UNIVERSITY OF TWENTE.

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# An Enterprise Architecture Approach Towards Sustainability and Environmental Performance

## Master Thesis

Ann-Cathrin Iseke

Supervisors:

DR. D.M. YAZAN
Faculty of Behavioural Management & Social sciences
Department of Industrial Engineering and Business Information Systems
University of Twente

DR. A. ABHISHTA
Faculty of Behavioural Management & Social sciences
Department of Industrial Engineering and Business Information Systems
University of Twente

DR. M. DANEVA
Faculty of Electrical Engineering, Mathematics and Computer Science
Department of Services, Cyber security & Safety
University of Twente

**Ann-Cathrin Iseke**

Student number: s2207249

E-mail: a.iseke@student.utwente.nl

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**Supervisors**

Dr. D. M. Yazan

Dr. A. Abhishta

Dr. M. Daneva

**University of Twente**

Business Information Technology

Faculty of Electrical Engineering, Mathematics and Computer Science

Drienerlolaan 5

7522NB Enschede, The Netherlands

# Abstract

For far too long, environmental sustainability has been considered an unrelated discipline, nearly independent from Information Systems research that is focused on the business environment and organizations' Enterprise Architecture approaches. Ultimately, integrating environmental strategies from the start saves costs, fosters effectiveness and creates synergies compared to half-hearted attempts of so-called green initiatives. In order to manage the transition to sustainable enterprises and sustainable enterprise systems development, environmental policies, strategies and standards need to be integrated in the domain of Enterprise Architecture to be tangible for Enterprise Architects. The Enterprise Architecture language ArchiMate provides the ideal vehicle for introducing environmental sustainability to the enterprise using Enterprise Architecture. This thesis combines a two-method approach where all necessary environmental concepts are gathered, defined and mapped to ArchiMate, consolidating relevant domain-specific concepts from literature which are later revisited and challenged by practice.

The contribution of this research is multifold: First of all, this research provides a new set of concepts based on the ArchiMate language that allows enterprises to model their individual environmental sustainability strategies embedded and aligned in the overall Enterprise Architecture. Second, a tool is provided to measure and analyze the organization's environmental performance. This tool offers the means for improvement of environmental performance on all levels of the enterprise and supports enterprise architects in the creation of new improved designs of their organizations' to-be enterprise architecture. Third, next to the approach, this research also completed a feedback-based evaluation of the proposal and incorporated the domain experts' feedback reflecting the need and relevance of the topic for the practitioners community. The approach is novel in several ways. First, to the best of our knowledge, this is the first attempt to complement enterprise architecture languages with sustainability analysis. Second, our evaluation indicated that our proposal on how to integrate sustainability into enterprise architecture, is promising and remains practical. However, more empirical research is needed to evaluate its usefulness in various context, so that more generalizable conclusions regarding its benefits could be drawn.

Lastly, this research allows to draw a number of implications which highlight the need for making the topic of environmental sustainability more accessible to practitioners in organizations. This already implies the prerequisite to integrate the topic in the student's curriculum to create more awareness and sensitivity for environmental sustainability in the organizational context. Further, with this research being characterized by the novelty of the topic, the discussion on how EA can support organizations in their environmental sustainability efforts only has been started in this thesis and calls the researchers community for further investigation.

# Preface

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## Glossary

| | |
|---|---|
| CSR | Corporate Social Responsability |
| DoDAF | Department of Defense Architecture Framework |
| EA | Enterprise Architecture |
| ECI | Environmental Condition Indicators |
| EIN | Eco-Industrial Networks |
| EMAS | Eco-Management and Audit Scheme |
| EMS | Environment Management Systems |
| EP | Environmental Performance |
| EPE | Environmental Performance Evaluation |
| EPI | Environmental Performance Indicators |
| FEAF | Federal Enterprise Architecture Framework |
| GERAM | General Enterprise Reference Architecture Model |
| GHG | Greenhouse Gas Emissions |
| GJ | Giga Joules |
| GRI | Global Reporting Initiative |
| GSSB | Global Sustainability Standards Board |
| Iaas | Infrastructure-as-a-Service |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| ISO | Innternational Standardization Organization |
| MDA | Model-Driven Architecture |
| MPI | Management Performance Indicators |
| MWh | Megawatt Hours |
| NPO | Non-Product Outputs |
| OMG | Object Management Group |
| OPI | Operational Performance Indicators |
| Paas | Platform-as-a-Service |
| PDCA | Plan-Do-Check-Act |
| SaaS | Software-as-a-Service |
| SC | Sub-Committe |
| SCPS | Socio-Cyber-Physical Systems |
| SDGs | Sustainable Development Goals |
| SLR | Systematic Literature Review |
| SRT | Sustainability Reporting Tool |
| TBL | Triple Bottom Line |
| TC207 | Technical Committee 207 |
| TEAF | Treasury Enterprise Architecture Framework |
| TOGAF | The Open Group Architecture Framework |

DoDAF Department of Defense Architecture Framework

| | |
|---|---|
| EA | Enterprise Architecture |
| ECI | Environmental Condition Indicators |
| EIN | Eco-Industrial Networks |
| EMAS | Eco-Management and Audit Scheme |
| EMS | Environment Management System |
| EP | Environmental Performance |
| EPE | Environmental Performance Evaluation |
| EPI | Environmental Performance Indicator |
| ESARC | Enterprise Services Architecture Reference Cube |
| FEAF | Federal Enterprise Architecture Framework |
| GERAM | General Enterprise Reference Architecture Model |
| GHG | Greenhouse Gas Emissions |
| GJ | Giga Joules |
| GRI | Global Reporting Initiative |
| GSSB | Global Sustainability Standards Board |
| ICT | Information and Communication Technology |
| IoT | Internet of Things |
| ISO | International Organization for Standardization |
| MDA | Model-Driven Architecture |
| MPI | Management Performance Indicators |
| MWh | Megawatt Hours |
| NPO | Non-Product Outputs |
| OMG | Object Management Group |
| OPI | Operational Performance Indicators |
| PDCA | Plan-Do-Check-Act |
| SC | Sub-Committee |
| SDGs | Sustainable Development Goals |
| SLR | Systematic Literature Review |
| SRT | Sustainability Reporting Tool |
| TC207 | Technical Committee 207 |
| TEAF | Treasury Enterprise Architecture Framework |
| TOGAF | The Open Group Architecture Framework |

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# 1. INTRODUCTION

*"Economic sustainability is air, while environmental and social sustainability are food: the first is more urgent however not more important than the second."*

(Blackburn, 2007)

Enterprise architecture languages enables Enterprise Architects to portray an enterprise's business environment as well as all its related organizational concerns and issues. An example of a well-established enterprise architecture language is the ArchiMate standard (The Open Group, 2017). However, environmental sustainability and associated environmental performance assessments are not yet among the concerns usually included in existing enterprise architecture frameworks, including ArchiMate in particular. ArchiMate is a commonly used tool, offering a wide variety of concepts and relationships that are compatible with one of the most important Enterprise Architecture frameworks. In this research the adoption of new environmental concepts to the ArchiMate language is proposed. EA models are the ideal means to evaluate environmental performance and achieve improvements on all levels of the enterprise in an integral way that contemplates all relevant factors from the enterprise's vision and mission to its IT landscape. Being a well-established practice in a large number of enterprises, EA models are readily available and offer the means to address environmental issues and concerns. Through environmental performance and sustainability modelling aligned with the needs of the organization and the concerns of key stakeholders, Enterprise Architects are able to build shared understanding and support for actions that guide organizations' green initiatives and align them with the overall goals and strategy.

## 1.1. Motivation

For the last 15 years, the threat of climate change has been one of the world's most pressing challenges. Although the Paris Agreement in 2015 achieved commitment of 186 countries to take action in limiting global warming to 1.5 degree Celsius, progress and advances in reducing the level of greenhouse gas emissions (GHG) are stagnating. Goal 13 of the Sustainable Development Goals (SDGs) states the urgency for a reduction of global carbon emissions to decrease about 55% of 2010s' emission levels followed by a steep reduction to zero emissions by 2050. However, according to the United Nations Report 2019 the future outlook does not look favorable with current actions in place that are far from the much-needed ambitious measures enabling radical change (United Nations, 2019, p. 48-49).

For many years, there has been an ongoing debate about the impact of Information and Communication Technology (ICT) on global warming. In 2008 the carbon footprint of the ICT sector was projected to account for 2.7 % of global $CO_2$ emissions in 2020, while in 2012 carbon emissions were estimated to account for 2.3 % of global carbon footprint in 2020. Following this trend, the ICT sector's carbon footprint is predicted to decline further, consequently creating opportunities to enable and contribute to reductions in other sectors and industries. Thus, the ICT sector is expected to overweight its negative impact on the environment by ICT-enabled benefits in the long-term (GeSI, 2015). Opposing these quite positive prospects, other projections show a dramatic increase from 1.7 % in 2007 up to 3.6 % in 2020 of global carbon emissions including both the energy consumption from production as well as operation of ICT devices and supporting infrastructure (Belkhir & Elmeligi, 2018, p. 461). With emerging technologies like cloud computing, big data, Internet of Things (IoT), data analytics, cryptocurrencies and increasing numbers of internet users worldwide, the intensity of data traffic is expected to rise considerably (Statista, 2019; Belkhir & Elmeligi, 2018, p. 461).

The rising prevalence of environmental issues has also reached the corporate level where enterprises re-think their strategies in light of these issues and attempt to address and manage them in a more systematic ways. This is due to a number of reasons. A recent survey on resource management reveals that next to costs, sustainability dominates among resource management drivers. Especially, when considering the development over the past years, with economics being top driver in 2016, it has slightly decreased, becoming number two right before sustainability driving corporate resource management (Deloitte University EMEA CVBA, 2019, p. 18). With companies making the climate change a top priority for 2020, there is a number of reasons for organizations intensifying their efforts in improving corporate sustainability. The need for action regarding environmental concerns has increased dramatically which is also reflected by the fact that companies give climate change a significantly higher priority compared to 2018. Cost reduction, regulatory requirements and product innovations are only a few to mention. However, a survey revealed that reputation, closely followed by customer demand and investor interest are the driving forces for enterprises to embark on sustainability initiatives. Reflecting a great part of motivation and eagerness with setting targets and priorities, companies however do not show the expected results. As most business initiatives, support from top-level management, stakeholder commitment and global alignment in the enterprise are key to success. Although numbers look promising with one quarter seeing sustainability as a top-three priority for their CEOs, the overall implementation of such strategies is doomed to fail (BSR & Globescan, 2019, pp 11ff). This is confirmed when taking into account that almost one third of the companies do not perceive sustainability as well integrated into the business (BSR & Globescan, 2019, pp 11ff).

Another aspect is the increasing perception of climate change posing a risk to business. Risks includes physical risks from extreme weather events, transition risks stemming from changing technologies, laws and marketplaces as well as legal risks of violating GHG emission boundaries (Deloitte University EMEA CVBA, 2019, p. 2-3). Next to a proper risk management, governance, strategy development, metric and target setting are recommended to address climate change (TCFD, 2017). Although pressure is increasing and companies are beginning to react, managing and measuring climate-change related risks is only the beginning and needs to be followed by a thorough integration in the corporate strategy to assure business sustainability in the long-term (Deloitte University EMEA CVBA, 2019, p. 10).

While national and international frameworks and standards are available, companies struggle with implementing green initiatives which are becoming imperative for the future. Only when organizations embrace environmental sustainability as a new business trend, anticipation of risks and opportunities will ensure competitive advantage and financial benefits in the long-term.

Enterprise Architecture is a well-established and recognized field. Efforts of the practitioners and researchers community have contributed to a wide coverage of aspects related to the enterprise. Examples include Enterprise Risk Management introducing security-related concepts (The Open Group, 2019) or Smart Manufacturing extending IT to the physical level (Franck et al., 2017). However, little research has been done yet guiding enterprises towards higher environmental performance. With the discipline of EA being extended to cover more and more enterprise related issues, the ArchiMate modelling language has been adopted steadily being the optimal vehicle for modelling these enterprise-related aspects. A major update has been the introduction of the physical and strategy layer in ArchiMate 3.0 (2016) published as an Open Group Standard.

## 1.2. Contribution

Although a great number of enterprises are willing to embrace sustainability initiatives, the issues and concerns raised, hinder a successful implementation. Striving for more environmental sustainability requires a holistic approach starting with the evaluation and measurement of the organization's environmental performance. Managing such a complex endeavor requires a structured process which can be addressed by the implementation of Enterprise Architecture.

This research intends to adopt the Enterprise Architecture Modelling Language ArchiMate for modelling and assessing environmental performance. The contribution is multifold:

First of all, this proposal provides a new set of concepts based on the ArchiMate language that allows enterprises to model their environmental sustainability strategies embedded and aligned in the overall Enterprise Architecture.

Second, an approach to measuring and analyzing the organization's environmental performance, is provided. This approach offers the means for improvement of environmental performance on all levels of the enterprise and enables a new improved design of a to-be enterprise architecture.

Third, next to the approach, this research also offers an evaluation of the proposal and incorporates the feedback provided by domain experts.

## 1.3. Research Goals

As indicated earlier, the aim of this research is to enable enterprises in order to improve their environmental performance, therefore securing business sustainability and contributing to a more sustainable future. In order to enhance environmental sustainability, companies need the right tools and guidance for embarking on such enterprise-wide green initiatives. An Enterprise-Architecture-based approach assists companies in assessing, planning and improving their environmental strategies without neglecting other business relevant aspects. To achieve this, the following objective has been formulated:

*To design and validate an environmental performance measurement tool that assists organizations to adopt green initiatives leveraged by Enterprise Architecture.*

Accordingly, the main research question has been formulated as follows:

***How can environmental performance be modelled in enterprise architecture (EA)?***

In order to answer the research question stated above, the main research problem is decomposed in its components. These are reflected in the following sub-research questions:

**(RO1) Research Objective 1: Identify current approaches and means how organizations measure environmental performance.**

a. (RQ1) What are the most common frameworks and standards to address environmental performance of organizations?

**(RO2) Research Objective 2: Identify the state-of-the-art of the relation of EA practices and environmental performance.**

a. (RQ2a) How do existing EA-based approaches measure environmental performance in literature?
b. (RQ2b) Which languages and frameworks allow to model environmental performance?

**(RO3) Research Objective 3: Map and integrate environmental performance into the EA practice and ArchiMate modelling language.**

a. (RQ3a) To what extent can environmental performance be represented in EA and ArchiMate?
b. (RQ3b) How can ArchiMate be adopted to achieve full expressiveness in order to model environmental performance in EA?
c. (RQ3c) How can EA models be used for quantitative analysis of environmental performance?

**(RO4) Evaluate and demonstrate the artifact in an example.**

a. (RQ4a) How do experts evaluate the usefulness of the artifact?
b. (RQ4b) To what extent does the artifact help to improve an organization's environmental performance?
c. (RQ4c) How does the artifact allow to derive opportunities for improving the environmental performance based on the design of a to-be-EA?

## 1.4. Research Design

This section outlines the research methods used in this thesis. The overall method adopted is the design science methodology completing the phases of the design cycle as further described in Chapter 1.4.1. The systematic literature review (SLR) is performed according to the approach of Webster and Watson (2002). Finally, the treatment design and validation of the proposed artifact are performed through a two-method approach.

### 1.4.1. Design Science Methodology

This research adapts the design science methodology as described by Wieringa (2014). The design science cycle describes the iterative process of designing an artifact covering three activities:

1. **Problem Investigation**: In the first phase the problem and its context are explored. This includes asking knowledge questions about the phenomena to be investigated (Wieringa, 2014, p. 27-28). The problem investigation is addressed by RQ1, RQ2a and RQ2b by performing a systematic literature review. The SLR is described in Section 1.4.2.

2. **Treatment Design**: The second phase is concerned with the design of the artifact that intends to address the problem (Wieringa, 2014, p. 27-28). The treatment design is an iterative process spanning over multiple steps. For this purpose, the findings of the SLR are used to build a first version of the artifact. To enhance the artifact, interviews are conducted. Based on the feedback provided in the interviews, a second version of the artifact is created based on the new findings. The interview design is described in Section 1.4.3. This phase addresses RQ3a, RQ3b and RQ3c.

3. **Treatment Validation**: In the third phase the artifact is validated in order to verify the artifact's contribution to the addressed target group with the intention to predict how it would interact in a real-world problem context (Wieringa, 2014, p. 31). The treatment validation consists of two steps. First of all, the artifact is exemplified using the case study of a fictional company in a single-case mechanism experiment. Secondly, interviews are conducted to evaluate the usefulness and contribution of the proposed approach in practice. This phase intends to answer RQ4, RQ4b and RQ4c.

### 1.4.2. Systematic Literature Review

The systematic literature review (SLR) follows the guidelines offered by Webster and Watson (2002). The problem investigation of the design cycle answers knowledge questions which are addressed by the research questions RQ1, RQ2a and RQ2b. As each question covers a different topic, three different queries are formulated as depicted in Table 1.

