'levels' in the Alliander organization. The experts were shown Figure 5.2, in which the experts could see the identified EA levels with their interactions. The experts were asked to provide their thoughts and feedback on the mapping of the EA levels to levels seen in the company. The validation showed that the experts agree with the defined levels and their interactions. Only small refinements to the model were proposed, ensuring the correctness of the levels and their interactions. The defined levels can therefore be used to design the EA process model.

More feedback about this model was collected in a the validation of the actual EA process model, presented in the following section. In these validation interviews the experts were shown this model as an introduction to further explain the identified EA levels. Although all experts identified the presence of the four levels in the organization, some experts indicated that they think a level relationship has to be refined. For example, one expert indicated that, departments do not deliver direct capabilities to projects. Experts questioning a part of the model can be explained by the organization rapidly reshaping its way of working. Feedback about minor refinements in the levels (and the interactions between them) were ignored in the rest of this research because they concerned only minor adjustments and do not lead to an alternation of the EA process model. We assumed that by validating the model with the selected experts, this model can be considered trustworthy, allowing this research to dive deeper into the design of the EA levels, and their desired artifacts, in order to complete the EA process model.

7.2.2 Validating the artifacts and interactions

Validation process

The next step is to validate if the EA process model of Section 5.3 matched the appropriate artifact categories with the EA levels, and explained an appropriate interactions between the levels. For the validation, we carefully selected the experts involved, so that at least one representative from all architecture disciplines within the company was included, together with the manager of the enterprise architects, who has a complete overview of architecture within the company. The profile of the selected experts is shown in Table 7.2

Table 7.2: Profile of experts involved in validating EA process model

Nr.	Function.	Experience
1	Manager Enterprise Architecture	2 years
2	Business architect	3 years
3	Energy system architect	10 years
4	Enterprise architect	12 years
5	Enterprise architect	12 years
6	Solution architect	4 years

Six individual validation interviews were conducted with the experts shown in Table 7.2. The interviews were started by giving the expert a presentation of the results of the research. First, the research question and the purpose of the research was presented. After this introduction, the EA benefit realization model (Figure 5.1) was shown and explained to the expert. Based on this framework, the experts were shown the entire process from EA artifact and service creation until the derivation of the organizational benefits. Next, the expert was explained why this research focused on the EA process quality, which was then highlighted in the benefit realization framework.

After this context was explained, the EA levels were introduced to the expert by first showing the identified EA levels, of Table 5.2. After quickly explaining these levels, the mapping of these levels to EA levels in the organization was explained. After, the EA benefit realization framework was used to explain the experts that, for the four EA levels, suitable EA artifacts need to be defined. The six EA artifact types were shown and the experts was asked to read the slide, in order to fully understand what is meant with the artifact types. Next, the experts were shown the EA process model of Figure 5.3, which showed them the complete overview of the levels, and their artifacts (relations). The expert was then asked to reflect on the artifact's usefulness, completeness, and correctness. The different elements shown above are presented to the expert through the use of a PowerPoint, which is shown in Appendix G.

Outcomes

The EA process model in Figure 5.5 shows the primary useful artifacts in the four different EA levels. The primary outcome of the validation sessions is an assessment of the experts to the broad outline of the artifact. The experts indicates that, currently, no well defined set of artifacts is seen in none of the EA disciplines. All experts agree that the six artifacts are categorized correctly, sometimes after explaining more about why an artifact type is placed in a level. However, the experts indicated they struggle with limiting the artifacts produced in the different levels to only the selected artifact types. According to some of the experts, an overlap in the EA artifacts would increase the value creation in the EA levels. For example, one expert in the BBN value chain indicates that there are specific standards that apply only to this BBN value chain, for which standards need to be designed. Also, the manager of the enterprise architects, indicated the desire to not limit the artifact types on the different levels to only the selected types. In contrast, also one architect specifically indicates to agree with limiting specific artifact types to the levels, as this could improve the structure in all EA in the organization and help stakeholders to know what they can expect from EA.

Two of the experts addressed the overall desire to solve architectural issues on the place these issues arise. These experts agree that EA at enterprise level, should indeed be EA to support the strategy. However, currently architectural issues on for example solution designs are sometimes escalated to enterprise level, which prevents this level fully focuss on this strategy. This confirms the outcome of the EA process model, in which was indicated that the enterprise level should not be involved in the creation of designs nor outlines artifact types.

The findings from this validation correspond with an outcome of a study of Kotusev et al. [108] in which the specialization of architecture positions in organizations was investigated. This finding is that in practice, many architects devote roughly equal portions of their time to enterprise- and solution-level planning activities and, thus, cannot be related to any pure 'archetype' of architects described in the literature.

7.2.3 Redesign

Based on the input acquired from the experts, a redesign was made. The most important outcome of the validation is that Figure 5.3 prescribes the appropriate artifact(s) to EA levels. However, experts also indicate this model implies that these are the only correct and useful artifacts at these levels, and no other artifacts are produced, which most experts do not agree to.

Since the experts agree with the selected artifacts on the levels, the EA process model is not redesigned. To comply with the experts indicating that the EA artifacts should not be limited to only these types, Figure 5.4 is redesigned, resulting in Figure 7.1, which shows an improved mapping of the four EA levels on the six artifact types. In Figure 7.1 can be seen that there is now an overlap between the different EA levels plotted on the EA artifact types. This means that, for example, the operation level should also partially produce landscape artifacts.

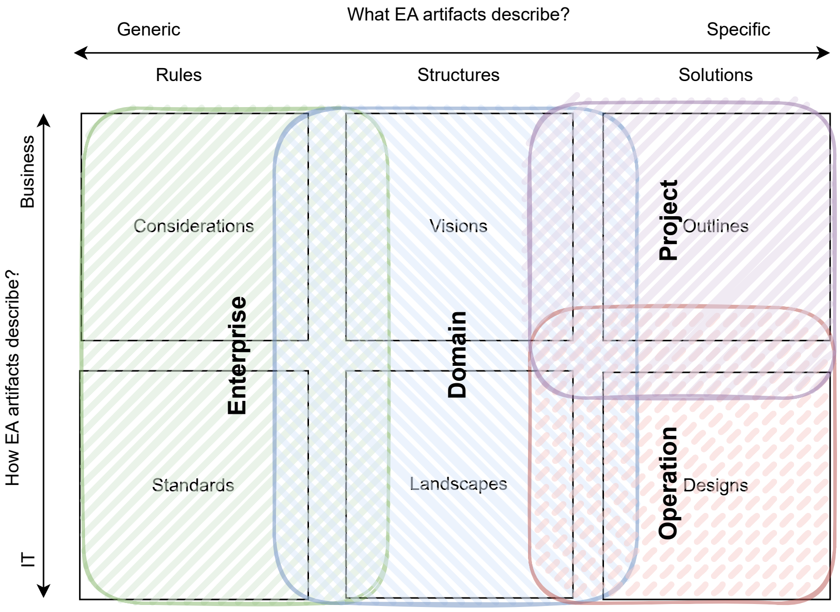


Figure 7.1: EA artifact types with highlighted levels redesign

7.3 Validation of the product reference capability model

The second part of the treatment validation includes the validation of the product reference capability map presented in Chapter 6. This validation has been conducted twofold, namely by gathering input from 6 architects as well as from 4 product developers in the PLM. This approach ensured that the model is validated using insights from both the creators and the intended users of the model. The purpose of this validation has been to assess how Alliander can use the artifact to support the development of flexibility products, or how it should be redesigned in order to achieve the desired effects. This validation therefore answers the effect question, by evaluating the usefulness of the designed product reference capability map to stakeholders in the PLM process.

7.3.1 Input from architecture users

First, the validation assesses if the designed product reference capability model can be useful for stakeholders in the PLM process (the end users of the artifact). For this validation, a set of experts were selected who had a comprehensive overview over (the development of) flexibility products. Since the experts were shown an EA artifact, it would be preferred for the experts to have some knowledge on EA. However, no PLM stakeholder was familiar with concepts of Enterprise Architecture. The profile of the selected experts is shown in Table 7.3. The semi-structured validation interviews validated the results presented in the sections of Chapter 6. Next to the validation interviews, a brainstorm meeting with PLM stakeholders was conducted, where the research outcomes were briefly presented and thoughts and inputs about the research were collected.

Four individual validation interviews were conducted. In these interviews, the experts were

Table 7.3: Profile of PLM experts involved in validating the capability model

Nr.	Function	Experience
1	Consultant policy and product development	3 years
2	Consultant product development	2 years
3	Senior productmanager congestionmanagement	2 years
4	Productmanager	7 years

first introduced to the research, and shown the research questions and the research relation to the PLM. Hereafter, the primary findings of earlier interviews with PLM stakeholders (Section 4.3) were presented, and experts were explained that these findings have resulted in the identification of a benefit mechanism, through which EA could have a positive impact on the development of flexibility products. The experts were asked if they think this benefit mechanism indeed covers a need in the PLM. The experts recognized the need for resource portfolio optimization, and confirmed the selected benefit mechanism.

The defined EA services, shown in Table 6.1, to realize this benefit mechanism were presented to the experts, empathizing that these services aim to contribute to identified bottlenecks in the PLM. The experts agree that these services would be valuable and desired in the PLM, and could contribute to the development of flexibility products.

Finally, we explained the experts that the EA service is based on an EA artifact. The designed product reference capability map of Figure 6.3 was presented to the experts, and they were asked to reflect on the model in terms of usability, usefullness and completeness. The experts mentioned they struggle to find the direct use cases for this model. One expert explicitly mentioned that, 'although the model looks interesting and I can recognize most capabilities, I have no clue how this model could help me in the development of flexibility products'. From the rest of the interviews an overall issue to understand the capability model is identified, which can be explained by experts being not familiar with capabilities and having no understanding of capability maps in general.