**Table 1: Queries**

| Query ID | Queries | RQs | Topic |
|---|---|---|---|
| **Q1** | Query 1 | RQ1 | frameworks and standards to address environmental performance of organizations |
| **Q2** | Query 2 | RQ2a | EA approaches to environmental performance |
| | | RQ2b | EA languages & frameworks |

The search is performed in two databases, namely Scopus and the Web of Science. These databases are chosen as they are perceived as most user-friendly and allow a convenient search with advanced querying and filtering options. Furthermore, they provide a wide coverage of literature accessing other research databases including SpringerLink, Wiley Online Library, Taylor & Francis, IEEE Xplore Digital Library or the ACM Digital Library. Moreover, the full access of the paper must be provided including all papers with free access and those accessible with the University of Twente credentials. For an exhaustive coverage all kinds of documents are taken into account including conference papers, conference reviews, articles, books and book chapters. The search criteria are summarized in Table 2.

Table 2: Search Criteria

| Search Criteria | |
|---|---|
| **Language** | English |
| **Electronic Databases** | Scopus (www.scopus.com), Web of Science (www.webofknowledge.com) |
| **Availability/Access** | Full paper available, free access or access with university credentials |
| **Document Type** | Conference Paper, Conference Review, Article, Book, Book Chapter |

After performing the search, the retrieved papers are reviewed according to their relevance for the objectives of this paper. An unbiased selection process is guided by predefined inclusion and exclusion criteria as summarized in Table 3 and Table 4. The Query ID depicts which criteria applies to which query. According to these criteria only those papers are selected that are peer-reviewed (IC1) and published in the English language (IC2). Further it is specified that papers retrieved from Q2 are published between 2009 and 2020 as a preliminary search indicated that relevant papers were published in this time period (IC3). The time period has not been limited for Q1 in order to ensure that no relevant frameworks and standards are excluded. Furthermore, the study has to be relevant according to the search terms defined in the query (IC4).

Table 3: Inclusion Criteria

| Inclusion Criteria | Query ID |
|---|---|
| **IC1**. The research paper is a peer-reviewed publication. | Q1, Q2 |
| **IC2**. The research paper is in English. | Q1, Q2 |
| **IC3**. The study is published between 2009-2020. | Q2 |
| **IC4**. The study is relevant according to the search terms defined in the query and the research questions. | Q1, Q2 |

Papers are not included in case they do not meet the above stated inclusion criteria (EC1). Studies are also excluded if the full version of the study is not available (EC2). Regarding query 1, studies will not be included if they do not focus on the frameworks assessing environmental performance on a corporate level, but rather on country level (among others) (EC3).

Table 4: Exclusion Criteria

| Exclusion Criteria | Query ID |
|---|---|
| **EC1**. Studies that do not meet inclusion criteria. | Q1, Q2 |
| **EC2**. The full version of the paper is not available. | Q1, Q2 |
| **EC3**. Studies that do not focus on the frameworks assessing environmental performance on a corporate level, but rather on country level (among others) | Q1 |

The queries were built after performing a preliminary search to identify relevant keywords. The formulation of the queries is presented in Table 5 and is exemplified with Q1. This query is basically built out of multiple strings in which the first two covers all terms and synonyms relating to the topic of "framework" while the last string includes terms associated to the topic of "environmental performance". Those two strings were connected through the Boolean operator "AND" in order to retrieve the results respectively. The Asterix was used to broaden the search as it allows to not restrict the search to only the adjective or verb, for instance, but also includes the substantive.

The search was performed in two databases. Consequently, the query operators had to be adopted as Scopus supports the search in title, abstract and keywords (TITLE-ABS-KEY) while Web of Science performs the search using the operator "topic" (TS).

In order to achieve a broad coverage of the search terms, synonyms were included in the query by using the Boolean operator "OR".

Table 5 depicts the queries as they were performed in the database Scopus.

**Table 5: Query**

| Query ID | Query |
|---|---|
| **Q1** | ( ( TITLE-ABS-KEY ( ( global OR national OR international ) AND ( standard* OR framework* ) AND (corporate OR business OR organiz* OR enterprise ) AND ( ( "Environment*Performance" OR "Environment* sustainability indicator*") AND ( "Evaluation" OR "Measure*" ) ) ) ) ) AND ( review ) AND ( LIMIT-TO ( LANGUAGE , "English" ) ) |
| **Q2** | TITLE-ABS-KEY (("Environmental performance" OR "Environmental impact" OR "Environmental sustainability" OR "environmental footprint") AND ("enterprise architect*" OR "enterprise model*")) 2009- 2020 |

A search was performed in Scopus and Web of Science.

**Table 6: Query Results**

| ID Query | Scopus | | Web of Science | | Total Selection |
|---|---|---|---|---|---|
| | total | selected | total | selected | |
| **Q1** | 97 | 41 | 36 | 8 | 49 |
| **Q2** | 14 | 2 | 6 | 1 | 4 |

The selection process was conducted for each query and will be exemplified with Q1. A search was performed in Scopus were the presented query and search criteria resulted in 97 results. The same search procedure was applied in the second database, namely Web of Science, were 36 results were returned. In order to avoid duplicates, the selection of the results in the second database excludes papers that are already included in the selection from Scopus. A manual review under consideration of the inclusion and exclusion criteria resulted in a final selection of 49 papers. The same procedure was performed for each query. The results are presented in Table 6. The total number of selected papers, hence, is 53 (see the rightmost column of Table 6).

### 1.4.3. Interviews

The qualitative research method of Interviews (King, Horock & Brooks, 2018) is chosen for the purpose of the phases of treatment design and treatment validation of Wieringa's design science cycle (Wieringa, 2014). In order to evaluate this first version of the artifact concerning its suitability in practice, practitioners are asked to take part in a semi-structured interview. Taking into account the exploratory nature of this research due to its topic's novelty, this enables a first step into testing the artifact towards a real-world like scenario and to involve actual users in the research design (Hevner et al. 2004, p.78-79).

Later in the validation phase, interviews are performed to validates the usability and usefulness of the proposed artifact. The interview design follows the approach of the RAND National Defense Research Institute for collecting data with semi-structured interviews as described in detail in Section 3.2.1.

### 1.4.4. Single-Case Mechanism Experiment

A case study of a fictional company has been chosen for a single-case mechanism experiment as the validation method of choice. The case provides a realistic and well-established scenario which allows to expose the artifact to a controlled environment where the interactions of the artifact in a realistic context can be analyzed and studied (Wieringa, 2014, p. 64). In this case, the usefulness and practical usability of the artifact was subject of evaluation and basis for the interviews.

## 1.5. Thesis Structure

The structure of this research is guided by the phases of the design science methodology. Table 7 presents the mapping of the phases to the chapters of this thesis while pointing out the applied research methods and the research questions addressed.

Chapter 2 provides the theoretical background and describes basic concepts introducing the terminology for environmental performance (Section 2.1.1) and Enterprise Architecture (2.1.2) in Section 2.1. With the foundation of theoretical concepts established, Section 2.2.1 dives into the first part of the design cycle, the problem investigation, answering RQ1 by reviewing relevant literature of environmental frameworks, standards and ratings/indices. Subsequently, Section 2.2.1 systematically explores literature investigating existing research on the relation of EA and environmental performance. This chapter is closed with the discussion of results for RQ2a asking for EA-based approaches to measure environmental performance as well as RQ2b looking on EA modelling languages and frameworks in the context of environmental performance.

Next, Chapter 3 covers the second part of the design cycle, presenting the treatment design. Based on the findings from literature as presented in the previous Chapter (2), this chapter addresses RO3, describing the mapping and integration of environmental performance into the EA practice and ArchiMate language. The process of the systematic approach of analyzing and mapping environmental concepts, provides a first version of the artifact which is documented in Section 3.1. In the following Section 3.2 these results are discussed with EA practitioners allowing the enhancement and ultimately, the creation of the final version of the artifact. The conclusion of Section 3.1 and 3.2 deliver the qualitative part of the artifact and therefore provide answers to RQ3a and RQ3b. The quantitative analysis approach is described in Chapter 3.1 and presents the results to RQ3c.

Chapter 4 handles the third part of the design cycle, the treatment validation and addresses RO4 by providing the evaluation and demonstration of the artifact in an example. This chapter concludes with answering the research questions RQ4a, RQ4b and RQ4c.

In the subsequent Chapter 5, limitations and future work are discussed. This thesis concludes with the final Chapter 6 revising the research objective of this work summarizing the results of the according research questions.

**Table 7: Thesis Structure**

| Chapter | Phase of the DSM | Research Method | Research Question | Research Objective |
|---|---|---|---|---|
| **1. Introduction** | - | - | - | - |
| **2.Theoretical Background** | Problem Investigation | Literature Review | RQ1<br>RQ 2a,<br>RQ 2b | RO1<br>RO2 |
| **3.Treatment Design** | Treatment Design | Literature Review Findings + Interviews | RQ 3a,<br>RQ 3b,<br>RQ 3c | RO3 |
| **4.Treatment Validation** | Treatment Validation | Single-Case Mechanism Experiment, Expert Opinion Interviews | RQ 4a,<br>RQ 4b,<br>RQ 4c | RO4 |
| **5. Discussion** | - | - | all | all |
| **6. Conclusion** | - | - | all | all |

# 2. THEORETICAL BACKGROUND

***This chapter provides insights in literature by discussing relevant concepts and answering the research questions RQ1 and RQ2a and RQ2b. First of all, Section 2.1 presents a number of basic concepts providing essential terminology of this research, including environmental sustainability (2.1.1) and EA (2.1.2). With the foundations being established, Section 2.2 provides insights on environmental frameworks, standards and ratings/indices addressing RQ1. Subsequent sections examine the relation between environmental performance and EA addressing RQ2a (2.2.3) as well as relevant EA frameworks and modelling languages in the context of environmental performance EA addressing RQ2b (2.2.2.).***

## 2.1. Basic Concepts

This section presents the basic concepts and terminology relevant for this research. Chapter 2.1.1 provides an overview on the topic of environmental sustainability. Chapter 2.1.1 covers the topic of Enterprise Architecture including a short summary of the modelling language ArchiMate.

### 2.1.1. Environmental Sustainability

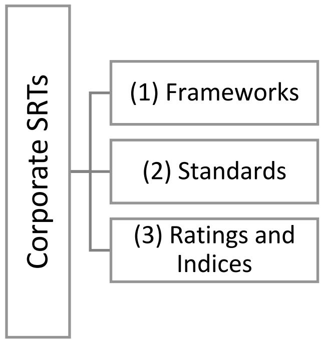
The United Nations Brundtland Commission defines sustainability as "meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs. (Bruntland Report, Chapter 1, 1987)." Sustainability has three dimensions: Economic, Social and Environmental. However, economic, social and environmental sustainability are interrelated and need to be addressed in an integral way (Bruntland Report, 1987).

Sustainable Development is explicitly addressed in the Sustainable Development Goals (SDGs) formulated by the United Nations striving for a socially, economically and environmentally sustainable future. With businesses playing a key role in adopting the agenda of the SDGs, reporting on sustainability performance allows the private sector to contribute to the SDGs. Focusing on the environmental dimension, environmental performance can be defined as the environmental positive or negative impact caused by the organization and their overall contribution to environmental sustainability (GRI, 2020, p. 3).

While the discussion of how to achieve sustainable development is still ongoing, it has been established that it is no longer only a matter for governments to address. As also stated in the SDGs and various environmental standards and frameworks, companies have a considerable stake in creating a more sustainable future. The practice of making companies accountable for their contribution to sustainable development started in the 1970s and has also been treated in literature under numerous terms such as Corporate Social Responsibility (CSR), Corporate Sustainability or the Triple Bottom Line (TBL). Literature reveals several reasons that facilitate the increasing reporting efforts of organizations worldwide. On one hand, the need and aspiration for sustainability reporting stems from regulatory requirements associated with potential costs and sanctions in case of non-compliance as well as economic and financial benefits resulting from decreased operational costs (Morhardt, Baird & Freeman, 2002, p. 215-216). On the other hand, stakeholders express growing interests not only in economic, but also environmental and social performance of organizations (Siew, 2015, p. 181). These interests may be motivated by the fact that higher environmental and social performance positively affect the company's reputation and consequently lead to an increased competitive advantage

(Morhardt, Baird & Freeman, 2002, p. 215-216). The most recent KPMG Survey of Corporate Responsibility Reporting in 2017 confirms the upward trend of reporting efforts among large and mid-cap companies globally. Since the first survey in 1993, until 2017, a growth rate of 93% can be observed regarding CR reporting in the 250 largest companies globally by revenue based on the Fortune 500 ranking of 2016 (KPMG, 2017, p. 4-9). This trend has been reinforced and maintained by the development of numerous corporate sustainability reporting tools (SRTs) that assist organizations in their efforts in reporting on economic, social and environmental sustainability (Siew, 2015, p. 181). Siew (2015) distinguishes corporate SRTs into (1) Frameworks, (2) Standards and (3) Rating and Indices (Fig. 1).

**Figure 1: Classification according to Siew (2015)**




Following Siew's definitions, frameworks come in the form of principles, guidelines or initiatives to offer guidance on reporting. Standards serve the same purpose, but are more formal as they usually come with a number of requirements such as formal documentation of disclosures comprising certain information and specifications. For this reason, standards achieve more comparability and consistency in reporting efforts. In contrast ratings and indices are characterized by an assessment of organizational sustainability by a third party (Siew, 2015, p. 181-182).

### 2.1.2. Enterprise Architecture

For the purpose of this research, the following definition of EA is adopted where EA 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" (Lankhorst, 2009, p.3). EA is a discipline that describes the integrated approach to business and IT, providing a holistic view on the enterprise. The goal of EA is twofold: On the one hand, architecture is regarded as a product which offers the means to guide the process of designing business processes and implementing IT systems in a way that supports the overall organization's business goals and constitutes a fit to the organization's strategy. New business processes and systems require responding to change and adaptability of the EA, consequently claiming a need for maintenance and flexibility to handle and steer the architecture's evolution. On the other hand, architecture is regarded as a process following the steps from the idea to the implementation and management covering the whole lifecycle (Lankhorst, 2009, p. 3ff). A number of methods, tools and frameworks are provided, offering the means to design the enterprise architecture from its business processes to its IT landscape. An architecture method is a structured set of steps and procedures guiding the design and management of an enterprise architecture. The identification and relation of viewpoints and associated modelling techniques are structured by architecture frameworks (Lankhorst, 2009, p. 20). Most established frameworks are among other The Open Group Architecture Framework (TOGAF), the Zachman Framework, the Object Management Group's (OMG) Model-Driven Architecture

(MDA), the Department of Defense Architecture Framework (DoDAF) (Lankhorst, 2009, p. 20ff), the Federal Enterprise Architecture Framework (FEAF), Treasury Enterprise Architecture Framework (TEAF) and the ARIS framework (Leist & Zellner, 2006, p. 1548ff). TOGAF has been established as a standard through collaborative efforts of the community and maintained by The Open Group. It provides a best practice framework and comes with an according modelling language: ArchiMate.

### ArchiMate

ArchiMate offers a uniform set of entities and relationship concepts for representing interrelated architectures, individual viewpoints for specific stakeholder groups. ArchiMate 1.0 (2004) is considered as the core and covers all concepts for describing the Business, Application and Technology layer. The extension in ArchiMate 2.0 also allows the modelling of implementation and migration concepts as well as motivation aspects enabling the modelling of the rationale behind the enterprise architecture including concepts like stakeholders, principles, goals and requirements. In 2017 the third extension (ArchiMate 3.0) was introduced by The Open Group adding concepts to model strategic aspects as depicted in Figure 4 (The Open Group, 2017, p. 1, 17f). Figure 2 depicts the ArchiMate Framework of the most recent release from The Open Group.