The experts struggling to understand the value of the EA artifact indicates the need for an appropriate EA service. The artifact in itself does not deliver direct benefits in the PLM, an appropriate service has to support this artifact to achieve the benefits. This corresponds with the findings shown in the EA benefit realization model (Figure 5.1), that an EA artifact does only contribute to the benefit mechanism through the EA service.

The experts have been asked what they think could be added to the model to make it more valuable and useful for them. By showing the business solution metamodel, the experts were shown how these capabilities are realized. All experts agree that having this overview of business solutions linked to the flexibility product capabilities would be very valuable. They indicate that this could help them having insight in all applications related to the operation of a flexibility product. One expert explicitly stated that the business solution metamodel itself could be useful to design and identify the product building blocks.

7.3.2 Input from the architects

The capability map was also validated with architects, since these are the stakeholders involved in the creation of the model. Finding appropriate stakeholders for the validation of the capability map from a 'creation' perspective was hard. The selected experts needed to be experienced in both Enterprise Architecture and be familiar with the PLM, specifically with developing flexibility products. Together with the supervisor of the research, two experts were found that can provide their expertise on these two topics combined. These two experts were also selected to validate the EA process model, so the validation of the EA process model and the capability model was done in one interview for these experts. Table 7.4 shows the profile of these two experts.

Table 7.4: Profile of EA experts involved in validating the capability model

Nr.	Function.	Experience
1	Enterprise architect	12 years
2	Enterprise architect	12 years

The two individual expert interviews used the EA benefit realization framework to show the experts that the research aimed to define an appropriate EA benefit mechanism, EA service and EA artifact to support the PLM in developing the flexibility products. The experts positively reacted on (application of) the benefit realization framework itself. One of the experts was specifically interested in this framework, and highlighted that this framework could be used in the organization to gain better insights in the EA benefits. This expert indicated that, these benefits are currently largely unknown, which leaves the exact purpose of an EA service or artifact open for interpretation.

Similarly to the validation with the architecture users, we explained the benefit mechanism, service and artifact. The experts were not asked to reflect on the benefit mechanism, since this is the defined need of stakeholders in the PLM process. The EA services described in Table 6.1 were shown to the experts and we asked if these are suitable services that can be delivered by the EA. The architects agree that these could be valuable services in the PLM.

We already explained the six EA artifact types to the experts in the validation of the EA process model, so we showed that a vision artifact type, specifically a capability model, was considered the most appropriate EA artifact to support the PLM. Both experts agree that this high level overview of elements related to a flexibility product would indeed be an appropriate artifact to help achieve the benefits. Both architects indicate that the capability model of Figure 6.3 can be useful in the PLM, with one expert explicitly that 'a capability map like this could be really valuable in the PLM', but the expert does make the addition that unlocking the full potential of the capability map requires an overview of all correct business solutions, and highlights that this is still work in progress.

7.3.3 Comparing the two designs

In the design of the capability map, capability C.1.2.3. 'Develop and manage products and services' stood out. As described in Section 6.5.4, this capability showed similarities with the defined 'Operate flexibility product' capability shown in Figure 6.3. The two designs of Figure 6.3 and Figure 6.4 have been shown to the experts, who were asked to reflect on the differences between these models. One expert explicitly states that the second version of the capability model is incorrect, as this model shows that the selected capabilities are part of the C.1.2.3. capability, which is incorrect. This expert explains that with capability C.1.2.3., the capability to execute PLM is meant, and the other identified capabilities are not part of this capability. The product reference capability map shown in Figure 6.3 is therefore selected as appropriate artifact.

7.4 Generalization

In order to answer the sensitivity and trade-off questions, the artifact has to be validated in another problem context. This section therefore describes the generalizability of this research. The context in this research is defined as a specific DSO organization in the energy transition, namely Alliander. Therefore, another DSO organization is considered as another problem context in this research.

7.4.1 External expert validation

To further assess the generalizability of this research, we conducted two expert validation interviews with experts outside of the Alliander organization. With this validation, an answer can be acquired to the sensitivity question, which aims to assess the effects of the designed artifacts in the alternative context of this stakeholders' organization. The supervisor of this research proposed two candidates with a suitable background experience in the field of EA. The first expert is an enterprise architect for another Dutch DSO, and also a key figure of the NBility model used in this research. The second expert is an enterprise architect from a French TSO, selected because he could offer this research a viewpoint from a different regulatory landscape and different grid operator type. Section 7.4 shows the profiles of the selected experts.

Table 7.5: External expert validation interviews

Nr.	Function.	Company type	Experience	Duration
1	Enterprise architect	Dutch DSO	6 years	45 minutes
2	Enterprise architect	French TSO	5 years	45 minutes

Similarly as in the earlier validation sessions, a PowerPoint presentation was used to show the expert the different artifacts produced in this research, which is shown in Appendix G. The semi-structured interview was guided by several questions, which are also shown in Appendix G.

The two architects indicate that their organization has similar architecture roles as seen in Alliander. The two primary roles being enterprise architects, who aim to support strategy and alignment of capabilities, and solution architects, who aim to support primarily IT development. Both architects also indicate that the energy transition increases the importance of appropriate EA in the organization. We asked the architects how EA value creation is ensured in their organization. One architect indicated he thinks this process is established, and EA adds value by influencing decision making in the company, while the other architect indicates that there is no insight in how EA contributes to the business goals, making it hard for the architect to explain stakeholders how he contributes to business, since the EA is often a vague and invisible product.

The EA benefit realization framework (Figure 5.1) was shown to the experts, and they were explained how this model was created and what its purpose is. We asked if they see value and usability of this artifact. Both architects think the framework correctly represents the most important elements involved in the EA benefit realization process, one architect highlighted also other factors such as the quality of the architects. The architects think this artifact is valuable and could help them in defining the purpose and added value of EA Both architects mention they immediately think about how this framework can be implemented, but that they do not directly know how. One expert gave an important reflection on the framework, he stated that the organizational benefits are not always known beforehand, because EA can actually help shaping them, which can make the EA benefit realization framework hard to use in practice.

The validation of the EA process model with the external architects revealed a shared recognition of the potential value of this artifact in clarifying the role and contribution of EA within organizations. Both experts acknowledged that EA artifacts are currently not well-defined within their organization, which they both believe should be addressed to achieve more EA benefits. One expert emphasized that EA's role is primarily advisory rather than decision-making. The experts viewed the EA process model as a useful framework that could provide clarity on what EA can deliver, supporting better communication of its value across different organizational levels. Furthermore, the model was seen as a helpful tool to make EA contributions more concrete.

The interview outcomes were used to answer the sensitivity and trade-off questions, complemented with other motivations.

7.4.2 Sensitivity question

In this research, some assumptions about the context were made, So to make the research generalizable to other DSOs, these assumptions should be validated. First, we assumed that the DSO is defining value chains (domains in the EA process model) in which they want to increase internal efficiency in an end-to-end process. Second, in this research we assumed that the DSO wants to increase the grid utilization, and develops flexibility products to realize this.

To start, the business capability model from DSOs in The Netherlands (NBility), makes the research assumptions valid for all DSOs in the Netherlands. The NBility model prescribes a value chain model, in which one value chain (P.E.) specifically aims to solve congestion problems with flexibility solutions. In these value chains, the different capabilities are linked to business processes. NBility makes us assume that DSOs in the Netherlands are divided into multiple departments, that have to be linked in an end-to-end value chain, which the external Dutch expert agrees on.

In the Netherlands, the national action program against grid congestion (LAN) is an initiative which aims to allow all Dutch citizens to get a connection to the electricity grid. In Section 2.2.1 we mentioned that one of the three ways it aims to achieve this is to increase the utilization of the existing electricity grid [42]. Therefore, the assumption that every DSO is working on increasing the grid utilization, is valid. The 'Beter Benutten Net' value chain is the Alliander specific implementation of improving the grid utilization.

Interviewing an expert from a French TSO makes us assume the research is also largely applicable for European grid operators (TSO and DSO). Who have a simmilar EA function that should support the enterprise strategy, portfolio, project and solution delivery. However, the need for EA to support flexibility products was not confirmed in this interview, because congestion issues are less severe. The application of the product reference capability map could therefore not be proven outside of the Dutch problem context.

7.4.3 Trade-off question

The trade-off question aims to assess if similar artifacts could also positively affect the problem context. However, we found no similar artifacts that help DSOs structure their EA function. Also the two external experts indicate to know no similar artifacts that shows them the EA benefit realization process and the EA process, increasing the value of the EA process model designed in this research. For the Product reference capability map, a similar artifact was identified in the external expert validation. We asked this expert to reflect on the product reference capability map, he indicates that a similar artifact is already available. The NBility P.E. value chain, called 'coordinate desired and available transportation capacity', shows these capabilities required in this value chain and therefore indirectly shows the capabilities required to operate a flexibility product. The expert indicates that he only sees added value in this capability model, if it is shows an improved ease of use and value to the architecture user.

The effects of this similar artifact in the problem context of this research is unknown, since it is not used to support the PLM, therefore, we cannot assess how the designed product reference capability map performs compared to this similar artifact. The trade-off questions can therefore not be accurately answered, since no similar artifacts are identified in the problem context of this research.

Chapter 8

Conclusion and discussion

In the previous chapters, the three DSRM phases problem investigation, treatment design and treatment validation were presented, and the corresponding research questions have been answered. This chapter presents the conclusion of the thesis, starting with answering the main research question, followed by discussing the research contributions, limitations, and finally, recommendations for future research.