**Figure 2: The ArchiMate Framework (The Open Group, 2017, p. 8)**

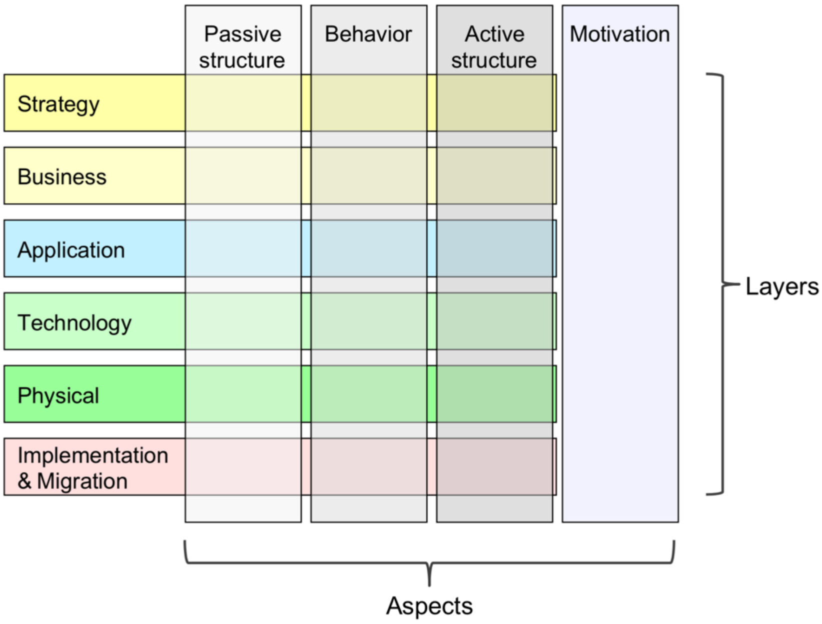
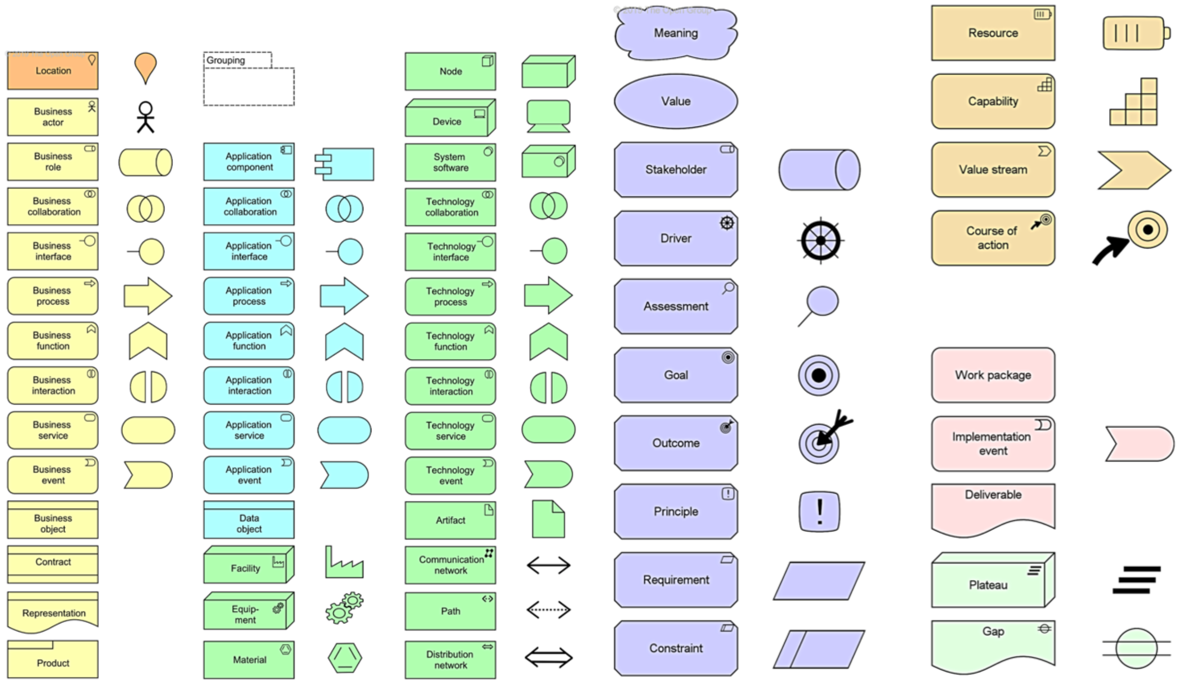



Figure 5 depicts all Core Elements, Motivation, Strategy as well as Implementation and Migration Elements as presented in the most recent ArchiMate 3.1 Specification.

**Figure 3: ArchiMate Elements (ArchiMate 3.1 Specification, The Open Group, 2012-2019)**




## 2.2. Problem Investigation – Findings from Literature

While the previous section discusses the key concepts of this research, this section specifically addresses the research questions by performing a SLR. Chapter 2.2.1 answers research question RQ1 and investigates environmental frameworks and standards that form the basis for the artifact design in Chapter 3. Literature findings answering RQ2a and RQ2b are described in Chapter 2.2.2. where the link between EA and environmental performance is investigated.

### 2.2.1. Environmental Frameworks, Standards and Ratings/Indices

A SLR (Section 2.2) on tools to assess organizational sustainability with focus on the environment has revealed 20 frameworks, standards and ratings/indices. Table 8 depicts a cumulated list of the results within the classification scheme according to Siew (2015) as presented in Chapter 2.1.1. Further, the number in the fourth column indicates how often a SRT is mentioned in literature.

**Table 8: Corporate SRTs in Literature**

| Classification | Pillar | SRT | Sources | # |
|---|---|---|---|---|
| **Standard** | Environmental | ISO 14044 | Pajula et al. (2017) | 1 |
| | Environmental | ISO 14051 | Liu & Wang (2018) | 1 |
| | Environmental | ISO 14067 | Pajula et al. (2017) | 1 |
| | Environmental | ISO 14040 | Schmidt et al. (2004); Amarakoon et al. (2018) | 2 |
| | Environmental | ISO 14000 series | Garland (2001); Langford (2007); Khan et al. (2020); Lo-Iacono-Ferreira, Capuz-Rizo, Torregrosa-López (2018), Buyukozkan & Karabulut (2018) | 5 |
| | Environmental | ISO 14031 | Langford (2007); Tyteca et al. (2002); Mohammadrezaie & Eskafi (2007); Cagno, Tardini & Trucco (2017); Günther & Kaulich (2005); Grigoroudis (2017); Bjorklund, Forslund & Isaksson (2016) | 7 |
| | Environmental | ISO 14001 | Mohammadrezaie & Eskafi (2007); Surette (2005); Ramos et al. (2013); Epstein & Roy (2007); Quaglino et al. (2010); Legrand et al. (2014); Henri & Journeault (2008); Pesce et al. (2018); Moja, Mphephu & Zuydam (2017); Rondinelli & Vastag (2000); Loney et al. (2003); Cushing, McGray & Lu (2005); Dejkovski (2016); Turki, Medhioub & Kallel (2017); Bindal & Dwivedi (2013); Dechezleprêtre et al. (2019); Polgár & Pájer (2015); Dočekalová, Kocmanová & Hornungová (2015); Rashid & Fazal (2017); Bjorklund, Forslund & Isaksson (2016); da Rosa et al. (2015) | 21 |
| | Environmental | EMAS | Ramos et al (2013); Quaglino et al. (2010); Staniskis & Stasiskiene (2006); Rondinelli & Vastag (2000); Legrand et al. (2014); Camilleri (2015); Lo-Iacono-Ferreira, Capuz-Rizo, Torregrosa-López (2018); Piecyk & Bjorklund (2015) | 7 |
| | Economic, Social & Environmental | Institute of Social and Ethical AccountAbility (AccountAbility) | Liu & Wang (2018); Piecyk & Bjorklund (2015) | 2 |

| | | | | |
|---|---|---|---|---|
| **Framework** | Economic, Social & Environmental | WBCSD | Langford (2007); Tyteca et al. (2002) | 2 |
| | Environmental | Sustainability Reporting Guidelines G3 | Langford (2007); Perez & Sanchez (2009); Adams (2004); Nikolaou & Tsalis (2013); Orazalin & Mahmood (2019); Kimbro & Cao (2011); Tyteca et al. (2002); Habek (2014); Garland (2001); Buyukozkan & Karabulut (2018); Bjorklund, Forslund & Isaksson (2016); da Rosa et al. (2015); Camilleri (2015); Piecyk & Bjorklund (2015); Fonseca, McAllister &Fitzpatrick (2014) | 15 |
| | Economic & Environmental | Reporting Guidelines for UK Business | Langford (2007) | 1 |
| | Economic & Environmental | A Manual for Preparers and Users of Eco-efficiency Indicators" (2004) – UNCTAD based on IASB Framework | Langford (2007) | 1 |
| | Environmental | Global Environmental Management Initiative | Eagan & Joeres (1997) | 1 |
| | Economic & Environmental | SEEA-2012 issued by the United Nations | Adams (2004) | 1 |
| | Economic, Social & Environmental | International Chamber of Commerce's (ICC) principles for sustainable development. | Eagan & Joeres (1997) | 1 |
| | Environmental | Carbon Disclosure Project (CDP) | Buyukozkan & Karabulut (2018) | 1 |
| **Rating and Indices** | Environmental | European Commission: Product and Organisation Environmental Footprint (PEF/OEF) methodology | Lehmann, Bach & Finkbeiner (2015) | 1 |
| | Environmental | Environmental Performance Index (EPI), formerly called Environmental Sustainability Index (ESI) | Huang, Wu & Yan (2015); da Rosa et al. (2015) | 2 |
| | Economic, Social & Environmental | Stock Exchange Sustainability Indices; (DJSI) | Buyukozkan & Karabulut (2018) | 1 |

For the purpose of this research, only those SRTs are taken into account that assist organizations in evaluating their environmental sustainability. In order to retrieve meaningful concepts that are actually used by companies, the most cited and therefore assumingly most adopted SRTs are considered in this research. It is to mention that most of the national reporting schemes and directives are based on international guidelines such as the GRI. Therefore, it can be concluded, that international SRTs form the bases for local directives and have been adopted by national legislations (Camilleri, 2015, p. 237).

Thus, within the scope of this research four SRTs have been selected: The ISO standard 14001, the ISO standard 14031, the Environmental Management Auditing Scheme (EMAS) and the Global Reporting Initiative (GRI) 300 series will be described in the following section.

### ISO 14001

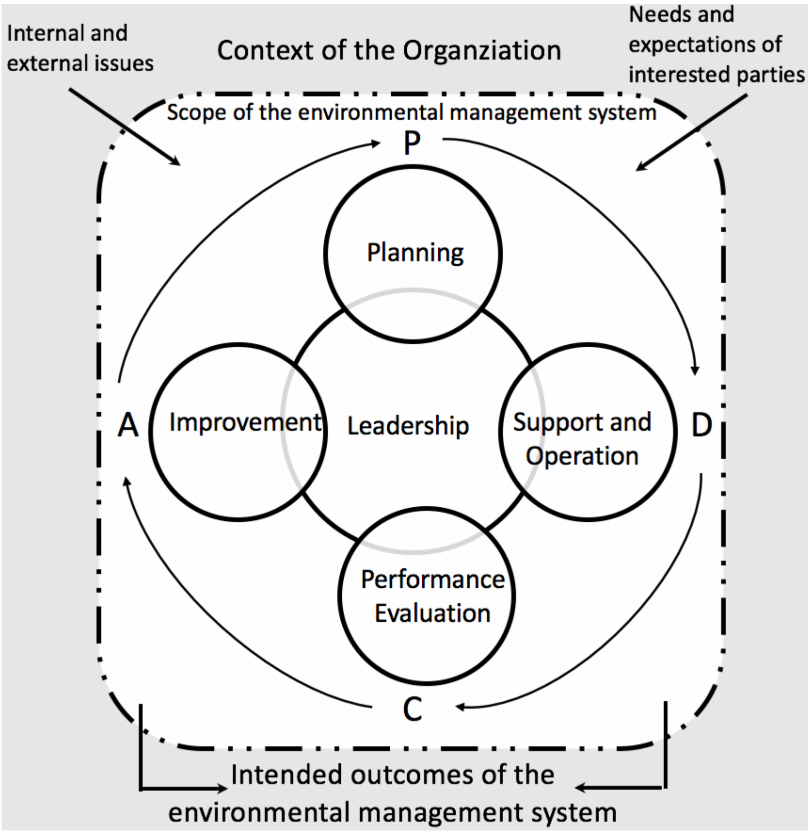
With the ISO 14000 family the International Organization for Standardization (ISO) responds to the need for environmental standards on a global scale that provide organizations with the tools to tackle environmental issues by setting up Environment Management Systems (EMS). The Technical Committee 207 (TC207) is responsible for the establishment of the ISO 14000 series and comprises seven sub-committees (SC) addressing different subjects:

- SC1: Environmental Systems
- SC2: Environmental Auditing
- SC3: Environmental Labelling
- SC4: Environmental Performance Evaluation
- SC5: Life Cycle Assessment
- SC6: Environmental Management — Terms and Definitions
- SC7: Greenhouse Gas Management and related activities

SC1 published a number of frameworks on requirements and guidelines for the implementation of an EMS. ISO 14001 are presented as the most popular standard and is the only one, organizations can be certified for (Jasch, 2000, p. 80-81). The most recent version of standard 14001 was published in 2015 (ISO 14001, 2015). It describes the requirements that need to be fulfilled in order to set up an EMS helping organizations to address environmental issues by improving their environmental performance, achieving compliance with environmental regulations and accomplishing environmental goals. While providing a systematic methodology to environmental management for organizations of all industries and sizes, ISO 14001:2015 does not specify any criteria for the assessment of environmental performance.

The methodological approach is based on the principle of continuous improvement following the Plan-Do-Check-Act Model (PDCA) which outlines the scope of the EMS within the organizational context (ISO 14001, 2015).

Figure 4: PCDA in ISO 14001 (adopted from ISO:14001, 2015)



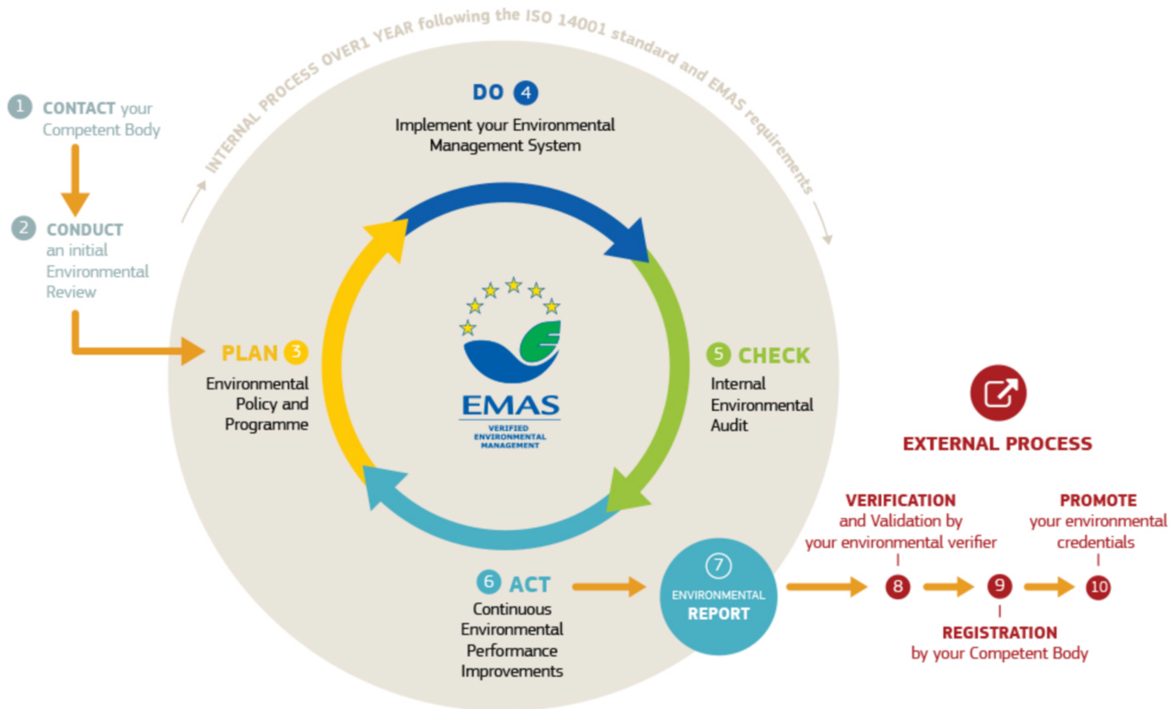

### ISO 14031

Sub-Committee 4 of the International Organization for Standardization has published a number of standards on environmental performance evaluation (EPE). ISO 14031:2013 has received most attention as it does not only provide guidelines but also specifies indicators for the EPE (ISO, 2013). According to this standard, EPE is defined as a process as well as a tool that enables the organization to assess its environmental performance against its own environmental objectives. In accordance with ISO 14001:2015 these environmental objectives can be established within the scope of an EMS. However, ISO 14031 can also be used independent from ISO 14001 and without any EMS in place. Similar to ISO 14001:2015 the process of EPE is based on an iterative cycle of the PDCA-Model as depicted in Figure 1. An essential part of this standard lays in the provision of indicators which can be used to quantify environmental data to measure against goals, analyse effectiveness of measures in place, compare performance over time, benchmark between other organizations and identify areas of improvement of environmental performance. For the quantification of environmental performance, indicators require the data to be expressed in absolute or relative measurements suitable for the evaluation following the methodology of an Input-Output Analysis. According to the standard, the organization that adopts this approach, is free to choose the unit of evaluation (e.g. site, firm, location, department etc.) as well as the indicators used for the evaluation as long as a comprehensive justification is provided and the selection of indicators is conducted following a number of principles such as comparability or target-orientation. The indicators can be distinguished in Environmental Performance Indicators (EPI) and Environmental Condition Indicators (ECI). While the latter one refers to direct environmental impacts, EPIs are classified in Management Performance Indicators (MPI) and Operational Performance Indicators (OPI). MPIs describe the efforts undertaken by management to improve the organization's environmental performance, while OPIs describe the environmental performance of the organizations' operations including the environmental impact related to its products, facilities, equipment and supplies (Jasch, 2000, p. 79-83). Further definitions are provided in Chapter 3.1.3.