8.1 Answering the research question

This research aimed to improve the Enterprise Architecture of DSOs, in order for EA to properly support the organization in enabling the energy transition. Specifically by supporting the development of the flexibility products with EA, required to increase the grid utilization. By following the DSRM methodology, an answer is given to the main research question:

How can distribution system operators improve their Enterprise Architecture to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

To address the research question, first, an extensive exploratory background study was conducted. In Chapter 2, the purpose of the energy transition was examined to clarify the broader motivation underlying this study. Subsequently, the chapter presented a comprehensive overview of the implications of the energy transition for DSOs, answering **RQ1**. The key takeaway derived from this overview is the need to increase the flexibility in the distribution grid, as this is essential to improve grid utilization and mitigate the risk of congestion. This is essential to ensure reliability of electricity and prevent blackouts. Implementing flexibility requires the DSO to develop new capabilities, realized by the design and implementation of new business processes, data and IT applications.

Enterprise Architecture can serve as a valuable tool in the development of the required business and IT capabilities. In Chapter 3, a comprehensive exploratory literature review about EA is presented. This review identified a range of organizational benefits associated with EA, however, these benefit are only realized through benefit mechanisms. Additionally, the chapter showed that EA artifacts can be classified into six primary categories. To gain insight in how EA is used within DSOs, a systematic literature review was conducted. Using targeted search queries, 183 studies were identified. After screening, eligibility assessment and citation searching, 16 studies were included in the final analysis. These studies were used to answer **RQ2**, mentioning relevant changes on business, information and application domains. However, no study provided insight in how DSOs internally use EA to achieve organizational benefits.

To assess the current application of EA within a DSO, a case study has been conducted at the Dutch DSO Alliander, as presented in Chapter 4. Within this organization, significant changes in the way of working were identified. The organization has introduced value chains to increase the internal efficiency, aiming to remove the organizational silos and improve collaboration. One of these value chains specifically aims to increase grid utilization with flexibility products. Chapter 4 details a series of expert interviews conducted with (enterprise) architects at the company, which resulted in a comprehensive understanding of the EA function in the company, and how this function is supporting the flexibility products. In addition, a second round of interviews was conducted with business stakeholders who are expected to benefit from architecture related to flexibility products. These interviews highlighted that EA is currently not supporting the development of flexibility products.

In order to design a treatment that improves the Enterprise Architectures, it is essential to have insight into the key constructs characterizing the process from EA creation to the realization of organizational benefits. **RQ3** has been answered by designing an EA benefit realization framework, presented in Section 5.1. The framework synthesizes findings from several high impact scientific publications and enabled the assessment of which constructs should be enhanced to improve the overall EA quality. The analysis revealed that the EA process quality is a key independent variable requiring attention to increase the EA quality and, consequently, enhance organizational benefits.

To improve the EA process quality, four distinct EA levels were identified in Section 5.2. These levels correspond to four different EA purposes and have been linked to matching business levels identified in the case study. Based on these levels, an EA process model has been designed in Section 5.3. This model specifies the desired types of the six EA artifacts types across the different levels. Additionally, the model defines the relations between (the artifacts across) the different levels. This EA process model supports the organization to create valuable EA artifacts and services that align with business needs.

Within one of the defined levels, namely the domain, a need was identified for an architecture artifact and service that supports the development of flexibility products. Chapter 6 presents the application of the EA benefit realization framework, used to answer **RQ4**. Based on information acquired in expert interviews with both architecture creators and users, an appropriate benefit mechanism, service and artifact have been defined. EA can contribute significantly through resource portfolio optimization, the most appropriate artifact for this benefit mechanism is found to be a product reference capability model. To answer **RQ5**, this capability map has been designed, presented in Section 6.5. This EA artifact shows the capabilities required to operate a flexibility product, which can help in the PLM process to guide capability developments, assess IT impact and helps to make appropriate investments.

To answer **RQ6**, the EA process model and the product reference capability map have been validated with experts, as discussed in Chapter 7. In this validation, the EA benefit realization framework was used to show experts the focus of, this research. This framework, designed to gather insight in the EA benefit realization process, had been created as a prerequisite for this research, in order to visualize how EA can contribute to the flexibility products. However, the experts indicate, the model itself could be of value in the EA discipline in the company, it could help the architects in defining the intended benefits for an EA artifact or service, improving the alignment of EA with organizational goals. In the validation of the EA process model, architects reflected on the EA artifacts categories linked to the identified EA levels, this led to the desire of overlap between the artifacts, for which a redesign was presented. The product reference capability map is validated with input gathered from architecture creators as well as its users, showing a high degree of usefulness of the artifact, but only if delivered with an appropriate EA service. To conclude the validation, the generalizability of this research is assessed by validating the primary research outcomes with external experts, highlighting promising first effects the artifacts can offer to other grid operators.

By answering all the research questions, this research managed to answer the main research question. With the EA process model, the DSO can ensure that valuable EA is created that supports decision making in every level of the organization. The model shows that EA, on the domain level, has to be able to support the development of flexibility products. With the development of the product reference capability map, the development of flexibility products can be supported. These developments results in an increase the flexibility in the distribution grid, consequently increasing the grid utilization, therefore, supporting the DSO in facilitating the energy transition.

8.2 Scientific contribution

The section discusses the main scientific contributions of this work and thereby describes the insights to academia, which can serve as a foundation for future works.

8.2.1 EA benefit realization insights

In the literature review about EA (Section 3.1), several different studies were found that describe the EA benefit realization process [57, 59, 62, 72, 84]. These studies explained how EA manifests itself into organizational benefits, focusing on either variables in the creation of EA, or in the usage of EA. In these studies, many of EA benefit mechanisms are described. As also mentioned in these studies, there is no shared view on the process of EA benefit realization. Also, existing studies about EA benefit realization define standardized sets of organizational benefits from EA (e.g., reduced IT costs), limiting the option to visualize the contribution of EA to other organizational goals, such as increased sales, or, in the case of this research, the development of flexibility products.

The lack of a usable generic model that provided insights in how EA can contribute to business goals, prevented the answering of the research question, because we could gather no insight in the process of EA contributions to the development of flexibility products. This research proposes an EA benefit realization framework in Section 5.1, which provides a comprehensive process flow from EA quality through to organizational benefits. In this model, the primary constructs found in the literature studies about EA benefit realization are exploited, complemented with inputs gathered in interviews. This model contributes to science by giving academia a framework in which they can assess the primary constructs in the EA benefit realization process. It can be used to assess the impact of EA on organizational goals, and assess the performance of EA.

8.2.2 Complete overview of EA function and deliverables

Existing literature (Section 3.1) has focused either on the EA process, without linking it with the content to be produced in this process [71, 73], or, focused solely on the artifacts without explaining which processes result in these artifacts [76, 78]. Consequently, there is limited guidance on which EA artifacts are most valuable at specific places in an organization. A recent study from Kotusev et al. [108] also identified a gap in literature providing meaningful answers relevant to the EA function in organizations. As a response, this study aims to structure the EA function and specifies design options of the EA function in organizations. However, it does not provide information about the content of EA (the artifacts), which the study recognizes to be an essential aspect of EA.

This research addresses these literature gaps by identifying four different (purpose) levels of EA in Section 5.2, and provides artifact categories that are valuable at these levels. The EA process model therefore ensure EA teams deliver relevant artifacts, matching with their purpose (service and benefit mechanism), as described in Section 5.3. This EA process model has been validated (Section 7.2) with experts, which, after a redesign, ensured valuable EA could be created in every level of the organization.

8.2.3 Product architecture

As identified in the literature about EA trends (Section 3.1.7), architectures from a product perspective are increasing in popularity. However, the literature review (Section 3.1) provided no specific scientific studies showing how Enterprise Architecture can contribute to the development of products. Products tend to be treated as outcomes of projects or business processes, not as explicit architecture focal points.

This research defines a thorough overview about how EA can contribute to the development of flexibility products in Chapter 6. By developing a product reference capability map the building blocks of a product were made insightful. After these capabilities have been linked with realization elements, this approach can result in a holistic overview showing product developers all business, data, application and technology elements related to a product. In this research the product is an energy connection agreement, but the same approach could be used for the development of other products.

8.3 Practical contribution

This section discusses the main contributions of this work to practice, and how this thesis produced value for Alliander.

8.3.1 Improved insight in EA benefits

The EA benefit realization model (Figure 5.1) has practical contributions as well, which were raised in the validation interviews with architecture experts, as described in Section 7.3. The model was created only to visualize how EA can contribute to the development of flexibility products, but can be used to assess how EA can contribute to other organizational goals (operational, tactical or strategic). In this process, the organization can use this model to track the benefits created by EA, to assess which EA elements need to be improved, and as communication tool to show how EA produces strategic value.

8.3.2 Improved EA governance

The EA process model proposed in this research (Section 5.3) can be used by organizations to shape their EA governance. The model prescribes EA levels, roles and responsibilities and links them with valuable EA artifacts to execute these responsibilities. In the model (more specifically Figure 5.3), the interactions between EA artifacts are shown, which are vital to ensure the consistency of the EA. The multi-tiered governance structure improves coordination between strategic planners on enterprise level and operational solutions on project or operational level, reducing misalignment and decision conflicts.

8.3.3 Well defined EA artifacts

In the EA process model, well defined EA artifact types have been shown on the different levels. These EA artifacts can provide several benefits for the EA within the company. First of all, this increases the re-usability of architectural artifacts such as reference models, solution designs and standards. Secondly, this improves the consistency across projects, ensuring that all architectural decisions and documentation follow a consistent format, delivering value to the organization and improving alignment between the defined domain, project and department level.

Furthermore, in some of the interviews conducted for this research, it was identified that stakeholders are sometimes unaware of how they can benefit from EA. This can be explained by the stakeholders not knowing what they can expect from the EA function in the company. This has been confirmed with interviews with architects, who indicate that there is no well defined set of EA artifacts, and that artifacts are tailored for specific purposes. This study provides a desired set of artifact types that are valuable in different levels of the organization. This can help the stakeholders in knowing what (artifacts and services) to expect from EA.

8.3.4 Improved product development

One of the interview outcomes with PLM stakeholders was the struggle to find the responsible department for the development of a capability. The designed capability map, with its defined services, makes it possible for the organization to define capability owners. This would make the capability map useful in the development of capabilities for a product. To ensure the generalizability of the capability map, these capability owners have not been defined in this research. Another important practical contribution of the capability map is the insights in the product 'building blocks', which is currently lacking. This offers the organization a clear overview of all the capabilities related to a flexibility product, and could help with identifying capability gaps, and increases the re-use of existing capabilities. The product capability map can be used for several secondary purposes such as application lifecycle- and costs assessments, as described in Section 6.5.6.

8.4 Limitations

From the scientific and practical point of view, this research achieved crucial results to support the DSO, specifically in the development of the flexibility products, by using Enterprise Architecture. Despite its approach and significant contributions, several limitations of this research must be acknowledged.

Generalization

This research has been executed at a specific DSO, namely Alliander. This limits the generalizability of this research. Sensitivity checks conducted during validation suggested that the designed artifacts and conclusions are likely relevant to other DSOs in the Netherlands, because of similar regulatory landscapes and use of the NBility standard, confirmed by validating the findings with an architect working for another Dutch DSO. Broader applicability across Europe is only evaluated with one stakeholder, although this showed promising first results, little can be said about the applicability of the research in other European DSOs. Involving experts from additional DSOs, especially those operating in different regulatory or organizational environments, would enhance the validity and generalizability of the research. However, based on the information gathered from, the research findings are expected to be similar.

Validation

Due to the limited time frame of this research it has been validated with a limited number of experts. From the validation interviews could be identified that every expert has a different opinion about how architecture can optimally support the DSO. While this diversity of opinions is valuable, it also indicates that further validation is needed to refine the proposed models and ensure their usability across different stakeholder groups. To improve the models further, and ensure the usability for every stakeholder, the EA process model (Section 5.3) and product reference capability map (Chapter 6), should be validated with more experts.

Domain bias

This research has been conducted in the BBN architecture group of Alliander. Therefore, the research is prone to bias. This architecture group (later classified as being domain level) supports the BBN value chain and is currently the only architecture group in the company specifically focusing on a value chain. To prevent the research becoming biased for the domain level architecture, many stakeholders were involved in the research outside of this architecture group. However, to fully ensure that the research is not biased, the same research should be conducted in other groups within different architecture levels, involving enterprise-wide and project-specific architecture functions.

Security architecture

While this research provides a structured overview of the Enterprise Architecture process and its artifacts, it does not explicitly address the roles of security and data architecture. These disciplines are essential components of a holistic EA function. It is expected that, security and data architecture will play a role in each of the identified EA levels.

8.5 Future research

By acknowledging the limitations, this research sets the stage for further improvement. Addressing these limitations through targeted research efforts can enhance the artifact robustness, applicability, and value in guiding the DSO through the energy transition.

SGAM scope expansion

The research scope included the SGAM enterprise and operation zones, and the SGAM distribution, DER and customer premises domains. The research therefore did not focus on the transmission grid, and the transmission system operation (TSO). However, TSOs are facing similar issues as DSOs, but in their high voltage grid. TSOs are similarly confronted with grid congestion, and also have to increase flexibility in their grid. Therefore, future research should assess the extent in which the results of this research are applicable for the TSO. This could further facilitate the energy transition, improving the entire national and European grid utilization, and not only the DSOs' medium/low voltage grid.

Elaborate artifact types

In the EA process model, six artifacts types were used, as initially categorized by Kotusev, Kurnia, and Dilnutt [75]. Every artifact type includes several different EA artifacts. It would be valuable for further research to assess in more detail which artifacts are categorized in these types, to answer which artifacts produce the desired effect on the different levels. This would increase the application span of the EA benefit realization framework, which in this research has only been used to find an artifact that could enhance the development of flexibility products.

Intention to use

In the designed benefit realization framework, the importance of intention to use was acknowledged. For EA to achieve the desired effects, this intention to use must be present. Otherwise, regardless of the quality of the artifacts created in this research, the desired EA results will probably not be achieved. It would be valuable for future research to focus specifically on the EA intention to use construct, which could increase the benefits that can be derived from EA. This work could identify cultural, structural, or incentive-related factors that influence EA adoption and effectiveness within DSOs and similar organizations

Business solutions

As identified and described multiple times in this research, currently, there is no clear architectural overview of all the business solutions in the company of the case study. According to the EA process model, the design of these business solution artifacts, is the responsibility of EA on operational level. The architects on this level (solution architects within the company) should be encouraged to make the solution designs available. Without these artifacts it is impossible to create landscape type artifacts (required on domain level according to the EA process model), and to fully utilize the designed capability map. It would be valuable for future work to ensure the availability of solution designs.

EA repository design

In the research, it became apparent that there is a need for centralized information about a variety of topics, including EA and flexibility products. Stakeholders indicate that the information produced by EA is sometimes scattered in multiple sources. Therefore, it is valuable for further research to focus on the design of an EA repository in which all architectural information and decisions are stored in a easy to use and accessible way.

NBility improvements

In the interview sessions, some of the architects pointed out their dissatisfaction with NBility. They claimed that the idea behind a business capability model for DSOs is valuable, but the capabilities NBillity provides are not sufficient in describing all business activities of the DSO of this study. It is indicated that the capabilities describe the traditional DSO, but not the DSO that is executing congestion management. Further research should identify all capabilities in different DSOs and compare them with available capabilities in NBility.

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Appendix A

An overview of EA artifacts

This appendix shows the identified EA artifacts in more detail. Three different tables were used in this research to find desired EA artifacts for a purpose: (1) Table A.1 shows the EA artifacts related to the six identified categories, Table A.2 describes commonly seen EA artifacts in more detail, and (3) Table A.3 shows EA artifacts as identified in TOGAF.

Type	**Related EA artifacts identified in organizations**	**Explanation**
Considerations	Core drivers, data models, maxims, policies, principles, strategic papers and strategy papers	All these EA artifacts provide some general considerations defining global architectural decision-making
Standards	Data schemas, IT principles, patterns, principles, reference architectures, standards, technology reference model	All these EA artifacts provide some technical standards influencing the designs of all information systems
Visions	Blueprints, capability models, business reference architectures, roadmaps, enterprise investment roadmap, function roadmaps, process model	All these EA artifacts provide some visions of the long-term future agreed by business and IT stakeholders
Landscapes	Asset register, inventories, one-page diagrams, platform architectures, platform roadmaps, reference architectures, technology blueprints and roadmaps	All these EA artifacts provide some views of the organizational IT landscape from the technical perspective
Outlines	Blueprints, conceptual architectures, idea briefs, key design decisions of SOs, solution overviews and solutions on a page	All these EA artifacts provide some brief outlines of proposed IT initiatives
Designs	Detailed designs, full solution architectures, high-level designs, key design decisions, preliminary solution architectures, solution blueprints and solution designs	All these EA artifacts provide some technical designs of proposed IT solutions

Table A.1: EA artifacts related to the six general types [75]

EA artifact	Informational contents	Practical Usage	Key Purpose
Solution Designs	Detailed technical and functional specifications of approved IT solutions (2̃5–50 pages)	Developed collaboratively by architects and project teams at implementation stages, archived after use	Improve solution quality and ensure traceability of business and architectural requirements
IT Roadmaps	Structured graphical views of all planned IT initiatives in specific business areas	Created by architects and senior business leaders to prioritize and schedule IT investments	Improve alignment between business strategy and IT investments
Technology Reference Models	Graphical representations of all technologies used in an organization	Used by architects and experts to select appropriate technologies and update standards	Enhance technological consistency and reduce IT complexity
Principles	High-level guidelines for decision-making and planning	Collaboratively formulated and used to assess architectural decisions	Ensure consistency between business and IT
Business Capability Models	Structured representations of business capabilities and hierarchy	Used for aligning IT investments with strategic business capabilities	Improve business-IT alignment and prioritization
Guidelines	IT-specific implementation standards for technology domains	Established by architects and experts to ensure best practices	Reduce technical complexity and facilitate best practice adoption
Solution Overviews	High-level descriptions of proposed IT solutions (1̃5–30 pages)	Developed at early IT stages to approve and assess impact before implementation	Enhance transparency of IT solutions and facilitate approvals
Landscape Diagrams	Graphical representations of IT infrastructure and system interactions	Used for planning new IT solutions and integrations	Help architects analyze and modify IT landscape
IT Roadmaps	Graphical views of planned IT initiatives with a technical focus	Used to plan technical improvements with minimal business impact	Reduce legacy dependencies and enhance IT efficiency
Inventories	Catalogs of IT assets describing their properties and features	Used to manage, reuse, and decommission IT assets	Improve asset control and lifecycle management
Patterns	Reusable IT solutions for common design problems	Used to standardize IT architectures and mitigate risks	Increase consistency and reduce heterogeneity in IT designs