### Eco-Management and Audit Scheme

The European Commission provides a more formal approach for organizations which extends the scope of the EMS proposed by the ISO. The Eco-Management and Audit Scheme (EMAS) is a voluntary environmental management tool for organizations providing guidance in the EMS implementation for continuous improvement of environmental performance. With an EMS in place, organizations are enabled to assess, improve and report on their environmental performance. While incorporating requirements of the ISO 14001, the scope of EMAS goes beyond. For instance, EMAS requires compliance to a number of requirements which need to be verified and validated externally before being admitted for registration. The process incorporates the PDCA-model, but is extended with additional steps that outline a detailed plan for organizations to achieve EMAS compliance (Figure 5). In addition to the external verification requirements, external communication is promoted by making environmental commitment public in a so-called EMAS environmental statement which include environmental goals and actions. Also, worth mentioning is the initial environmental review before the planning phase where the actual environmental issues related to the organization are assessed thoroughly. The review serves the identification of environmental problems, their origins and consequences, the stakeholders as well as legal requirements. It forms the bases for setting up the EMS which then can take all those factors into account for further actions (European Commission, 2018). Further definitions of EMAS concepts are provided in Section 3.1.3.

**Figure 5: EMAS Process Modell according to the European Commission (2018)**

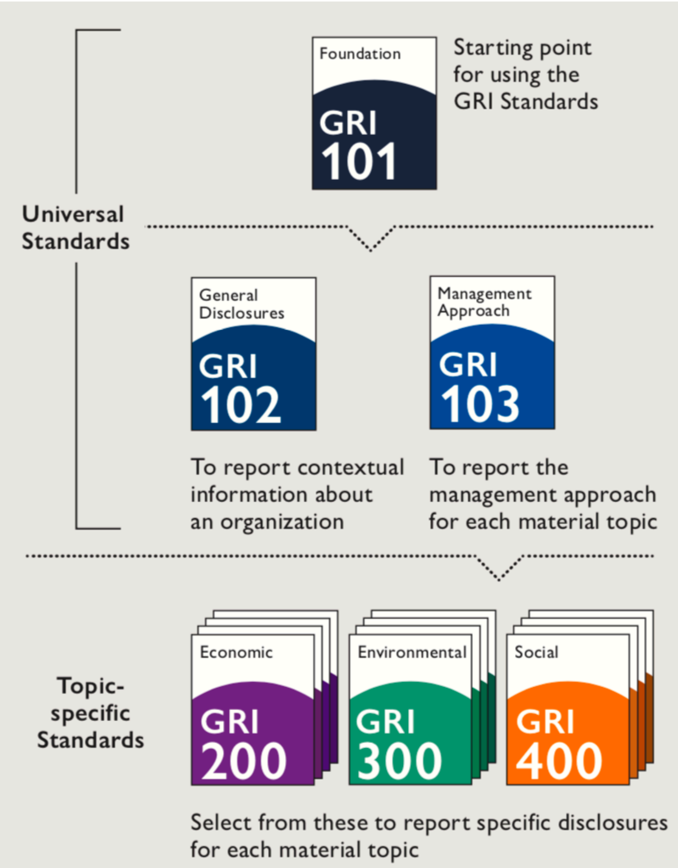


Similarly to the ISO 14031, the EMAS provides a number of indicators to evaluate the organization's environmental performance. Six key indicators are specified which are mandatory for reporting (Jasch, 2000, p. 80-81). The environmental performance indicators are further specified in Section 3.1.3.

### Global Reporting Initiative: GRI 300

Since 1997 the Global Sustainability Standards Board (GSSB) publishes a number of standards which assist organizations in their efforts of reporting in sustainability development. The sustainability standards are established to disclose an organization's social, environmental and economic negative and positive impacts and therefore reveal the organization's contribution to the SDGs. The standards can be seen as a guide and present best practices that organizations can adopt for sustainability reporting (GSSB (GRI website), 2020). Figure 3 depicts the different standards and their relations. While the GRI 100, including GRI 101 Foundations, GRI 102 General Disclosures and GRI 103 Management Approach are universal standards, the GRI series 200 Economic, GRI 300 Environmental and GRI 400 Social, represent topic-specific standards. The structure of the topic-related standards relates to the three pillars of sustainable development. In order to prepare a complete sustainability report, organizations adopt the GRI 100 standards to disclose general information about the organizational profile, their strategy and governance structures among others. Further, the GRI 100 series offers guidance for the selection of material topics and provides a set of reporting principles on the quality and contents of the report (GSSB (GRI 100), 2016).

Figure 6: GRI Standards according to the GSSB (GSSB (GRI 101), 2016)



The GRI 300 series focusses on the disclosure of an organization's environmental impacts and its contributions to environmental sustainability. The series on environmental sustainability comprises eight material topic standards:

- GRI 301: Materials (2016)
- GRI 302: Energy (2016)
- GRI 303: Water and Effluents (2018)
- GRI 304: Biodiversity (2016)
- GRI 305: Emissions (2016)
- GRI 306: Effluents and Waste (2016)
- GRI 307: Environmental Compliance (2016)
- GRI 308: Supplier Environmental Assessment (2016)

An organization can choose a material topic for its report. A material topic standard includes requirements, recommendations and guidance on a number of Management Approach Disclosures referring to GRI 103 and Topic-Specific Disclosures referring to GRI 301-308. Table 9 provides an example of a number of disclosures as provided in GRI 301.

**Table 9: Example of Disclosures in GRI 301 (GSSB (GRI 301), 2016)**

| Disclosure | Description | Reporting Requirements |
|---|---|---|
| **Disclosure 301-1** | Materials used by weight or volume | Total weight or volume of materials that are used to produce and package the organization's primary products and services during the reporting period, by:<br>- non-renewable materials used<br>- renewable materials used |
| **Disclosure 301-2** | Recycled input materials used | Percentage of recycled input materials used to manufacture the organization's primary products and services |
| **Disclosure 301-3** | Reclaimed products and their packaging materials | - Percentage of reclaimed products and their packaging materials for each product category<br>- How the data for this disclosure have been collected |

For instance, examples for recommendations are referring to the type of materials that should be included, how units should be selected or calculations and measurements should be performed (GSSB (GRI 301), 2016).

### 2.2.2. Environmental Performance and EA

Out of the 20 papers retrieved by query 2 (Table 10), four studies were found relevant investigating the relationship of environmental performance and EA as formulated in RQ2. The representation of the insights is structured within a concept matrix allowing the identification of mutual concepts and an overlap of topics discussed in the four papers. The results are presented in Table 10.

**Table 10: Results: Environmental Performance and EA in Literature**

| ID | EA concepts | Source | Environmental Performance Concepts | | | | |
|---|---|---|---|---|---|---|---|
| | | | energy consumption | Eco-Industrial Networking | $CO_2$ emissions | EP of ICT | green initiatives |
| 1 | Archimate technology layer | Cavaleiro, Vasconcelos & Pedro (2010) | x | | x | x | |
| 2 | GERAM Life-Cycle | Noran & Romero (2014) | | x | | | |
| 3 | EA Framework | Scholtz et al. (2014) | | | | | x |
| 4 | | Gill, Bunker & Seltsikas (2011) | | | | | x |

The scarce amount of results shows that the relationship of environmental performance and EA has not yet been investigated sufficiently. In fact, only two studies offer an EA-based approach to environmental performance (Cavaleiro, Vasconcelos & Pedro, 2010). The approach presented uses the EA language ArchiMate for modelling infrastructure of the technology in order to measure energy consumption and $CO_2$ emissions with the goal of assessing the overall environmental performance of ICT. In contrast, the other study presents a more general approach, proposing how eco-industrial networks (EINs) promote closed-loop systems of, among others, natural resources, energy, waste and information and featuring the evolution of symbiotic relationships to stimulate environmental performance by means of EA frameworks. While Cavaleiro, Vasconcelos and Pedro (2010) rely on ArchiMate for modelling purposes, Noran and Romero use the General Enterprise Reference Architecture Model (GERAM) as a source for comprehending the complex environment of organizations or networks by putting it in a lifecycle context.

Two studies are focusing on a framework supporting green initiatives with one study looking into sustainability reporting (Scholtz et al., 2014) and the other laying emphasis on the adoption green technologies (Gill, Bunker & Seltsikas, 2011).

Scholtz et al. (2014) propose a novel EA framework that ensures the alignment of IT planning and environmental management in order to address the lack of integrated systems that hinder efficient sustainability reporting of organizations embarking on green initiatives. While the authors do not refer to any existing EA standards, they highlight the focus of the proposed artifact on aligning existing EAs with the organisation's environmental goals on a strategic level.

Gill, Bunker and Seltsikas (2011) do research on how green technology will impact EA and IT vision of organizations in the financial service sector. Their findings show how enterprises perceive the new technology as a challenge as well as an opportunity and study how organizations intend to realize practices inherent to the adoption of green technologies to their own advantage. As a result of their analysis the authors state the "need of a structured and contextual framework to assist financial organisations in the systematic assessment and integration of these emerging technologies to their existing local and collaborative inter-organization environment" (Gill, Bunker & Seltsikas, 2011, p. 702). Although the need for such a framework is clearly stated and empirically proven, no complete framework is yet proposed.

In regard of research question RQ2a asking for EA-based approaches to measure environmental performance, it can be held that only one study (Cavaleiro, Vasconcelos & Pedro, 2010) can be found in literature that investigates EA-based measurement of environmental performance. The approach presented uses the EA language ArchiMate for modelling infrastructure of the technology in order to measure energy consumption and $CO_2$ emissions with the goal of assessing the overall environmental performance of ICT. However, the paper only focusses on single infrastructure components in the technology layer and does not take into any other layers of the organization's architecture into account.

Answering research question RQ2b, literature suggests the usage of the EA-modelling language ArchiMate as well as the usage of GERAM to approach environmental performance from an EA perspective. Further, new EA frameworks are proposed supporting organizations in aligning environmental strategies and embracing green technologies in the overall EA (Scholtz et al., 2014, Gill, Bunker & Seltsikas, 2011).

In summary, the EA practice has not yet contemplated, but rather disregarded environmental performance modelling. Therefore, literature does not suggest established best practices where frameworks and languages suitable for EA-based environmental performance modelling have stayed unnoticed by the researchers' and practitioners' community so far. With the results obtained from the SLR, the treatments design phase in the following Chapter 3 can carry out an analysis of the environmental concepts of the presented SLRs (2.2.1) and analyse its fit to the ArchiMate language (2.1.2)

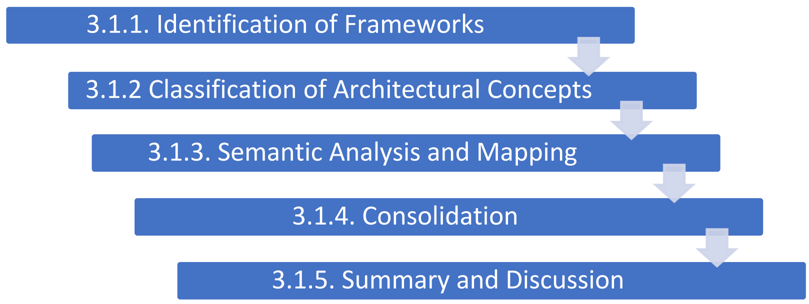
# 3. TREATMENT DESIGN

***Chapter 3 deals with the second phase of the design cycle: The treatment design of the artifact. For this purpose, all necessary concepts are gathered, defined and mapped to ArchiMate, consolidating relevant domain-specific concepts from literature (Section 3.1) and revisited and challenged by practice (Section 3.2). Section 3.1.5 delivers the first version of the artifact. Results addressing research question RQ3a and RQ3b are discussed in Section 3. Subsequent Section 3.4 describes the quantitative approach, thus provides answers for research question RQ3c. The final artifact and results for research objective RO3 are presented in Section 3.5.***

## 3.1. Concepts from Literature

This section assesses a range of well-established paradigms for environmental performance modeling and evaluation, retrieves a set of principal concepts from literature, and maps them to ArchiMate elements. Figure 7 depicts the steps of the selection and mapping process per section.

**Figure 7: Selection and Mapping Process**




Section 3.1.1 describes the SRTs that are subject of the analysis.

In Section 3.1.2, the underlying guidelines for the identification and qualification as architectural concepts are described. Further, concepts extracted from the SRTs are classified as architectural concepts. Concepts that do not qualify as such are excluded and not considered for the following semantic analysis and mapping process.

Based on this, Section 3.1.3 provides a semantic analysis of the ISO 14031, the Eco-Management and Audit Scheme and the Sustainability Reporting Guidelines G3. This includes the careful examination of each concept and its definition. On the grounds of this analysis, the concepts are mapped to ArchiMate elements which are described in Section 2.1.2.

Section 3.1.4. presents a consolidated list of all the retrieved and mapped concepts while Section 3.1.5 summarizes the insights gained from the mapping process.

### 3.1.1. Identification of Frameworks

Literature as presented in Chapter 2 reveals a variety of SRTs that support organizations in the reporting and evaluation of environmental performance on a corporate level.

In Section 2.1.1 a general overview has been provided about the different types of corporate SRTs that are available. The retrieved results provide a starting point for this research which seeks to arrive at a consent for a consolidated set of essential concepts. These concepts aim at providing the means for modelling the following activities:

- Representation of Environmental SRTs
- Environmental Performance Evaluation

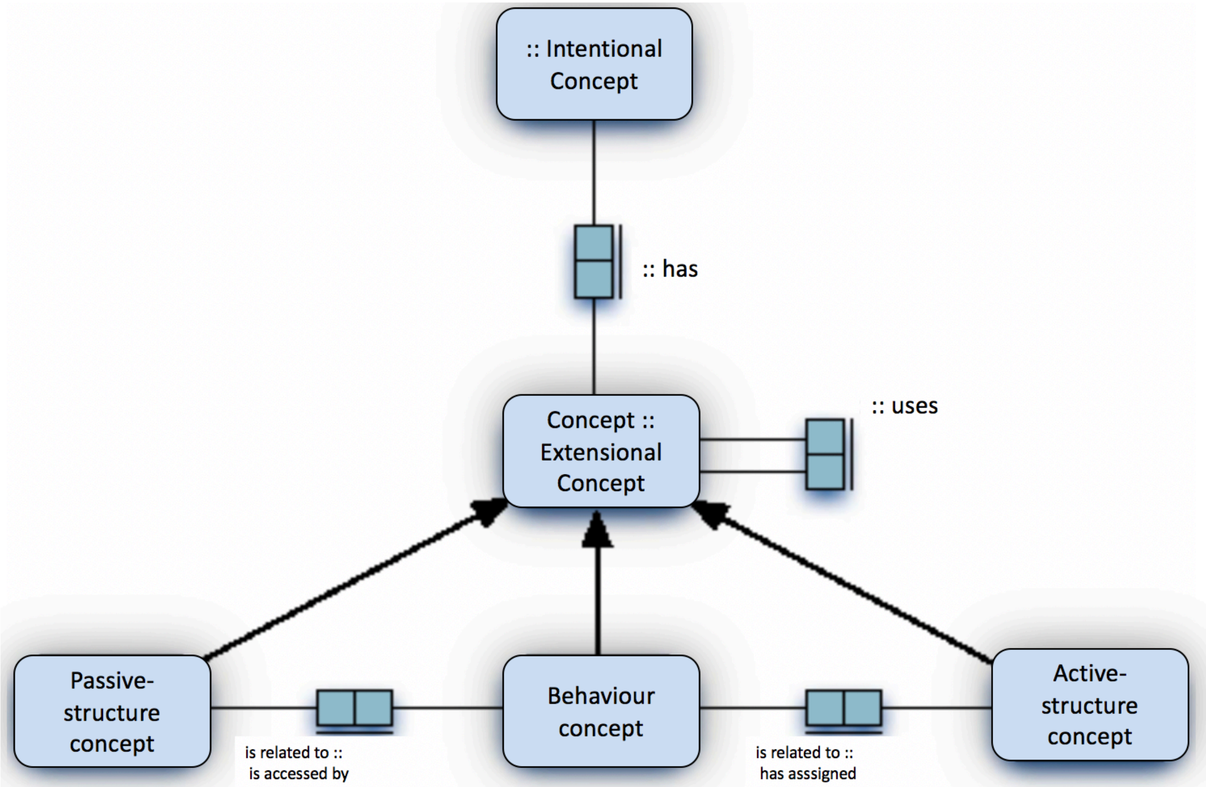
Due to the limited scope of this research, only the ISO 14001, the ISO 14031, the Eco-Management and Audit Scheme and the Sustainability Reporting Guidelines G3 are taken into account. The SLR shows that these are the most common SRTs (see Section 2.2.1).

### 3.1.2. Classification of Architectural Elements

In order to identify which environmental performance concepts qualify as architectural concepts that can be visualized in ArchiMate, the new concepts need to be aligned to the ArchiMate elements. For this purpose, the development and identification process of the ArchiMate elements itself is followed, guided by the definition of concepts on different abstraction levels. As described in Lankhorst (2010), on the most abstract level, the distinction between entities and relationships is made. On the next level, the abstract entities are further specialized as *Active Structure Element*, *Passive Structure Elements* and *Behaviour Elements*. Further specializations are then performed into specific architectural elements which enable the design of detailed EA models (Lankhorst, 2010, p. 13ff).