EA artifact	Informational contents	Practical Usage	Key Purpose
IT Principles	High-level IT guidelines for decision-making	Used to ensure consistent IT planning and feasibility checks	Promote consistent IT approaches and standardization
Options Assessments	Lists of available IT implementation options with pros/cons	Used at early IT initiative stages to discuss and evaluate options	Improve IT-business engagement and solution transparency
Target States	High-level graphical descriptions of desired future IT states	Defines long-term IT investment goals, updated as strategy changes	Facilitate IT-business strategic alignment
Enterprise System Portfolios	High-level mappings of IT systems to business capabilities	Used to rationalize IT landscape and manage assets	Control IT asset duplication and improve efficiency
Policies	Organizational norms and compulsory IT prescriptions	Used to ensure compliance with security and governance standards	Enhance security, compliance, and consistency
Initiative Proposals	Early-stage descriptions of IT initiatives	Used for evaluating business potential before full approval	Support early-stage IT investment decisions
Preliminary Solution Designs	Early high-level technical and functional designs (20–40 pages)	Created before implementation for validation and approval	Ensure feasibility and alignment with earlier approvals
Conceptual Data Models	Abstract definitions of key business data entities	Used to align IT solutions with enterprise-wide data needs	Improve global data consistency and information handling
Direction Statements	Strategic organization-wide decisions with far-reaching impact	Used to guide IT-related planning decisions	Maintain consistency between business and IT directions
Logical Data Models	Platform-specific logical definitions of key data structures	Used to define appropriate data structures for IT systems	Improve data interoperability and consistency
Analytical Reports	Executive-level technology trend analyses	Used for assessing new technology impacts on business	Align IT strategy with emerging technology trends
Context Diagrams	High-level descriptions of current operational flows	Used for strategic IT discussions and investment planning	Provide a common framework for business-IT discussions
Value Chains	Graphical representations of value-adding business processes	Used for strategic IT investment focus	Align IT with core business functions

EA artifact	Informational contents	Practical Usage	Key Purpose

Table A.2: Commonly used EA Artifacts [77]

Artifact	Description
Architecture Principles	Principles are general rules and guidelines, intended to be enduring and seldom amended, that inform and support the way in which an organization sets about fulfilling its mission.
Architecture Repository	The Architecture Repository acts as a holding area for all architecture-related projects within the enterprise. The repository allows projects to manage their deliverables, locate re-usable assets, and publish outputs to stakeholders and other interested parties.
Business Principles, Business Goals, and Business Drivers	Business principles, business goals, and business drivers provide context for architecture work, by describing the needs and ways of working employed by the enterprise.
Organizational Model for Enterprise Architecture	In order for an architecture framework to be used successfully, it must be supported by the correct organization, roles, and responsibilities within the enterprise.
Request for Architecture Work	This is a document that is sent from the sponsoring organization to the architecture organization in order to trigger the start of an architecture development cycle.
Tailored Architecture Framework	Tailoring at this level will select the appropriate deliverables and artifacts to meet project and stakeholder needs.
Architecture Change Request	In the case where the original Architecture Definition and requirements are not suitable or are not sufficient to complete the implementation of a solution, a Change Request may be submitted in order to kick-start a further cycle of architecture work.
Requirements Impact Assessment	A Requirements Impact Assessment assesses the current architecture requirements and specification to identify changes that should be made, and the implications of those changes.
Compliance Assessment	Once an architecture has been defined, it should be governed through implementation in order to ensure that the original Architecture Vision is appropriately realized, and that any implementation learning is fed back into the architecture process.
Solution Building Blocks	Implementation-specific building blocks from the enterprise's Architecture Repository.
Architecture Building Blocks	Architecture documentation and models from the enterprise's Architecture Repository.
Architecture Contract	Architecture Contracts are the joint agreements between development partners and sponsors on the deliverables, quality, and fitness-for-purpose of an architecture.
Implementation Governance Model	Once an architecture has been defined, it is necessary to plan how the Transition Architecture that implements the architecture will be governed through implementation.
Implementation and Migration Plan	The Implementation and Migration Plan provides a schedule for the implementation of the solution described by a Transition Architecture. The Implementation and Migration Plan includes timing, cost, resources, benefits, and milestones for the implementation.

Artifact	**Description**
Transition Architecture	A Transition Architecture shows the enterprise at incremental states that reflect periods of transition that sit between the baseline and target architectures.
Architecture Definition Document	The Architecture Definition Document is the deliverable container for the core architectural artifacts that are created during a project.
Architecture Requirements Specification	The Architecture Requirements Specification provides a set of quantitative statements that outline what an implementation project must do in order to comply with the architecture.
Architecture Roadmap	The Architecture Roadmap lists individual increments of change and lays them out on a timeline to show progression from the baseline architecture to the target architecture.
Architecture Vision	The Architecture Vision is created early on in the project lifecycle and provides a high-level, aspirational view of the end architecture product.
Capability Assessment	Before embarking upon a detailed Architecture Definition, it is valuable to understand the baseline and target capability level of the enterprise.
Communications Plan	Enterprise architectures contain large volumes of complex and interdependent information. The effective communication of targeted information to the right stakeholders at the right time is a critical success factor for enterprise architecture.
Principles Catalog	The Principles catalog captures the business and architecture principles that describe what a "good" solution or architecture should look like.
Location Catalog	The Location catalog provides a list of all locations where an enterprise carries out business operations or houses architecturally relevant assets.
Application Portfolio Catalog	The purpose of the Application Portfolio catalog is to identify and maintain a list of all the applications in the enterprise.
Technology Standards Catalog	The Technology Standards catalog documents the agreed standards for technology across the enterprise, covering technologies, versions, and lifecycle details.
Requirements Catalog	The Requirements catalog captures things that the enterprise needs to do to meet its objectives.
System/Technology Matrix	The System/Technology matrix documents the mapping of business systems to the technology platform.
Value Chain Diagram	A Value Chain diagram provides a high-level orientation view of an enterprise and how it interacts with the outside world.
Functional Decomposition Diagram	The purpose of the Functional Decomposition diagram is to show on a single page the capabilities of an organization relevant to an architecture.
Project Context Diagram	A Project Context diagram shows the scope of a work package to be implemented as part of a broader transformation roadmap.
Benefits Diagram	The Benefits diagram shows opportunities identified in an architecture definition, classified according to their relative size, benefit, and complexity.

Table A.3: EA artifacts according to TOGAF [76]

Appendix B

Smart Grid Architecture Model

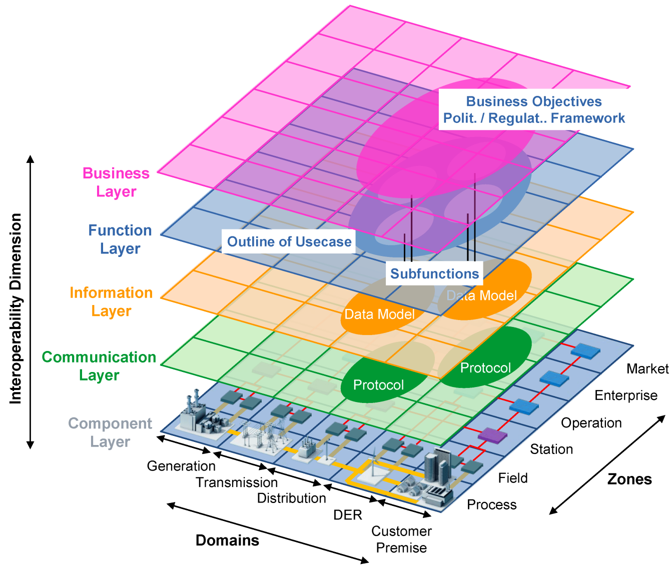


Figure B.1: Smart Grid Architecture Model [63]

Zone	Description
Process	Involves physical transformations of energy, including equipment such as generators, transformers, and sensors, directly involved in the energy processes.
Field	Contains equipment used for protecting, controlling, and monitoring the energy process, such as protection relays and intelligent electronic devices.
Station	Represents the level for aggregating data from the field, enabling local automation and control, including substations and SCADA systems.
Operation	Manages power system control operations for domains, involving systems like Distribution Management Systems (DMS) and Energy Management Systems (EMS), microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Encompasses organizational and commercial processes, including asset management, workforce management, and customer relations.
Market	Addresses market operations along the energy chain, such as energy trading, retail, and demand response management.

Table B.1: SGAM Zones [63, 64]

Domain	Description
Bulk Generation	Refers to large-scale power generation, such as fossil fuel plants, nuclear power, hydroelectric, and large-scale renewables typically connected to transmission systems.
Transmission	Involves the infrastructure and organizations responsible for long-distance electricity transportation.
Distribution	Covers the infrastructure and organization involved in electricity distribution to end-users.
DER (Distributed Energy Resources)	Represents small-scale energy resources, often directly connected to the distribution grid, and includes solar PVs, micro-turbines, and small wind farms.
Customer Premises	Encompasses end-user facilities, including industrial, commercial, and residential sites with potential for electricity generation, storage, and load management.

Table B.2: SGAM Domains[63, 64]

Layer	Description
Business Layer	Reflects the business models, regulatory policies, and economic interactions for decision-making at the market level, supporting stakeholders like regulators and executives.
Function Layer	Defines functions and services from an architectural viewpoint, representing use case functions independent of actors and physical systems.
Information Layer	Describes the information exchange between functions, including data models and semantic consistency to enable interoperable information exchange.
Communication Layer	Specifies protocols and methods for reliable information exchange between components, supporting network interoperability.
Component Layer	Focuses on the physical distribution of components in the grid, including hardware like transformers, relays, routers, and computers in the smart grid environment.

Table B.3: SGAM Interoperability Layers[63, 64]

Appendix C

Systematic literature review

C.1 Search queries

According to the defined synonyms, queries have been created for the different libraries. The queries are shown in Table C.1

ACM	("Distribution System Operator" OR "DSO" OR "Grid Operator" OR "Network Operator" OR "System Operator" OR "Distribution Network Operator") AND ("Digital Architecture" OR "Information architecture" OR "Data architecture"OR"Smart Grid Architecture" OR "IT Architecture" OR "Enterprise Architecture" OR "Information Systems Architecture" OR "Application Architecture" OR "Business Architecture" OR "Process Architecture" OR "Communication Architecture" OR "TOGAF") AND ("Energy transition" OR "Smart Grid" OR "Intelligent Grid" OR "Smart Energy System" OR "Energy Management" OR "Demand Side Management" OR "Demand Response" OR "Flexibility")
IEEE	(("Distribution System Operator" OR "DSO" OR "Grid Operator" OR "Network Operator" OR "System Operator" OR "Distribution Network Operator") AND ("Digital Architecture" OR "Smart Grid Architecture" OR "IT Architecture" OR "Enterprise Architecture" OR "Information Systems Architecture" OR "Application Architecture" OR "Business Architecture" OR "Process Architecture" OR "Communication Architecture" OR "TOGAF" OR "Information architecture" OR "Data architecture") AND ("Energy transition" OR"Smart Grid" OR "Intelligent Grid" OR "Smart Energy System" OR "Energy Management" OR "Demand Side Management" OR "Demand Response" OR "Flexibility"))
Web of Science	TS=("Distribution System Operator" OR "DSO" OR "Grid Operator" OR "Network Operator" OR "System Operator" OR "Distribution Network Operator") AND TS=("Digital Architecture" OR "Smart Grid Architecture" OR "IT Architecture" OR "Enterprise Architecture" OR "Information Systems Architecture" OR "Application Architecture" OR "Business Architecture" OR "Process Architecture" OR "Communication Architecture" OR "TOGAF") AND TS=("Energy transition" OR "Smart Grid" OR "Intelligent Grid" OR "Smart Energy System" OR "Energy Management" OR "Demand Side Management" OR "Demand Response" OR "Flexibility")
Scopus	TITLE-ABS-KEY ("Distribution System Operator" OR "DSO" OR "Grid Operator" OR "Network Operator" OR "System Operator" OR "Distribution Network Operator") AND TITLE-ABS-KEY ("Digital Architecture" OR "Smart Grid Architecture" OR "IT Architecture" OR "Enterprise Architecture" OR "Information Systems Architecture" OR "Application Architecture" OR "Business Architecture" OR "Process Architecture" OR "Communication Architecture" OR "Data architecture" OR "Information architecture" OR "TOGAF") AND TITLE-ABS-KEY ("Energy transition" OR "Smart Grid" OR "Intelligent Grid" OR "Smart Energy System" OR "Energy Management" OR "Demand Side Management" OR "Demand Response" OR "Flexibility")

Table C.1: Search queries

C.2 Eligibility assessment

In Table C.2 all the papers are mentioned that got through the screening. These papers have been assessed according to the four quality criteria.

Title	**Author(s)**	**1**	**2**	**3**	**4**	**Ref.**

Title	**Author(s)**	**1**	**2**	**3**	**4**	**Ref.**
"CIM, 61850, COSEM Standards Used in a Model Driven Integration Approach to Build the Smart Grid Service Oriented Architecture"	Brédillet, Lambert, and Schultz (2010)	N	N	N	Y	-
"EcoGrid EU — A prototype for European Smart Grids"	Jørgensen et al. (2011)	N	N	Y	Y	-
"Communication infrastructure for emerging transmission-level smart grid applications"	Dong and Kezunovic (2011)	N	N	N	Y	-
"Information standards to support application and enterprise interoperability for the smart grid"	Hargreaves, Taylor, and Carter (2012)	Y	Y	Y	Y	[102]
"Prosumer management in socio-technical smart grid"	Rathnayaka, Potdar, and Ou (2012)	Y	Y	Y	Y	[91]
"Realization of smart grid employing powerrouter"	Gopakumar et al. (2012)	N	N	Y	N	-
"Smart Grid Architecture Model use case management in a large European Smart Grid project"	Trefke et al. (2013)	Y	Y	Y	Y	[67]
"Multi domain information architecture and modeling for Smart Grids"	Chandra-Sekaran, Wiesmaier, and Hessler (2013)	Y	N	Y	Y	-
"Assessment and outlook of the opennode smart grid architecture"	Leménager et al. (2013)	N	N	Y	Y	-
"A communication architecture for power routing in the smart grid"	Bouhafs, Merabti, and Hardy (2013)	Y	N	Y	Y	-
"Towards consistent smart grid architecture tool support: From use cases to visualization"	Neureiter et al. (2014)	N	N	Y	Y	-
"Scope of electrical distribution system architecture considering the integration of renewable energy in large and small scale"	Tobar, Ul Banna, and Koch-Ciobotaru (2014)	N	N	N	Y	-
"SGAM-based methodology to analyse Smart Grid solutions in DISCERN European research project"	Santodomingo et al. (2014)	N	N	Y	N	-
"A Review of Architectures and Concepts for Intelligence in Future Electric Energy Systems"	Strasser et al. (2015)	Y	Y	Y	Y	[94]
"Smart Grid Architecture Based on Active Demand Approach"	Antolić et al. (2016)	Y	Y	Y	Y	[100]
"Enabling the Integrated Grid: Leveraging Data to Integrate Distributed Resources and Customers"	McGranaghan et al. (2016)	Y	Y	Y	Y	[96]
"Enabling European electrical transmission and distribution smart grids by standards"	Reinprecht, White, and Peters (2016)	N	N	Y	N	-
"Agent based communication architecture for smart grid"	Siddappa, Prakash, and Sridhar (2016)	Y	Y	Y	Y	[103]
"An executable model driven framework for enterprise architecture application to the smart grids context"	Seghiri et al. (2016)	Y	Y	Y	Y	[93]
"Smart grid architecture model standardization and the applicability of domain language specific modeling tools"	Wilker, Meisel, and Sauter (2017)	Y	N	Y	Y	-
"Enabling novel smart grid energy services with the nobel grid architecture"	Piatkowska et al. (2017)	Y	Y	Y	Y	[99]
"Combination of standards to support flexibility management in the smart grid, challenges and opportunities"	Elshaafi et al. (2017)	N	N	Y	N	-
"Smart Grid Architecture, Communications and Data Model: The WiseGRID approach"	Stratogiannis and Gkiala-Fikari (2018)	Y	N	Y	N	-
"A Resilient Architecture for the Smart Grid"	Lopez, Rubio, and Alcaraz (2018)	N	N	N	N	-
"ICT Requirements and challenges for provision of grid services from renewable generation plants"	Shahid et al. (2018)	N	N	N	Y	-
"Analyzing an Agile Solution For Intelligent Distribution Grid Development: A Smart Grid Architecture Method"	Babar and Nguyen (2018)	Y	Y	Y	Y	[92]
"System architecture for customer-led distribution system"	Kong et al. (2018)	Y	Y	Y	Y	[101]

Title	Author(s)	1	2	3	4	Ref.
"SGAM-Based Comparative Study of Interoperability Challenges in European Flexibility Demonstrators: Methodology and Results"	Kupzog et al. (2018)	N	N	Y	Y	-
"Applied Internet of Things Architecture to Unlock the Value of Smart Microgrids"	Gonzalez et al. (2018)	Y	N	Y	Y	-
"CIM-based integration in smart grids: Slovenian use cases"	Souvent, Kodek, and Suljanović (2019)	N	N	Y	Y	-
"Flexible Platform for the Study and Testing of Smart Energy Systems Enabling-Technologies"	Iosif Ciontea et al. (2020)	N	N	Y	N	-
"Representing Decision-Makers in SGAM-H: The Smart Grid Architecture Model Extended with the Human Layer"	Szekeres and Snekkenes (2020)	N	N	N	Y	-
"A Novel Methodology for the Scalability Analysis of ICT Systems for Smart Grids Based on SGAM: The InteGrid Project Approach"	Menci et al. (2020)	N	N	Y	N	-
"On the Use of Common Information Model for Smart Grid Applications-A Conceptual Approach"	Shahid et al. (2021)	N	N	Y	Y	-
"Distribution Control Centers in the US and Europe: Commonalities, Differences, and Lessons"	Vadari et al. (2022)	N	N	Y	N	-
"Technological Architecture Design for Energy Communities: The Colombian Case"	Molina et al. (2022)	N	N	Y	N	-
"On an Information and Control Architecture for Future Electric Energy Systems"	Xie et al. (2022)	N	N	N	N	-
"Perspectives on Future Power System Control Centers for Energy Transition"	Marot et al. (2022)	Y	Y	Y	Y	[97]
"The (still unexplored) social side of smart grid development: towards a social layer for the smart grid architecture model (SGAM)"	Paustian et al. (2022)	N	Y	Y	Y	-
"Transmission and Distribution Systems Coordination using the Design Structure Matrix"	Ayad and Bouffard (2023)	N	N	N	Y	-
"Smart Framework to Study Energy Transition in the Electric Grid"	Palahalli et al. (2023)	N	N	N	Y	-
"FLEXGRID – A novel smart grid architecture that facilitates high-RES penetration through innovative flexibility markets towards efficient stakeholder interaction"	Efthymiopoulos et al. (2023)	N	Y	Y	Y	-

Table C.2: SLR quality assessment

Citation searching in the papers assessed (Table C.2) resulted in four more papers that were included in the study, shown in Table C.3.