This procedure can be transferred to the identification of concepts related to environmental performance and enables the modelling and visualization of environmental performance management in the enterprise architecture using ArchiMate. The identification of concepts as either an *Active Structure*, a *Passive Structure* or a *Behaviour element* enables the qualification of concepts as suitable for architectural modelling and integration to ArchiMate. This is necessary to assure the alignment of new concepts to existing ArchiMate elements. The distinction in *Active Structure*, *Passive Structure* or *Behaviour elements* is generic as they cover the core elements of the ArchiMate language including the Business, Application and Technology layers as defined for the Dynamic System approach described by Lankhorst (2010). While those concepts are defined as *extensional concepts* being of an objective and descriptive nature, a second class is identified as *intentional* concepts which capture subjective notions about the extensional concepts originating from various stakeholders' interests (Lankhorst, 2010, p. 13ff.). Intentional concepts are elaborated as *motivation* elements in the most recent ArchiMate 3.1 Specification. Motivation elements form the fourth group of classification for the purpose of recognizing architectural concepts from the depicted frameworks and standards. Figure 8 shows the classification of concepts in the ArchiMate language by Lankhorst (2010).

**Figure 8: Concept in ArchiMate (adopted from Lankhorst, 2010)**




Considering the most recent ArchiMate Specification 3.1 from The Open Group (2012-2019), in addition to the core layers including Business, Technology and Application, new elements are introduced: Physical elements and Implementation & Migration elements. According to The Open Group, physical elements are core elements as they are part of the Technology layer whereas the elements of Implementation and Migration constitute a new layer (The Open Group, 2012-2019).

Accordingly, a classification of the concepts that were extracted from the frameworks and standards has been performed. Table 11 shows the classification of concepts in *Active Structures*, *Passive Structures*, *Behavior* or *Motivation* elements. Concepts that can be found in this classification scheme qualify as architectural concepts. The classification scheme does not indicate to which layer the element belongs (Business, Application, Technology, Physical, Implementation & Migration).

Here, only concepts related to the domain of environmental performance are considered here. General concepts, such as "organization" or "stakeholder", that are not domain-specific but common concepts in EA modelling with ArchiMate are out of the scope of this research.

Table 11: Identification of Architectural Concepts

| | Active Structure | Passive Structure | Behaviour | Motivation |
|---|---|---|---|---|
| **ISO 14001** | | EMS | plan, do, check, act | environmental policy, environmental aspect, environmental objective, environmental condition, environmental impact, environmental performance |
| **ISO 14031** | | EMS | plan, do, check, act, environmental performance evaluation | indicator principles, management performance indicators, operational performance indicators, environmental condition indicators, environmental impact, environmental aspect, environmental objective, environmental performance, environmental target, environmental policy |
| **EMAS** | EMAS verifier, management representative | | environmental review, planning, EMS implementation and operation, checking, verification, validation, management Review, environmental management system, action | EMAS environmental statement, environmental policy, legal compliance, legal requirements, enforcement authority, environmental objective, environmental target, core indicators, environmental impact, environmental aspect |
| **GRI** | | | conservation and efficiency initiative | environmental laws and regulations, reporting principles for defining report quality, reporting principles for defining report content, material topic specific disclosures, management approach disclosure, impact |

This first classification into architectural concepts allows the mapping of environmental concepts to ArchiMate elements.

For a number of concepts, a straightforward mapping can be realized as presented in Table 12.

Table 12: Examples of Mapping

| Environmental Concepts | Relationship | ArchiMate Element | SRT |
|---|---|---|---|
| **Environmental Laws and Regulations** | Corresponds to | Driver | GRI |
| **Legal Compliance** | | | |
| **Legal Compliance** | | | EMAS |
| **Legal Requirements** | | Requirement | |
| **Enforcement Authority** | | Stakeholder | |
| **EMAS Verifier** | | Business Role | |
| **Management Representative** | | | |

However, this is not the case for all environmental concepts. Concepts extracted from the SRTs that cannot be classified as architectural concepts are listed in Table 13.

Table 13: Environmental Concepts that cannot be mapped

| SRT | Concepts |
|---|---|
| **ISO 14001** | prevention of pollution |
| **ISO 14031** | MPI, OPI, ECI |
| **EMAS** | core indicators |
| **GRI 300** | non-renewable material, recycled input material, renewable material, reclaimed, renewable, non-renewable, effluent, freshwater, groundwater, produced water, runoff, seawater, surface water, third-party water, water consumption, water discharge, water withdrawal, energy reduction, protected area, area protected, area restored, area of high biodiversity value |

In these cases (see Table 13), the definition and mapping process identifies deficiencies of the ArchiMate Modelling Language. According to Wand & Weber (2002) four types of deficiencies can be distinguished. These are depicted in Table 14.

Table 14: Deficiency Types according to Wand & Weber (2002)

| Type | Definition (Wand & Weber 2002, p. 365) | Deficiencies in ArchiMate |
|---|---|---|
| **Construct Redundancy** | Several grammatical constructs map to one ontological construct. | Several ArchiMate concepts map onto one environmental concept |
| **Construct Excess** | A grammatical construct might not map to any ontological construct | An ArchiMate concept might not map onto any of the environmental concepts |
| **Construct Deficit** | An ontological construct might not map to any grammatical construct. | An environmental concept might not map onto any of the ArchiMate concepts |
| **Construct Overload** | Several ontological constructs map to one grammatical construct. | Several environmental concepts map onto one ArchiMate concept |

Based on the types of deficiencies, more suitable modelling options for the environmental concepts into ArchiMate can be identified.

To begin with, a construct redundancy is an indicator for a generalization relationship where an environmental concept can be mapped to several ArchiMate elements depending on the context and intention of the modeler.

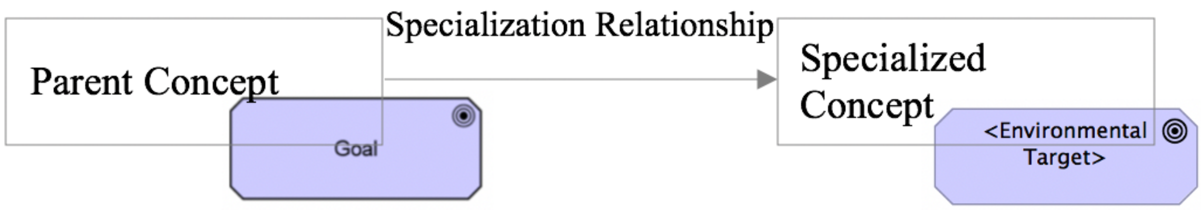
In contrast, the deficiency type of a construct excess is not relevant for the mapping of environmental concepts to ArchiMate elements as its domain-specificity will only make use of certain ArchiMate elements. It is not the intention of this research to narrow the scope of the ArchiMate language. Quite the contrary, the broad expressiveness for multiple domains which the ArchiMate language covers offers a huge advantage in EA Modelling.

A construct deficit however, requires the introduction of a new ArchiMate element. For this purpose, the ArchiMate language provides so-called language customization mechanisms as described by The Open Group Standard (The Open Group, 2012-2017). These mechanisms allow next to generic EA modelling, also domain-specific modelling or specific types of analysis. Thus, the customization mechanisms also support the modelling and analysis purposes regarding environmental performance in organizations (The Open Group, 2012-2017, p. 109).

One of the language customization mechanisms that facilitates the modelling and analysis of environmental performance, is the "profiling" specialization mechanism. Through profiles which are defined as data-structures that are linked to ArchiMate elements or relationships, it is possible to assign attributes. Two types of profiles are described: While Pre-Defined Profiles have pre-defined attribute structures, with User-Defined Profiles, users are enabled to define new attributes that can be linked to ArchiMate elements and relationships (The Open Group, 2012-2017, p. 109-110).

The role of language customization mechanisms is twofold: (1) it provides the means to introduce specializations of concepts (the parent concept). Figure 9 shows how the existing element *Goal* can be customized to introduce a specialized element *Environmental Target*. The Specialization relationship denotes that the specialized concept has the same properties as the Parent Concept. However, the parent Concept can be distinguished from the specialized concept as the latter one has some additional properties justifying its introduction as a specialization. To demonstrate the link as well as the distinctiveness of the specialized concepts in comparison the parent concept the graphical notation as shown below shows a strong resemblance between both elements. A typical notation uses angled brackets in the Specialization. (The Open Group, 2012-2017, p. 109-110).

**Figure 9: Example of a Specialization using the "Profiling" Specialization Mechanism**



(2) it offers a way to define metrics as attributes and link them to respective elements. For instance, the specialized concept <<*Energy Source*>> stemming from an original ArchiMate concept *Material* has been linked to an attribute. Attributes are not expressed as separate elements but are defined as a property. The whole of properties of a respective element can defined as a profile. Figure 10 shows the profile including the attribute *renewable* which in turn further defines the element *Energy Source*. Next to the attribute itself a value can be added allowing a quantification of one or more attributes of an element.

**Figure 10: Example of an Attribute using the Profiling Specialization Mechanism**

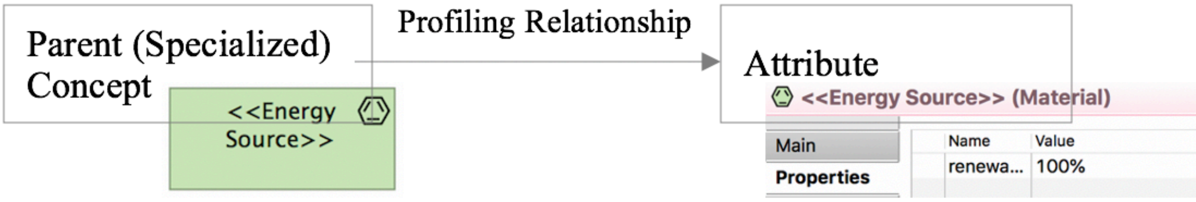
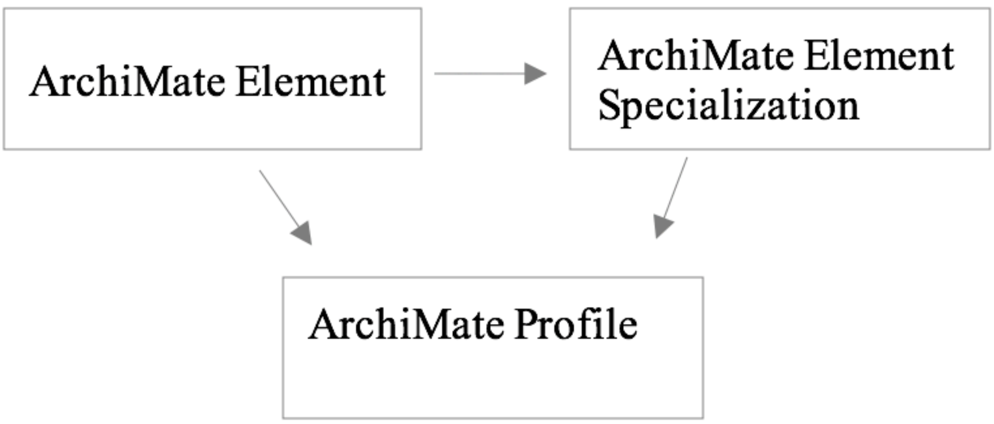



Figure 11 illustrates how elements in ArchiMate can be used to model a specialization (ArchiMate Element Specialization) and how attributes can be assigned to both original ArchiMate elements or specialized ArchiMate elements. Both the creation of specialized elements as well as the definition of attributes is based on profiles (The Open Group, 2012-2017, p. 109-110). The definition of attributes is from now on referred to "Profiles" while Specializations are referred to as "Specializations". The representation of profiles as well as specializations in ArchiMate is exemplified in Figure 11 and 12. The tool used for modelling is "Archi" (https://www.archimatetool.com).

**Figure 11: ArchiMate Modelling Customization Options**




Lastly, a construct overload implies that a suitable ArchiMate construct is available but that it is too generic to express different environmental concepts. Thus, a construct overload denotes the need for a specialization, based on the language customization mechanism, in order to distinguish environmental concepts in ArchiMate.

### 3.1.3. Semantic Analysis and Mapping

After identifying those concepts suitable to be integrated into the ArchiMate language, we mapped the environmental concepts to ArchiMate elements. In order to do this, all architectural concepts of each SRT are mapped to a specific ArchiMate element by comparing the concepts' definitions. In case a straightforward mapping is not possible, the type of deficiency is taken into account to identify more suitable modelling options. As the SRTs selected provide a large number of concepts, concerning the attributes, only a selection is presented in Chapter 3.1.3 in order to exemplify such a mapping.

There are four options in the mapping process (Table 15):

1. In the simplest option an environmental concept can be mapped to the ArchiMate elements as it corresponds to its original definition in the standard.

2. Construct Overload: A second option is the specialization of ArchiMate elements in order to express an environmental concept.

3. Construct Redundancy: This involves the case that an environmental concept can be mapped to several ArchiMate elements dependent on the modelling intentions (generalization).

4. Construct Deficit: The third option necessitates the introduction of a new element. This option involves the possibility to define customized attributes as described for the profile language mechanisms. In contrast to the specialization which can also be considered as the introduction of a new element, the specialization is based on an already existing element which is just considered to be too generic to be able to express the complete meaning of the concept. Attributes however cannot be expressed by any element yet and need to be defined anew.

**Table 15: Mapping Options and Relationships**

| Mapping Option | Deficiency Type | Type of Mapping Relationship |
|---|---|---|
| **(1) ArchiMate element available** | No Deficiency | Corresponding |
| **(2) Too generic ArchiMate elements available** | Construct Overload | Specialization |
| **(3) Multiple suitable ArchiMate elements available** | Construct | Generalization |
| **(4) No corresponding ArchiMate element available** | Construct Deficit | Creation and definition profile |

#### ISO 14001 Concepts

In this section core concepts retrieved from ISO 14001 are defined and mapped to the ArchiMate language. A summary is presented in Table 17. The colors in the table indicate to which ArchiMate layer or type of element the respective element belongs. Strategy elements are depicted in orange, business elements are shown in yellow and motivational elements are represented in violet. If not indicated otherwise, the definitions refer to the International Organization for Standardization, 2015 (ISO, 2015).

**Environmental Management System (EMS):** The EMS is defined as the "part of the management system used to manage environmental aspects, fulfil compliance obligations and address risks and opportunities" (ISO, 2015). As an EMS is comprised by a number of elements such as people and processes in order to achieve the high-level and long-term goal of environmental sustainability, it maps most naturally to a *Capability* element in ArchiMate.

**Environmental Policy:** According to the ISO 14001 this policy states the "intentions and direction of an organization related to environmental performance, as formally expressed by its top management" (ISO, 2015). Further, it includes commitment regarding environmental aspects, the prevention of pollution as well as continuous improvement of the organization's environmental performance. As a framework of action, the policy guides the organization's environmental strategy and specification of respective objectives and targets. The environmental policy can be seen as "a directive that is not directly enforceable, whose purpose is to govern or guide the enterprise" (The Open Group, 2012-2017, p. 114). As it matches the description provided in the ArchiMate Specification for a *Principle* element it can be represented as a new specialization of a *Principle*.

**Environmental Aspect:** This concept describes an element, possibly input-related, of an organization's activities, products or services that potentially impacts the environment. Environmental aspects are distinguished in their type (direct/indirect) and their magnitude (e.g. significant environmental aspect). The environmental aspect appears to have the characteristics of an attribute or a describing property. However, taking into account that properties or attributes do not meet the criteria of architectural concepts as defined in 3.1.2, environmental aspects have no corresponding element in ArchiMate yet. Nevertheless, considering the concept's relevance in this standard, it is recommended to express its meaning by different means. The specialization relationship allows the modelling as a specialized *Activity*, *Product* or *Service* element.

**Environmental Condition**: This concept is defined as the „state or characteristic of the environment as determined at a certain point in time" (ISO, 2015). This concept maps most naturally to an *Assessment* element and should be modelled as a specialization.

**Environmental Objective:** This concept refers to a rather general environmental goal, derived from the environmental policy. It defines what the organization intends to achieve in regard to environmental performance and is expressed in measurable terms if possible. Representing a high-level statement of intent, this concept most naturally maps to the *Goal* element in ArchiMate.

**Environmental Impact**: This concept describes the effect an environmental aspect causes and specifies what kind of harm it creates to the environment. An impact could be mapped as an *Outcome* as is presents the result of an analysis. It is proposed to introduce a specialized element of the *Outcome* element to depict the environmental impact concept. An environmental impact could be for example "GHG emissions rising about 10%" could be associated with *Drivers* like "comply to environmental regulations".

**Prevention of Pollution**: This concept describes the "use of processes, practices, techniques, materials, products, services or energy to avoid, reduce or control (separately or in combination) the creation, emission or discharge of any type of pollutant or waste, in order to reduce adverse environmental impacts" (ISO, 2015). In order to be able to measure and quantify the pollution of processes, practices, techniques, materials, products or services, it is recommended to model it as an attribute. The prevention of pollution is therefore assigned to a process or product for example. However, an energy reduction is not solely limited to business processes, but also other behavior elements, but could also be a property of a passive structure such as products or materials. The profiling options are depicted in Table 16.

Table 16: Profiling Options: Prevention of Pollution

| Attribute: reduction/saving | Type of measure | Element |
|---|---|---|
| **Prevention of Pollution** | Respective measure e.g. KG for materials or GW for energy | Behavior elements, Passive Structures |

**Environmental Performance**: This concept describes the "performance related to the management of environmental aspects [where] results can be measured against the organization's environmental policy, environmental objectives, environmental targets and other environmental performance requirements" (ISO, 2015). Similarly, to the impact concept, environmental performance needs to be measured and improved. Considering the fact that environmental performance can be measured against the policies and objectives set by the organization, in this research we propose to introduce a specialized element of the O*utcome* element to depict this concept. An example could be "environmental performance increased about 10%".

**Plan**: This concept describes a *Business Process, Business Function* or *Capability* and includes the section of indicators.

**Do**: Similarly, to the "plan" concept, the "do" concept can be depicted as a *Business Process, Business Function* n or *Capability*. Classified as a *Business Process,* it consists out of four sub-processes, including the following: Collect data, analyse data, assess information as well as report and communicate.

**Check**: This concept can be depicted as a *Business Process, Business Function* or *Capability*. It comprises a review process.

**Act**: This concept can be classified as a business process, function or *Capability*. It comprises an "improve" process.

**Table 17: Mapping between ISO 14001 concepts and ArchiMate Elements**

| **ISO 14001 Concept** | **Relationship** | **ArchiMate Element** | **Deficiency Type** |
|---|---|---|---|
| EMS | Specialization | Capability <EMS> | Construct Overload |
| Environmental Policy | Specialization | Principle <Environmental Policy> | |
| Environmental Aspect | | Activity, Product or Service <Environmental Aspect> | |
| Environmental Condition | | Assessment <Environmental Condition> | |
| Environmental Impact | | Outcome <Environmental Impact> | |
| Environmental Performance | | Outcome <Environmental Performance> | |
| Environmental Objective | Corresponds to | Goal | No Deficiency |
| Plan | Generalization | Business Process/Function/Capability* | Construct Redundancy |
| Do | | Business Process/Function/Capability* | |
| Check | | Business Process/Function/Capability* | |
| Act | | Business Process/Function/Capability* | |
| Prevention of Pollution | Profiling | Behavior elements, Passive Structures | Construct Deficit |

Note: * while a *Business Process* and a *Business Function* belong to the Business Layer in ArchiMate, a *Capability* belongs to the Strategy Layer. Due to limited space the *Capability* is depicted in yellow in Table 17 where the color indicates falsely its relation to the Business Layer.

### ISO 14031 Concepts

In this section core concepts retrieved from ISO 14031 are defined and mapped to the ArchiMate language. A summary is presented in Table 19. If not indicated otherwise, the definitions refer to the International Organization for Standardization, 2013 (ISO, 2013).

**Environmental Aspect**: See ISO 14001.

**Environmental Impact**: See ISO 14001.

**Environmental Management System (EMS):** See ISO 14001.

**Environmental Objective**: See ISO 14001.

**Environmental Performance**: See ISO 14001.

**Environmental Performance Evaluation (EPE)**: This concept describes a "process to facilitate management decisions regarding an organization's environmental performance by selecting indicators, collecting and analyzing data, assessing information about environmental performance, reporting and communicating, and periodically reviewing and improving this process" (ISO, 2013). The generalization relationship indicates that depending on its context, this concept can either be mapped to a *Business Process*, a *Business Function* or a *Capability*.

**Environmental Policy**: See ISO 14001.

**Environmental Target:** This concept is derived from the environmental objectives set by the organization and specifies a detailed performance requirement that has to be met in order to fulfill the environmental objectives. Representing a specific and detailed description of expected outcomes, this concept presents a specialization of the *Goal* element in ArchiMate.

**Principles for Indicators**: Principles serve as guidelines to determine environmental indicators. The ISO 14031 defines six principles according to which the selected indicators should be comparable, target-oriented, balanced, continued, frequent and comprehensive (Jasch, 2000, p. 82). This concept maps most naturally as specialization of a *Principle* element.

**Management Performance Indicators (MPI)**: According to the ISO, MPI "provide[s] information about the management activities to influence an organization's environmental performance" (ISO, 2013). Examples are provided in Table 18. The mapping of the performance indicators is somewhat ambiguous and dependents on the context and the indicator itself. Considering the example "number of environmentally friendly suppliers", the organization could conduct an assessment to evaluate the exact number of environmentally friendly suppliers. In this example the MPI would map most naturally to the *Assessment* Element in ArchiMate. To be more specific, it is recommended to introduce a specialization of an *Assessment* element. However, taking other examples, it would be more intuitive to express the indicator as a profile. This would be enabled by using the profiling mechanism of the ArchiMate language. Especially, indicators which, for instance, measure energy consumption per technology device or business process, it would be useful to attach the indicator as an attribute to the designated element.

**Operational Performance Indicators (OPI)**: The ISO defines this concept as an indicator that "provides information about the environmental performance of an organization's operational process "(ISO, 2013). Examples are provided in Table 18. The mapping corresponds with the mapping of the MPI as described above.

**Environmental Condition Indicators (ECI)**: According to the ISO these type of indicators "provides information about the local, regional, national or global condition of the environment "(ISO, 2013). Furthermore, indicators are defined as "measurable representation of the condition or status of operations, management, or conditions" (ISO, 2013). Examples are provided in Table 18. The mapping corresponds with the mapping of the MPI as described above.

**Table 18: Examples for Indicators (Jasch, 2000, p. 83)**

| Management Performance Indicators | Operational Performance Indicators | Environmental Condition Indicators |
|---|---|---|
| number of environmental audits undertaken | electricity consumption per production unit | effect of air emissions on the regional air quality |
| percentage of employees with environmental training | total waste | effect of water emissions on waterways in the vicinity of a production site |
| number of environmentally friendly suppliers | average petrol consumption of the transport fleet. | |

**Plan**: See ISO 14001.

**Do**: See ISO 14001.

**Check**: See ISO 14001.

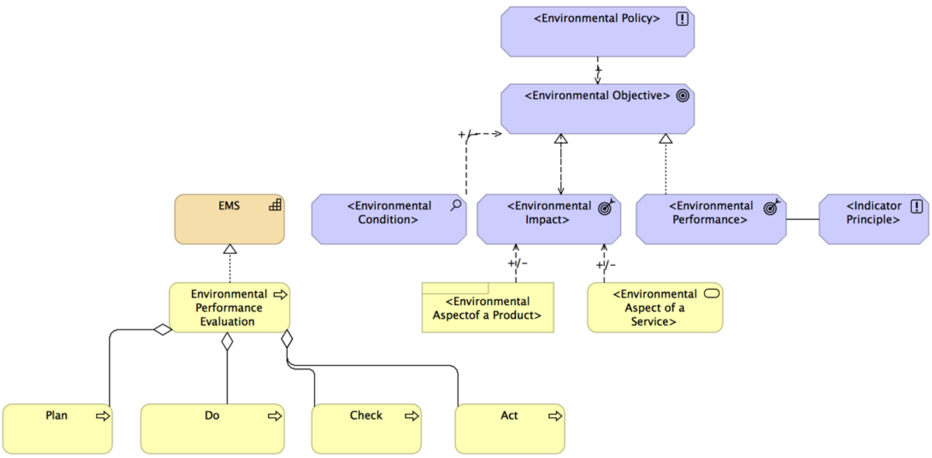
**Act**: See ISO 14001.

**Table 19: Mapping between ISO 14031 concepts and ArchiMate Elements**

| ISO 14031 | Relationship | ArchiMate Element | Deficiency Type |
|---|---|---|---|
| Principles for Indicators | Specialization | Principle <Indicator Principle> | Construct Overload |
| Environmental Target | | Goal <Environmental Target> | |
| Environmental Impact | | Outcome <Environmental Impact> | |
| Environmental Policy | | Principle <Environmental Policy> | |
| Environmental Performance | | Outcome <Environmental Performance> | |
| EMS | Specialization | Capability <EMS> | |
| Environmental Aspect | Specialization | Activity, Product or Service <Environmental Aspect> | |
| Environmental Performance Evaluation | Generalization | Business Process/Function/Capability* | Construct Redundancy |
| Plan | | Business Process/Function/Capability* | |
| Do | | Business Process/Function/Capability* | |
| Check | | Business Process/Function/Capability* | |
| Act | | Business Process/Function/Capability* | |
| Management Performance Indicators | Profiling | Behavior elements, Passive Structures | Construct Deficit |
| Operational Performance Indicators | | | |
| Environmental Condition Indicators | | | |

Note: * while a *Business Process* and a *Business Function* belong to the Business Layer in ArchiMate, a *Capability* belongs to the Strategy Layer. Due to limited space the Capability is depicted in yellow in Table 19 indicating falsely its relation to the Business Layer.

**Figure 12: Metamodel ISO 14001 and ISO 14031**



### EMAS Concepts

In this section core concepts retrieved from EMAS are defined and mapped to the ArchiMate language. All definitions of environmental concepts provided in this section refer to the Official Journal of the European Union, 2017 (EEC, 2017) and are, henceforth, not specified individually for each definition. A summary is presented in Table 21. The colors in the table indicate to which ArchiMate layer or type of element the respective element belongs. Strategy elements are depicted in orange, business elements are shown in yellow and motivational elements are represented in violet. As the EMAS is partially based on the ISO 14000 series in general and the ISO 14001 and ISO 14031 in specific, some concept definitions are identical to the ones provided in the previous section. For those concepts, a respective reference is given.

**EMAS environmental statement**: This concept refers to the comprehensive information to the public and other interested parties regarding an organization's: structure and activities; environmental policy and environmental management system, environmental aspects and impacts; environmental programme, objectives and targets; environmental performance and compliance with applicable legal obligations relating to the environment.' (EEC, 2017, p. 61) The EMAS environmental statement can be considered as a *Representation* of the overall intentions of an organization towards environmental sustainability. For instance, it represents the commitments to environmental policy as well as to the environmental programme. This concept maps most naturally as a specialization of a *Representation* element.

**Environmental Policy**: See ISO 14001.

**Legal Compliance:** Legal compliance refers to the identification and application of relevant legal environmental requirements and is a key requirement of the EMAS regulation. Legal compliance presents an external driver motivating the organization to address environmental issues. Thus, this concept corresponds with the *Driver* element.

**Legal Requirements:** This concept includes national, regional as well as local requirements, such as licenses and permits which state necessities an organization must fulfill in order to comply with environmental legislation. This concept maps most naturally to the *Requirements* element in ArchiMate.

**Enforcement Authority:** Enforcements authorities are entities associated with certain responsibilities related to environmental requirements. Their tasks include the provision of information to organizations about relevant environmental requirements and their fulfilment. Representing certain interests, the enforcement authority maps most naturally to the *stakeholder* element in ArchiMate.

**Environmental Objective**: See ISO 14001.

**Environmental Target**: See ISO 14001.

**Environmental Programme**: The environmental programme assists the organization in planning and realizing environmental improvements. This includes the "description of environmental objectives, linked to direct and indirect aspects, specific targets to achieve the objectives, actions, responsibilities, means and timeframe for each target." (EEC, 2017, p. 51). The environmental programme could be mapped as a specialization of the *Course of Action* element as it can be characterized as a long-term plan to achieve some goal by providing a strategy.

**Environmental Aspect**: See ISO 14001.

**Environmental Impact**: See ISO 14001.

**Environmental Review:** This concept comprises the „initial comprehensive analysis of environmental aspects, environmental impacts and environmental performance related to an organization's activities, products and services." (EEC, 2017, p. 46). This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**Planning:** The planning can be defined as a process that includes the definition of the environmental objectives and targets and the setting up of the environmental programme. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**EMS implementation and operation**: The process of implementation and operation refers to several subject matters such as: (1) resources, roles, responsibility and authority, (2) staff competence, training and awareness, including employee involvement, (3) Communication (internal and external) (4) documentation and control of documents, (5) operational control as well as (6) emergency plans. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**Checking:** This process involves several sub-processes, namely: (1) the monitoring and measurement of defined parameter and core performance indicators, (2) the evaluation of legal compliance, (3) the procedures in case of non-conformity and need for corrective and preventive actions, (4) the control of records and (5) the internal audit. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**Verification:** This concept describes an evaluation process ensuring conformity with the regulations' requirements. This includes the overall set-up of the EMS by the organization. The verification process is conducted by the EMAS verifier. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**Validation**: This concept describes the process directly following the verification. It involves the verifier confirming the reliability, credibility and correctness of the environmental information provided by the organization (e.g. in its environmental statement) and its fulfilment of the requirements of the regulation. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**EMAS Verifier**: This concept describes an entity entitled for the verification and validation of EMAS for an organization. For this purpose, proper accreditation and licenses in accordance with the respective regulations have to be obtained. As an EMAS verifier is defined by certain responsibilities and competencies and its assignment to a specific task, it corresponds to a *Business Role* in ArchiMate.

**Management Review:** The management review is a re-occurring process of top management revising the management system in place regarding its effectiveness and value. A management review can lead to modifications in the EMS including its objectives or the environmental policy. This concept can be depicted by multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements are a *Business Process*, a *Business Function* or a *Capability*.

**Management Representative:** This concept describes a role in charge for the operation and maintenance of the EMS. The management representative is selected by top management which has to ensure his/her qualification for the role is obtainable within the organization. As a management representative is defined by certain responsibilities and competencies and its assignment to a specific task, it corresponds to a *Business Role* in ArchiMate.

**Action:** Actions are activities that are derived by environmental targets and are carried out to achieve environmental improvements. An action maps most naturally to a specialization of a *Course of Action* in ArchiMate as it is undertaken in order to achieve some kind of goal specified as an environmental objective or target.

**Environmental Management System**: See ISO 14001.

**Core Indicators:** This concept enables the assessment of the organization's environmental performance in regard to six areas including: energy, materials, water, waste, biodiversity (through land use) and emissions. The European Commission established a number of core indicators which are mandatory to be included in the report. Core indicators are a valuable source of information when assessing environmental performance within an organization. From this point of view, these should be modelled as attributes which can be assigned to the respective active structure, passive structure or behavior elements to which they are associated. Using the profiling mechanism, Table 20 presents the core indicators, their measures and respective metrics and associated elements.

Table 20: Profiling Options: Core Indicators and respective Metrics (EEC, 2017, p. 63-65).

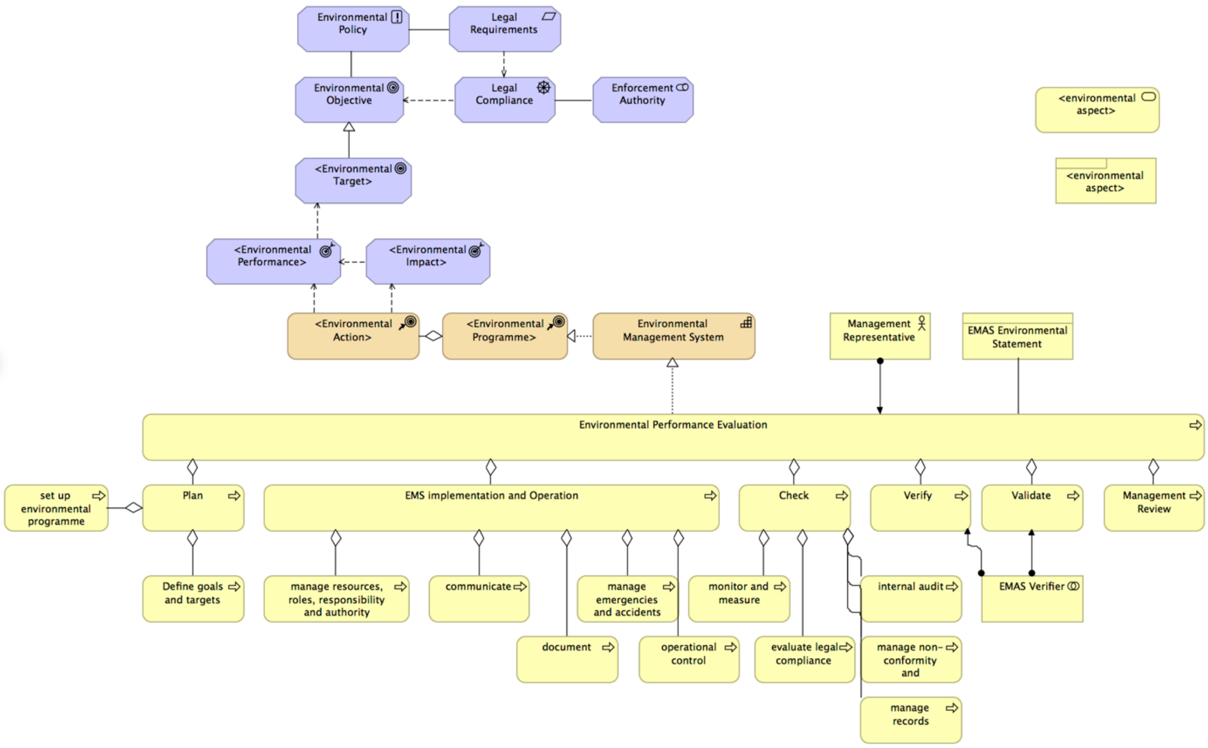
| Attribute: Core Indicator | Type of measure | Metric | Element |
|---|---|---|---|
| Energy | I. Total annual energy consumption | MWh or GJ (MegaWatt Hours/ Giga Joules) | Active structure, Passive Structure, Behavior |
| | II. Percentage of I. from renewable energy sources, produced by the organisation | % (Percentage) | |
| Materials | III. Annual mass flow of materials | t (Tones) | |
| Water | IV. Annual water consumption | $m^3$ (Cubic meter) | |
| | V. Percentage of IV. from different water sources | % (Percentage) | |
| Waste | VI. total annual generation of waste (broken down by type) | t (Tones) | |
| | VII. hazardous waste, expressed in tonnes or kilograms | t (Tonnes) or kg (Kilograms) | |
| Biodiversity /Land Use | VIII. Use of Land | $m^2$ of built-up-area (square meters) | |
| Emissions | IX. Total annual emissions of greenhouse gases ($CO_2$, $CH_4$, $N_2O$, HFC, PFC, $SF_6$) | t (tonnes of $CO_2$ equivalent) | |
| | X. Total annual air emissions (including at least $SO_2$, NOx, PM) | t (Tonnes) or kg (Kilograms) | |