Title	Author(s)	1	2	3	4	Ref.
"Smart Transmission Grid: Vision and Framework"	Li et al. (2010)	Y	Y	Y	Y	[98]
"Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads"	Palensky and Dietrich (2011)	Y	Y	Y	Y	[95]
"Towards a Model-Driven-Architecture Process for Smart Grid Projects"	Dänekas et al. (2014)	Y	Y	Y	Y	[90]
NIST framework and roadmap for smart grid interoperability standards, release 4.0	Gopstein et al. (2021)	Y	Y	Y	Y	[112]

Table C.3: Citation searching result

Appendix D

EA activities in the different levels

Table D.1 shows the different EA activities performed in the enterprise, domain, project and operational EA levels.

Level	Responsibilities	Feed-Forward (F/I)	Feedback (F/I)
Enterprise	EA Decision Making EA Delivery	Validate EA conformance domain(F) Provide EA guidance and support for domain (I)	Handle domain escalations and requests (F) Use feedback to maintain EA products (I) Use operational knowledge and data in EA decisions (I)
Domain	EA Decision Making EA Delivery EA Conformance	Conform to enterprise EA products (F) Validate project and operational EA conformance (F) Utilize and provide support in applying the EA products (I)	Handle project and operational escalations and requests (F) File EA requests towards enterprise Improve domain EA products (F) Use and provide feedback to maintain EA products (I) Use operational knowledge and data in EA decisions (I)
Project	EA Conformance	Conform to domain EA (F) Utilize support in applying EA and deploying project (I)	Escalate project-level EA exceptions (F) Use operational expert knowledge to run project Provide feedback on new EA products (I)
Operational	EA Conformance	Conform to domain EA products (F) Support deploying project results (I)	Escalate operational EA exceptions (F) Provide real-world insights for EA improvement (I)

Table D.1: EA functions, activities, and processes (adopted from [71])

Appendix E

NBility capability model

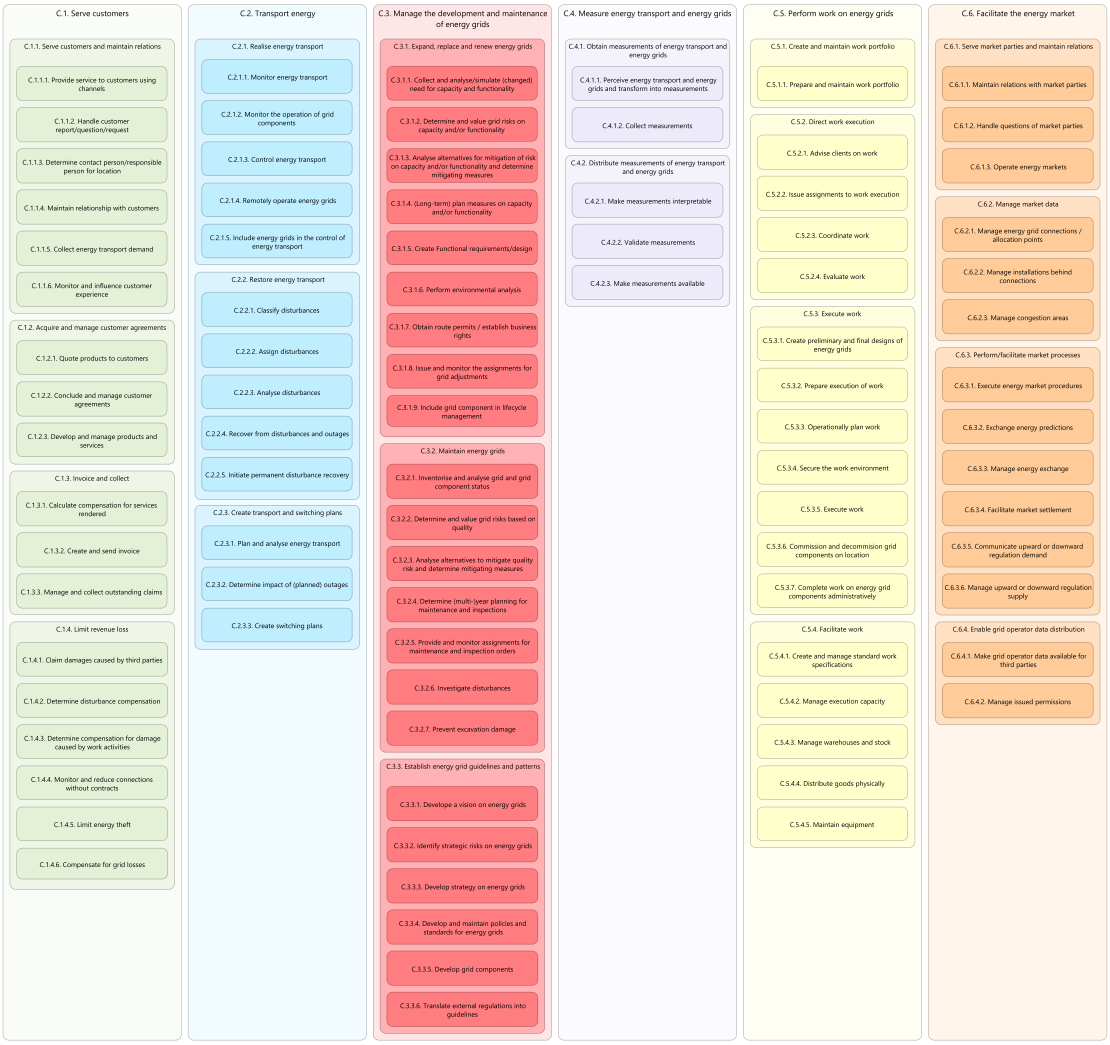


Figure E.1: NBility core capabilities level 3

Appendix F

Interview questions

If the interviewee was Dutch speaking, the questions were asked in Dutch.

F.1 Architects interview

Introduction

1. I introduce myself to the interviewee
2. Explain the main research question of my thesis, and the purpose of the research
3. Explain the purpose of this interview
4. Ask for consent to use this interview as input for my research, also indicated in the mail sent to the interviewees

EA quality

1. Literature shows us three primary EA quality aspects **Show the model from Figure 5.1**. Could you elaborate on these variables, which one do you think we should focus upon?

Architecture function

1. The organization wants to work in end-to-end value chain, in your opinion, how does this affect EA within Alliander?
2. Do you think there are well established roles (e.g. enterprise-, business-, solution architecture funtions) that realize EA processes and products?
3. Based on these responses, a conversation is carried out about the EA function within the company

EA benefits

1. **Show participant list of seven benefit enablers** These are the found EA benefit realization mechanisms. Could you indicate your top 3
2. In the design of architectural artifacts, do you consider the benefits the artifact aims to achieve?

Architecture for flexibility products

1. Could you show me an architectural artifact that shows a flexibility product, and all its relations, such as applications and data elements?
2. Do you think architecture is currently supporting the development of flexibility products?

F.2 Flexibility product developers interview

Introduction

1. I introduce myself to the interviewee
2. Explain the main research question of my thesis, and the purpose of the research
3. Explain the purpose of this interview
4. Ask for consent to use this interview as input for my research, also indicated in the mail sent to the interviewees

PLM process

1. Could you briefly explain the PLM process
2. Which stakeholders are involved in the development of flexibility products.
3. What are the biggest challenges you face in the development of flexibility products
4. What application(s), or other tools are used in the PLM process?

Information need

1. Could you inform me about the information you need in the development of a flexibility product?
2. Is the needed information always available for you?

Product capabilities

1. How do you find out which are required capabilities (building blocks, functionalities)
2. how do you ensure the required capabilities are established?

Product architecture

1. I introduce what I'm aiming to produce in my research, do you think an artifact like this could be useful in the PLM process?

Appendix G

Validation questions and presentation

G.1 External expert validation interview structure

Introduction

1. I introduce myself to the interviewee
2. Explain the main research question of my thesis, and the purpose of the research
3. Explain the purpose of this interview
4. Ask for consent to use this interview as input for my research, also indicated in the mail sent to the interviewees
5. Ask the interviewee if he/she could briefly introduce

Architecture within the company

1. Which architecture roles are defined in your organizations, could you briefly explain them in terms of focus points and responsibilities?
2. Do you think these architecture roles are well defined? Are they impacted by the results of the energy transition?
3. How does your organization ensure it creates value with EA (and thus, that EA is matching with business needs and contributing to business goals)?
4. Are you aware of the EA benefit realization process?

EA benefit realization framework Show and explain the interviewee the EA benefit realization framework

1. Do you think that this framework correctly shows the primary variables in the process from EA creation to organizational benefits?
2. Do you think this EA benefit realization framework could be of value in your organization, ensuring value creation from EA?

EA process Explain that this research focused on the EA process.

1. Are you aware of the true purposes of EA?
2. Show the 4 EA purposes according to TOGAF (Table 5.2). Do you agree with these four EA purpose levels?
3. Do you have well defined artifacts to support the different EA purpose levels?
4. Show the EA process model (Figure 5.3). Do you think such an EA process model could help the EA function in your organization to support value delivery on every 'level' of the organization.

G.2 Validation presentation

Enabling value creation from enterprise architecture: supporting the grid operator in facilitating the energy transition

alliander

Tijs Berkenbosch | Master thesis presentation EA group | 12-06-2025

1

Research question

alliander

How can distribution system operators improve their enterprise architectures to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

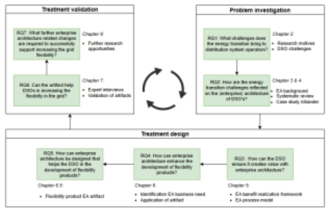


Figure 1.2: DSRM methodology applied in this research

EA = All architecture within Alliander!

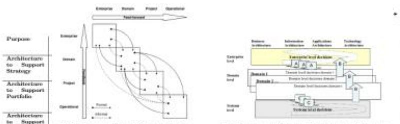
2

Problem investigation

Literature review

alliander

- Explorative and systematic literature reviews:
  - The energy transition and its implications for DSOs
  - Enterprise architecture for DSOs
- Some highlights used in the rest of the study include:
  - EA purposes
  - EA process models
  - EA benefit realization
  - Artifact categories



(a) EA process showing formal and informal feedback and feed-forward loops between EA levels [71]

(b) EA process showing enterprise level decisions (A), decisions from parallel domains to systems (C), and upstream feedback (B) [73]

Figure 3.5: EA process models

3

Problem investigation

Case study Alliander

alliander

- Moving towards e2e 'ketens'
- Architecture roles unclarities
  - Enterprise, solution, business
  - BBN-architecture
- Flexibility product development in PLM

4

Research question

alliander

How can distribution system operators improve their enterprise architectures to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

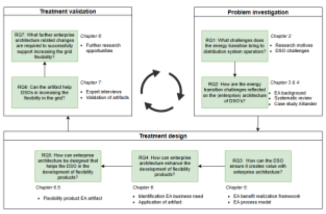
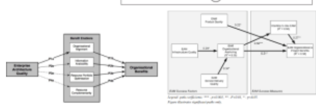


Figure 1.2: DSRM methodology applied in this research

5

EA benefit realization framework

- Insight needed in how EA leads to organizational benefits
  - Benefit tracking
  - Assess performance
  - Align EA outcomes with business outcomes
- Several significant literature contributions, few commonalities
- Importance of a service mindset



(a) Tamm et al. [59]

(b) Lange, Mendling, and Recker [72]

Figure 3.8: EA benefit models

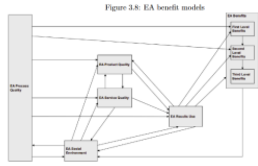


Figure 3.9: Overview of constructs interacting in the EA benefit realization process [84]

6

EA benefit realization framework

Figure 5.1: EA benefit realization model (based on [95], [96], [51], [67], interviews)

7

7

EA benefit realization framework

Benefit mechanisms

- Mediating variable between EA usage and organizational benefits, i.e., how and why does EA lead to the organizational benefit

1. **Organizational Alignment:** The extent to which an organization's subunits share a common understanding of its strategic goals and contribute towards achieving these goals [95].
2. **Information Availability:** The extent of useful, high-quality information accessible to organizational decision makers[95].
3. **Resource Portfolio Optimization:** The extent to which an organization leverages its existing resources, invests in resources that target performance gaps, and minimizes unnecessary investments in duplicated resources[95].
4. **Resource Complementarity:** The extent to which the organization's resources synergistically support the pursuit of its strategic goals[95].
5. **Improving IT Decision-Making**: EA enhances decision-making by providing structured processes, objective information, and educating decision-makers on effective IT investment practices [94].
6. **Enhancing IT Project Delivery**: EA improves project coordination through contextual awareness and accelerates projects by guiding standards [94].
7. **Optimizing the IT Platform**: EA aligns the IT platform with business needs, increasing flexibility and improving resource utilization and complementarity [94].

8

8

EA benefit realization framework

Figure 5.1: EA benefit realization model (based on [95], [96], [51], [67], interviews)

9

9

EA process model

- 'The EA process is referring to the day-to-day operations of the EA function', 'its attributes relating to EA methodologies, frameworks, tools, organization, and stakeholder participation have an extensive impact on this process'
- Identification of four EA purpose levels

Table 5.2: EA levels summary

Raadt and Vliet [71]	Pulkkinen [73]	TOGAF [68] EA to support:	TOGAF EA role [74]	KPI level [105]
Enterprise	Enterprise	Strategy	Enterprise architect	Strategical
Domain	Domain	Portfolio	Segment architect	Tactical
Project	Systems	Project	Segment architect	Tactical
Operational		Solution delivery	Solution architect	Operational

- EA levels within Alliander

Table 5.3: EA levels within Alliander

Raadt and Vliet [71]	Alliander
Enterprise	Alliander
Domain	Value chain
Project	Strategic theme
Operational	Department / ART

10

10

EA process model

- And the interactions between these different levels

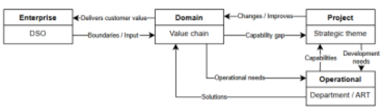


Figure 5.2: Identified EA abstraction levels

- How can these 'levels' optimally be supported with architecture?

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EA process model

- Defined the four architecture levels in a structured table

Table 5.4: EA description metamodel

Characteristic	Definition	
Title	EA function title	
Purpose	The purpose, that frames the depth and breadth of the EA. Divided in purposes described in Table 3.1: EA supporting strategy, portfolio, project or solution	
Decision scope	The level of influence this architecture function	
Policy level	Strategical / Tactical / Operational	
Primary stakeholders	The primary stakeholders involved in the creation of the EA product	
Primary responsibilities	The primary responsibilities of this function	
Artifacts	A summarization of deliverables of this function. Categorized into considerations, standards, visions, landscapes, outlines, designs [75] (see Section 3.1.5).	
Input (feedback)	From: stakeholder. The EA level where input is acquired from	The content of the information or decisions that has to be conformed to, based on [71] complemented with interview outcomes.
Output (feed-forward)	To: stakeholder. The EA level where this output is consumed	The content of the made decisions and which artifact, based on [71] complemented with interview outcomes.

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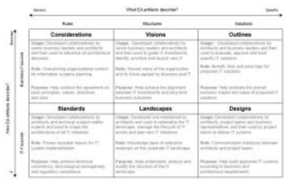
EA process model
Artifacts

- According to the EA benefit realization framework, every level needs EA artifacts and services.



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EA process model
Artifact relationships

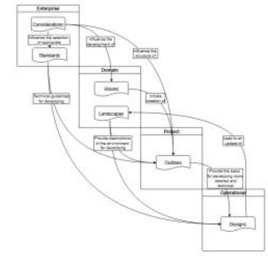

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Figure 5.3: EA process model showing desired artifact relations

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EA process model

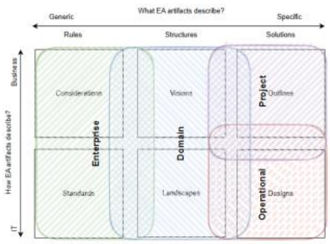

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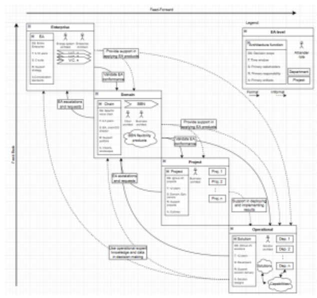
Figure 7.1: EA artifacts mapped on EA levels

15

EA process



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Research question

How can distribution system operators improve their enterprise architectures to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

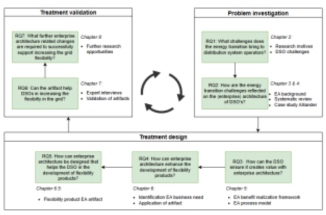

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Figure 1.2: DSRM methodology applied in this research

17

EA for flexibility products

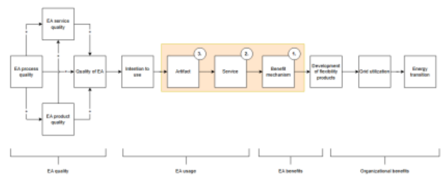

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Figure 6.1: EA benefit realization framework with filled in organizational benefits

18

EA for flexibility products
Capability map

- Resource portfolio optimization: The extent to which an organization leverages its existing resources, invests in resources that target performance gaps, and minimizes un-necessary investments in duplicated resources.
- Identify, prioritize and guide (IT) investments (duplicity, reusability, responsibilities, building blocks)
- Product reference capability map

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EA for flexibility products

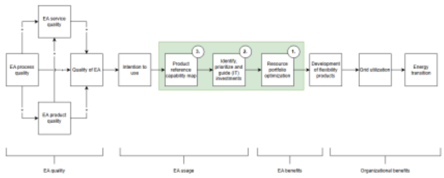

Figure 6.2: EA benefit realization framework for the development of flexibility products

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Research question

How can distribution system operators improve their enterprise architectures to efficiently increase the flexibility in the distribution grid in order to optimize grid utilization?

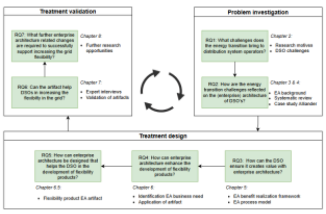

Figure 1.2: DSRM methodology applied in this research

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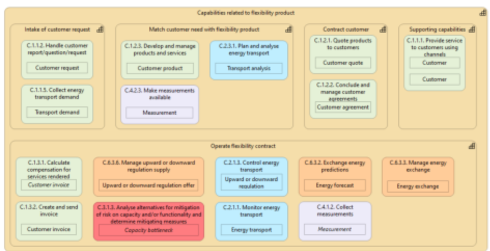
EA for flexibility products
Capability map V1



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Conclusion

- It is important to be aware of the EA benefit realization process
- We need EA to support
  - Strategy
  - Portfolio
  - Project
  - Solution delivery
- This can only be done with appropriate EA artifacts and services, mat
- Relationships between artifacts are identified, required to ensure con
- An EA process model can contribute to this
- Flexibility products can be supported with EA, artifact and service has

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