**Table 21: Mapping between EMAS concepts and ArchiMate Elements**

| **EMAS** | **Relationship** | **ArchiMate** | **Deficiency Type** |
|---|---|---|---|
| Environmental Impact | Specialization | Outcome <Environmental Impact> | Construct Overload |
| Environmental Policy | | Principle <Environmental Policy> | |
| Environmental Target | | Goal <Environmental Target> | |
| Environmental Aspect | Specialization | Activity, Product or Service <Environmental Aspect> | |
| EMAS Environmental Statement | | Representation <Environmental Statement> | |
| Environmental Programme | Specialization | Course of Action <Environmental Programme> | |
| Action | | Course of Action <Environmental Action> | |
| EMS | | Capability <EMS> | |
| Core Indicators | Profiling | Of Active Structure, Passive, Behaviour | Construct Deficit |
| Environmental Review | Generalization | Business Process/Function/Capability* | Construct Redundancy |
| Planning | | Business Process/Function/Capability* | |
| EMS implementation and operation | | Business Process/Function/Capability* | |
| Checking | | Business Process/Function/Capability* | |
| Verification | | Business Process/Function/Capability* | |
| Validation | | Business Process/Function/Capability* | |
| Management Review | | Business Process/Function/Capability* | |
| Environmental Objective | Corresponds to | *Goal* | No Deficiency |
| Legal Requirements | | Requirement | |
| Enforcement Authority | | Stakeholder | |
| EMAS Verifier | | Business Role | |
| Management Representative | | | |
| Legal Compliance | | Driver | |

Note: * while a *Business Process* and a *Business Function* belong to the Business Layer in ArchiMate, a *Capability* belongs to the Strategy Layer. Due to limited space the *Capability* is depicted in yellow in Table 21 falsely indicating its relation to the Business Layer.

**Figure 13: Metamodel of EMAS**




## GRI 300 concepts

In this section core concepts retrieved from the Global Reporting Guidelines (GRI) are defined and mapped to the ArchiMate language. A summary is presented in Table 24. The colors in the table indicate to which ArchiMate layer or type of element the respective element belongs. Strategy elements are depicted in orange, business elements are shown in yellow and motivational elements are represented in violet.

**Reporting Principles for Defining Report Quality:** This concept delineates guiding expectancies regarding choices made in the reporting process that determine the report quality. These principles include the following: Accuracy, balance, clarity, comparability, reliability and timeliness (GSSB (GRI-101), 2016). Serving as a guideline with a qualitative statement intent, this concept maps most naturally as a specialization of a *Principle* element in ArchiMate.

**Reporting Principles for Defining Report Content**: This concept delineates guiding expectancies regarding choices made in the reporting process that determine the report content. These principles include as follows: stakeholder inclusiveness, sustainability context, materiality and completeness (GSSB (GRI-101), 2016). Serving as a guideline with a qualitative statement of intent, this concept maps most naturally as a specialization of a *Principle* element in ArchiMate.

**Material Topic Specific Disclosures:** this concept refers to the organization's reporting on its material topics and associated impacts (GSSB (GRI-101), 2016). These disclosures concern the following material topics: Energy (GRI 302), Water and Effluents (GRI 303), Biodiversity (GRI 304), Emissions (GRI 305), Waste and Effluents (GRI 307), Environmental Compliance (GRI 308) and Supplier Environmental Assessment (GRI 309). Each topic contains a number of disclosures that should be revealed in a report. Disclosures of the GRI 300 series comprise a number of indicators exposing the organization's level of impact on the environment.

Disclosures can be considered as a summary of topic-specific impacts measured over the reporting period for the whole organization. They reflect the organization's environmental performance in total for a number of specific topics and can be measured against the environmental goals and objectives set by the organization. Further they serve the public to determine how environmentally sustainable the organization is. From that perspective, the topic specific disclosures can be considered as *Representation* of the overall the organization's reporting on its material topics and associated impacts. It represents the overall assessments conducted by the organization. It is rather a summary in form of a report which contains all the assessments of impacts measured by a number of indicators than an assessment itself. It is recommended to use a specialization of a *Representation* element.

**Management Approach Disclosure**: This concept refers to the organization's reporting on its management approach of material topics and associated impacts (GSSB (GRI-101), 2016). The management approach can be considered as a *Representation* of the overall the organization's reporting on its management approach of material topics and associated impacts. The management approach disclosure represents the overall assessments conducted by the organization. It is rather a summary in form of a report which contains all the assessments of impacts measured by a number of indicators. It is recommended to use a specialization of a *Representation* element.

**Environmental Laws and Regulations:** This concept includes all legislation concerned with environmental issues that are relevant for the organization (GSSB (GRI-301), 2016). Environmental laws and regulation present external requirements forcing the organization to address environmental issues. Thus, this concept corresponds with the *Requirements* element.

**Non-Renewable Material:** This concept refers to a "resource that does not renew in short time periods" (GSSB (GRI 301), 2016, p. 9). Non-renewable materials map most naturally to the *Material* element in ArchiMate. To indicate the distinctive type of material, it is proposed to assign attributes to the *Material* element. This Material element can then be assigned to another element where it is used for (e.g. a business process). This allows to model what material (as *Material*) and what type of material (as its attribute expressed in weight or volume) are used for certain other elements. The profiling options for this concept are depicted in Table 22.

**Recycled Input Material:** The GRI Standards define recycled input materials as "material that replaces virgin materials, which are purchased or obtained from internal or external sources, and that are not by-products and non-product outputs (NPO) produced by the organization" (GSSB (GRI 301), 2016, p. 10). Recycled input materials map most naturally as an attribute of a *Material* element in ArchiMate. The modelling of this concept corresponds to the proposal for non-renewable material (see above). The profiling options for this concept are depicted in Table 22.

**Renewable Material:** According to the GRI Standards this concept refers to "material that is derived from plentiful resources that are quickly replenished by ecological cycles or agricultural processes, so that the services provided by these and other linked resources are not endangered and remain available for the next generation" (GSSB (GRI 301), 2016, p. 10). Renewable materials map most naturally as an attribute of a *Material* element in ArchiMate. The modelling of this concept corresponds to the proposal for non-renewable material (see above). The profiling options for this concept are depicted in Table 22.

**Reclaimed**: This concept refers to „collecting, reusing, or recycling products and their packaging materials at the end of their useful lives" (GSSB (GRI 301), 2016, p. 9). It maps most naturally as an attribute to the *Product* element in ArchiMate. The profiling options for this concept are depicted in Table 22. As a product depicted in an EA model will most likely depict a product category rather than one instance of a product, the possibility arises to measure this attribute in relative numbers, indicating the percentage of reclaimed products and their packaging materials for each product category. Alternatively, companies could also simplify the measurement by just stating whether a product category in its whole is reclaimed or not.

Table 22: Profiling Options: Materials from GSSB (GRI 301), 2016 mapped to ArchiMate

| Attribute: Material Type | Type of measure | Element |
|---|---|---|
| **Non-renewable** | weight or volume | Material |
| **Recycled Input Material** | weight or volume | Material |
| **Renewable Material** | weight or volume | Material |
| **Reclaimed** | Absolute: yes/no<br>Relative: Percentage of reclaimed products and their packaging materials for each product category | Product |

**Non-renewable Energy Source**: According to the GRI Standards this concept is an "energy source that cannot be replenished, reproduced, grown or generated in a short time period through ecological cycles or agricultural processes "(GSSB (GRI 302), 2016, p.14). The question of energy sources plays a key role for organizations to address environmental issues. Being a vital element in the GRI Standard 302, energy sources are recommended to be expressed as a specialization of a *Material* element in ArchiMate. To indicate the type of energy source, it is proposed to assign attributes to the *Material* element. This Material element can then be assigned to another element where it is used for (e.g. a business process, a technology etc.). This allows to model what energy source (as Material) and what type of energy (as its attribute expressed in % or Joules) are used for certain other elements. The profiling options for this concept are depicted in Table 23.

**Renewable Energy Source:** The GRI Standards defines this concept as an "energy source that is capable of being replenished in a short time through ecological cycles or agricultural processes "(GSSB (GRI 302), 2016, p.14). The modelling of this concept corresponds to the proposal for non-renewable energy (see above). The profiling options for this concept are depicted in Table 23.

Table 23: Profiling Options: Energy Sources (GSSB (GRI 302), 2016 ) mapped to ArchiMate

| Attribute: Energy Type | Type of measure | Element |
|---|---|---|
| **Renewable** | Proportion in %, Joules | Material: <Energy Source> |
| **Non-renewable** | Proportion in %, Joules | Material: <Energy Source> |

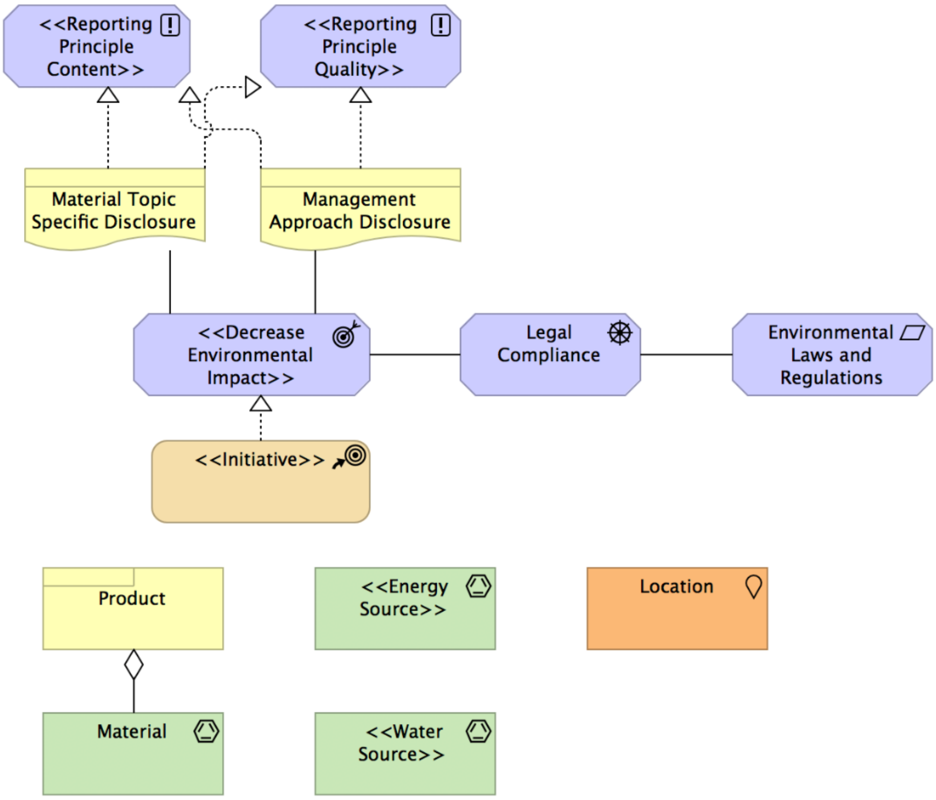
**Conservation and Efficiency Initiative:** This concept is guided by a formulated goal aiming for energy conservation and efficiency through organizational or technological modification which enables the organization to perform a certain process or task consuming less energy. This can be identified as an approach for setting up organizational capabilities and resources to achieve a high-level goal and therefore qualifying as a *Course of Action* element. Further, it is suggested to create a Specialization to provide unambiguous concept *Course of Action <Environmental Action>* element.

**Impact:** This concept describes the economical/ environmental/ societal effect an organization creates and therefore denoting its level and type of contribution to sustainable development. (GRI-101 Foundations). Impacts are reported in relation to a specific material topic: Energy (GRI 302), Water and Effluents (GRI 303), Biodiversity (GRI 304), Emissions (GRI 305), Waste and Effluents (GRI 307), Environmental Compliance (GRI 308) and Supplier Environmental Assessment (GRI 309). In this thesis, impact relates to environmental effects. The modelling of this concept corresponds to the proposal for the concept of the impact (see ISO 14001). It is henceforth referred to as an environmental impact mapped to a specialization of an *Outcome* element.

**Table 24: Mapping between GRI 300 Concepts and ArchiMate Elements**

| **GRI Concept** | **Relationship** | **ArchiMate** | **Deficiency Type** |
|---|---|---|---|
| Environmental Laws and Regulations | Corresponds to | Requirement | No Deficiency |
| Management Approach Disclosure | Specialization | Representation <Management Approach Disclosure> | |
| Material Topic Specific Disclosure | | Representation >Material Topic Specific Disclosure> | |
| Reporting Principles for Defining Report Quality | | Principle <Reporting Quality> | |
| Reporting Principles for Defining Report Content | | Principle <Report Content> | |
| Environmental impact | | Outcome <Environmental Impact> | Construct Overload |
| Conservation and Efficiency Initiative | Specialization | Course of Action <Environmental Action> | |
| Non-Renewable Material | Profiling | Attribute of Material | Construct Deficit |
| Recycled Input Material | | | |
| Renewable Material | | | |
| Reclaimed | | Attribute of Product | |
| Renewable | | Attribute of Material Specialization <Energy Source> | |
| Non-Renewable | | | |

Figure 14: Metamodel of the GRI 300




### 3.1.4. Consolidation and Mapping between Environmental Concepts and ArchiMate Elements

As standards, frameworks and guidelines are not used in an exclusive manner but are complementing each other, it is not uncommon that an organization adopts two different SRTs to assess its environmental performance. In order to create a holistic view that eliminated redundancies and represents concepts clearly and unambiguously, the different concepts are mapped to each other in a consolidated list as depicted in Table 25. The colors in the table indicate how the concepts overlap. Specifically, single concepts that cannot be found in any of the other SRTs are shown in grey font. Where concepts from three SRTs correspond concerning their meaning, a green colouring can be seen. In the case of an overlap between concepts of two SRTs, concepts are depicted in yellow.

**Table 25: Mapping of Concepts between ISO 14001, ISO 14031, EMAS and GRI 300**

| No | ArchiMate Elements | ISO 14001 | ISO 14031 | EMAS | GRI |
|---|---|---|---|---|---|
| **1** | **Capability <EMS>** | EMS | EMS | EMS | - |
| **2** | **Business Process/Function/ Capability*** | - | - | Management Review | - |
| **3** | **(1) Assessment <Environmental Condition>; (2) Business Process/Function/ Capability** | (1) Environmental Condition | - | (2) Environmental Review | - |
| **4** | **Principle <Environmental Policy>** | Environmental Policy | Environmental Policy | Environmental Policy | - |
| **5** | **Course of Action <Environmental Programme>** | - | - | Environmental Programme | - |
| **6** | **Goal** | Environmental Objective | Environmental Objective | Environmental Objective | - |
| **7** | **Goal <Environmental Target>** | | Environmental Target | Environmental Target | - |
| **8** | **Course of Action <Environmental Action>** | | - | Action | Conservation and Efficiency Initiative |
| **9** | **Outcome <Environmental Impact>** | | Environmental Impact | Environmental Impact | Environmental Impact |
| **10** | **Activity, Product or Service <Environmental Aspect>** | Environmental Aspect | Environmental Aspect | Environmental Aspect | - |
| | **Profiling** | - | OPIs (MPIs) (ECIs) | Core Indicators | Non-Renewable Material |
| | | | | | Reclaimed |
| | | | | | Recycled Input Material |
| | | | | | Renewable Material |
| | | | | | Non-Renewable Energy Source |
| | | | | | Renewable Energy Source |
| **11** | **Principle <Reporting Content>** | - | - | - | Reporting Principles for Defining Report Content |

| | | | | | |
|---|---|---|---|---|---|
| **12** | **(1) Principle <Indicator Principle>; (2) Principle <Reporting Quality>** | | (1) Principles for Indicators | - | * (2) Reporting principles for defining Report Quality |
| **13** | **(1) Driver; (2), (3) Requirements** | | - | (1) Legal Compliance | (3) Environmental Laws and Regulations |
| **14** | | | - | (2) Legal requirements | |
| **15** | **Stakeholder** | - | - | Enforcement Authority | - |
| **16** | **Business Role** | - | - | EMAS Verifier | - |
| **17** | **Business Role** | - | - | Management Representative | - |
| **18** | **(1) Representation <Environmental Statement>; (2) Representation <Management Approach Disclosure>; (3) <Representation Material Topic Specific Disclosure>** | - | - | (1) EMAS Environmental Statement | (2) Management Approach Disclosures |
| **19** | | - | - | | (3) Material Topic Specific Disclosure |
| **20** | **Business Process/Function/ Capability** | Plan | Plan | Planning | - |
| **21** | **Business Process/Function/ Capability** | Do | Do | Implementation and Operation | - |
| **22** | **Business Process/Function/ Capability** | Act | Act | | - |
| **23** | **Business Process/Function/ Capability** | Check | Check | Checking<br>Verification<br>Validation | - |
| **24** | **Outcome <Environmental Performance>** | Environmental Performance | Environmental Performance | - | - |
| **25** | **Business Process/Function/ Capability*** | - | Environmental Performance Evaluation | - | - |

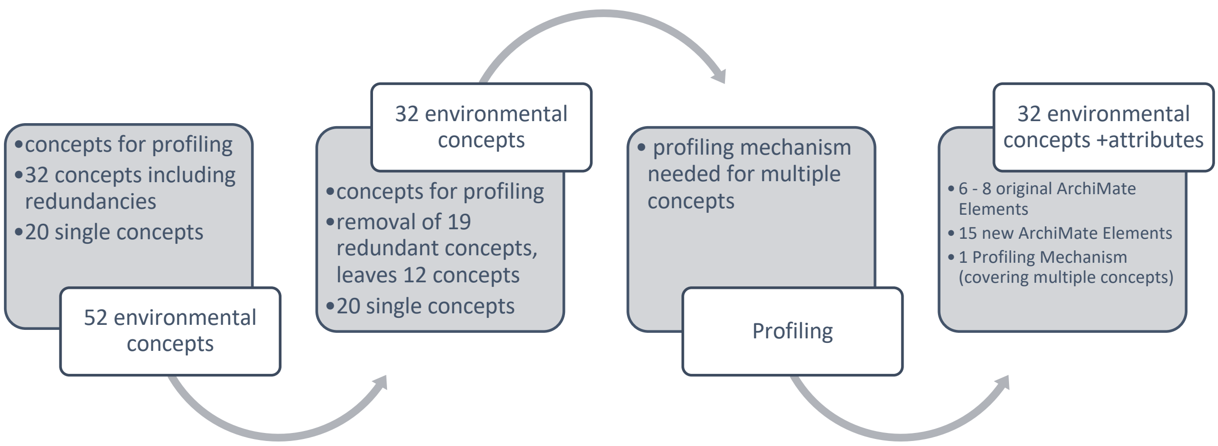
A total of 79 concepts has been retrieved. However, the mapping shows a great overlap of concepts between the four SRTs. A complete consensus between three SRTs can be found in 21 concepts (depicted in green) (EMS, environmental policy, environmental objective, environmental aspect, environmental impact, plan, check). The semantic analysis of these concepts has shown that their definitions are in agreement. A partly consensus can be seen in 30 concepts. In this case concepts correspond to each other in their general idea but show differences in their scope. For instance, are *Core Indicators* in EMAS not specified in the same way as they are in the GRI 300. Nevertheless, the GRI does provide also concepts to express core indicators.

A concept overlap between two SRTs is the case for ten concepts (depicted in yellow) (environmental target, environmental performance, do, act, check, environmental laws and regulations/ legal requirements) while a partly consensus occurs for several concepts (e.g. environmental condition, environmental review, principles for indicators, reporting principles for defining report quality). These concepts are treated as individual concepts which need to be expressed with individual ArchiMate concepts in order to assure that no meaning is lost. Considering these, no overlap can be found for 20 concepts (depicted in grey) (single concepts).

After the identification and mapping of 52 concepts, a total of 32 concepts can be counted by removing identical and therefore redundant concepts. Figure 16 depicts the concept identification process.

Regarding the profiling options to express attributes, only the examples which were described in Section 3.1 are considered here. As attributes are only presented as single examples, they are not considered in the number count of concepts as described below. The examples only serve the purpose of showing a way how the profiling mechanism can be used to express environmental attributes in ArchiMate. Further those attributes are rather industry and organization specific and need to be defined by the organization itself.

**Figure 15: Concept Identification Process**



The semantic analysis uncovers the need for a number of concepts to be expressed in ArchiMate by using the profiling mechanism. In total 31 ArchiMate elements (profiling mechanism is not counted) are required to model environmental concepts. For this purpose, 6 original ArchiMate elements can be used (Business Process/ Function/ Capability; Goal; Driver; Requirement; Stakeholder; Business Role). In these cases, there is no need to introduce a new element to express an environmental concept. However, 15 new ArchiMate elements (specializations) are required where a construct deficit has been determined (depicted in bold writing in Table 26).

As presented in Table 26, for the representation of the environmental concepts in ArchiMate, the following elements are required:

**Table 26: Consolidated List of required ArchiMate Elements**

| # | **ArchiMate Elements** | **Used to express x (number) environmental concepts** |
|---|---|---|
| **15 new ArchiMate elements (specializations)** | **Capability <EMS>** | 1 |
| | **Assessment <Environmental Condition>** | 1 |
| | **Principle <Environmental Policy>** | 1 |
| | **Course of Action <Environmental Programme>** | 1 |
| | **Goal <Environmental Target>** | 1 |
| | **Course of Action <Environmental Action>** | 2 |
| | **Outcome <Environmental Impact>** | 1 |
| | **Activity, Product or Service <Environmental Aspect>** | 1 |
| | **Principle <Reporting Principle Content>** | 1 |
| | **Principle <Indicator Principle>** | 1 |
| | **Principle <Reporting Principle Quality>** | 1 |
| | Representation <Environmental Statement> | 1 |
| | Representation <Management Approach Disclosure> | 1 |
| | Representation <Material Topic Specific Disclosure> | 1 |
| | **Outcome < Environmental Performance>** | 1 |
| **6-8 original ArchiMate Elements** | Business Process/Function/ Capability* | 8 |
| | Driver | 1 |
| | Requirement | 2 |
| | Stakeholder | 1 |
| | Business Role | 2 |
| | Goal | 1 |
| - | Profiling | Various attributes |

### 3.1.5. Summary and Implications: Findings from Literature

Moving forward in the treatment design phase, the consolidated list of environmental concepts and respective ArchiMate elements that are identified serve as the basis and input for the interviews which are carried out and documented in Chapter 3.2.

In summary, the process of identifying relevant SRTs from literature, the retrieval and analysis of key concepts and the subsequent mapping to the ArchiMate language has led to a list of 32 environmental concepts that can be modelled by using six to eight original ArchiMate elements, 15 new ArchiMate elements (Specializations) as well as the profiles to create attributes.

Especially the analysis of concepts that were later identified as attributes and introduced by using the profiling mechanism shows the vast scope of this topic. Further it becomes clear that those attributes depend to a great part on the individual company and its characteristics. Considering the example of a technology service provider the topic of energy might be significant while the topic of materials for product packaging might be less relevant. Having that said, it can be concluded that the definition of attributes and especially their type of measurement need to be adopted and adjusted individually by each company. However, the previous analysis and mapping offer guidance for companies on how to model environmental concepts providing the fundamentals for individual adjustments.

Following the methodology of Wand & Weber (2002) as well as the rules for the classification of architectural concepts ensures a systematic and rational mapping process and guarantees the conformity and interoperability with existing ArchiMate models.

## 3.2. Concepts from Practice

This section reviews and evaluates the initial mapping presented in the previous section.

### 3.2.1. Study Design

Hevner et al. (2004) emphasize the importance of the dichotomy characteristic for the research paradigm of design science. This describes the twofold meaning of design as a process and design as a product. Following this paradigm, to build a problem-solving solution, the design process described in this research is oriented towards the "build-and-evaluate loop". In order to do so, a two-step approach is taken which combines theory and practice in a complementary way. To build a foundation and a sufficient body of knowledge, Section 3.1 describes in detail the literature-based part of the treatment design. Additionally, to evaluate this first version of the artifact concerning its suitability in practice, practitioners are asked to take part in a semi-structured interview. Taking into account the exploratory nature of this research due to its topic's novelty, this enables a first step into testing the artifact towards a real-world like scenario and to involve actual users in the research design (Hevner et al. 2004, p.78-79).

Table 27 presents the interview design following the guidelines of the RAND National Defense Research Institute for collecting data with semi-structured interviews. This qualitative research technique was chosen as it guarantees that relevant questions are answered while allowing the researcher to retrieve more detailed information and a deeper understanding by asking follow-up questions where perceived as necessary or useful (Hevner et al. 2004, p. 27). The interview protocol is used during the interview to guide the researcher and ensures consistency and completeness of the information collected during the interview.

The research question demands knowledge in the EA language ArchiMate. Knowledge in the field of sustainability is preferred but not a necessary selection criterion. In fact, the novelty of the topic combination of EA and sustainability comes with the circumstances that practitioners knowledgeable in both topics and available for an interview is assumed to be rather rare. To find suitable candidates, the research was published via a website providing information and a contact form via a group on the social networking website LinkedIn (www.linkedin.com) which is focusing on ArchiMate. In the end a total of 9 participants have been recruited. In order to familiarize the participants with the topic without requiring any prior preparation, a short interview guide was sent to the interviewees before the actual interview. According to Harrel & Bradley (2009) this type of sampling, known as *Convenience Sampling,* refers to a sample that is taken from a group close to hand. Convenience sampling has been chosen due to time constraints, but without neglecting the selection criteria for finding suitable candidates (Harrel & Bradley, 2009, p. 7).

The interview itself was performed remotely and guided by the researcher's interview protocol. With permission of the interviewees the interview was audio recorded. A visualization of the concepts was essential for a number of questions; thus, a presentation was shared during the session. The interview is structured in three parts, A, B and C. These are explained as follows. The interview questions are in the Appendix (see Chapter 8.1).

Part A includes the introduction of the researcher, the research and the purpose of the interview to provide information and establish rapport as well as explaining the ground rules. Moreover, the interviewees background and experiences with EA and ArchiMate were addressed with open and descriptive questions to encourage the respondent to share his/her insights.

Part B introduces a number of general questions asking the participants about their opinion about the importance of bringing the topic of sustainability and environmental performance into the context of EA and particularly ArchiMate. These descriptive questions allow the participant to go into more detail according to their field of expertise and experiences and permit follow-up questions where appropriate.

Part C includes a number of structural questions were participants were particularly asked to review the mapping from Section 3.1. Specifically, the interviewees were asked whether they agree or disagree with the mapping. In contrast to a questionnaire, the interview clearly poses the advantage that participants can provide explanations for their answers. This allows the improvement of the artifact and clearly provides qualitative value for the development of the final artifact. Final open questions provided more insights about the proposed improvements from the practitioners' perspective. Due to the possibility of in-depth follow-up questions where needed, the semi-structured interview does not require any follow-up activities.

Table 27: Interview Design

| Phase | Item | Description |
|---|---|---|
| **Framing the research** | Research question | How can environmental Performance be modelled in EA using ArchiMate? |
| | Information source | Practitioners familiar with ArchiMate |
| | # Respondents | 9 |
| **Sampling** | Convenience | Participants were recruited through a LinkedIn Group with the topic "ArchiMate" |
| **Designing questions & probes** | Descriptive and structural questions | See questions in appendix (Chapter 8.1) |
| **Developing the protocol** | Introduction | Introduction of the researcher, the purpose of the interview and the research |
| | | Establish rapport |
| | | Explain ground rules |
| | Ground rules | The interview aims at reviewing prior research findings. |
| | | With permission of the interviewee the interview will be audio recorded. |
| | | The interview will take 30 to 60 minutes. |
| | | The interview is confidential. |
| | | The interview will only be used within the context of the research |
| | | Responses will be anonymized in this thesis. |
| | Questions and probes | See questions in appendix (Chapter 8.1) |
| | Closing | No follow-up required |
| **Preparing the interview** | | Prepare Presentation<br>Send interview guide to participants |
| **Conducting the interview** | | Conduct interview following this protocol. |
| **Capturing the data** | | Summarize interviews and analyze results |

In the last phase, capturing the data, the data from the audio records has been summarized and analyzed. The following Section 3.2.2. describes how the qualitative data has been analyzed and presents the results in detail.

### 3.2.2. Results

The results are presented following the interview structure. Part A covers three questions concerning the practitioners' professional background and experience with EA and ArchiMate (Q1-Q3). Further, Part B explores the participants interests, experiences and expert opinion regarding the introduction of environmental sustainability into the organization using EA and ArchiMate in particular (Q4-Q8). Lastly, Part C presents the practitioner's evaluation of the proposal of the mapping of environmental concepts to the ArchiMate language as well as the proposed usage of attributes as described in Section 3.1.

### Evaluation of Part A

Part A of the Interview provides insights into the professional background and experience with EA and ArchiMate. Table 28 presents the distribution of job roles across the sample while table 29 shows the distribution of the sample across the sectors they work in. All in all, the participants have a strong relation to EA where most of them work in the IT sector (IT Security and IT Service Management) or in industries that heavily rely on IT (Music Streaming Service Provider).

Table 28: Job Roles included

| Role of Participants (Q1) | # |
|---|---|
| Enterprise Architect | 2 |
| EA Consultant | 3 |
| CTO | 1 |
| Lead Architect | 1 |
| Information Engineer | 1 |
| Solution & Enterprise Architect | 1 |
| | 9 |

Table 29: Industries covered

| Sector of Participants (Q2) | # |
|---|---|
| IT (Security) | 2 |
| IT Service Management | 2 |
| Consultancy Bureau | 2 |
| Music Streaming Services | 1 |
| Financial Service Provider | 2 |
| | 9 |

Furthermore, it could be revealed how many years of expertise the participants have in the domain of Enterprise Architecture and ArchiMate (see Table 30). While five participants already have more than ten years of experience, 2 interviewees work in the domain of EA and ArchiMate in particular for more than five years and one participant more than one year.

Table 30: Years of Experience of the Participants

| Years of Experience in EA and ArchiMate (Q3) | # |
|---|---|
| > 10 years | 6 |
| > 5 years | 2 |
| > 3 years | 1 |
| | 9 |

### Evaluation of Part B

Part B of the interview explores the participants interests, experiences and expert opinion regarding the introduction of environmental sustainability into the organization using EA and ArchiMate in particular.

Table 31 presents the results to question four (Q4) asking for the participants interest is modelling sustainability with ArchiMate. Although the topic combination of EA and sustainability is very novel, seven of the participants expressed an interest in the modelling sustainability with ArchiMate. Participants interested in this, also see great potential in using ArchiMate to depict environmental sustainability in the organization's architecture. However, practical experience in modelling sustainability with ArchiMate is only described by one interviewee who worked with ArchiMate in the context of environmental and social sustainability. The participants which are interested in modelling sustainability with ArchiMate share the interest in modelling subjects outside of the technology domain including social, ethical and environmental issues, striving towards a more holistic and purpose-oriented architecture rather than the IT-centric view most enterprise architectures focus on.

In contrast, one interviewee expressed an opposing opinion. First of all, the participant is not interested in modelling sustainability with ArchiMate due to the current job role which is not related in that topic in any way. Secondly, ArchiMate is not the right tool for modelling sustainability. This is due to the fact that modelling sustainability in the motivational layer does not offer any value as the motivational elements provided by ArchiMate only offer an unclear and overlapping grammar of concepts. According to the interviewee, depicting sustainability with motivational elements is not beneficial as they cannot reflect the contradictory concepts of reality which cannot be pressed in clear structures as described by ArchiMate elements. Additionally, the modelling of, for instance, sustainability goals would not be useful considering the fact that they might be unrelated to the organization's landscape which is not as evolvable and agile as the environmental strategies and initiatives might change.

**Table 31: Results Question 4**

| Q4: Are you interested and/or experienced in modelling sustainability with ArchiMate? | # |
|---|---|
| **Interested, but no experience** | 7 |
| **Interested and some experience** | 1 |
| **Not interested** | 1 |

Table 32 presents the results to question five (Q5) asking the participants how they rate the importance of organizations evaluating their environmental performance. While seven participants consider the organization's environmental performance evaluation as very important, two of them think they are only seen as important for certain industries as for instance in the construction or manufacturing industry. However, five interviewees rate the evaluation as very important, but do not see any organization realizing such evaluation endeavors in the present or near future. The reason for this is twofold. On the one hand, the interviewees mention missing incentives and the lack of external pressures resulting in sanctions and fines for non-compliance. On the other hand, companies rate environmental performance evaluation as rather unimportant as it does not present a priority for companies, specifically for for-profit organizations. This is due to the fact that nowadays market-pressures are the driving factor for those companies, and environmental sustainability initiatives depend on the stakeholders' interests and ambitions and therefore are only implemented on a voluntary basis.

**Table 32: Results Question 5**

| Q5: How do you rate the importance of evaluating the environmental performance of an organization? | # |
|---|---|
| **Very important for some organizations/industries at the moment** | 2 |
| **Very important, but not realized yet** | 5 |
| **Not important** | 2 |

Table 33 presents the results to question seven (Q6) asking the participants whether the environmental performance evaluation should be an integral part of the enterprise's activities. Seven participants think that the environmental performance evaluation should be an integral part of the enterprise's activities. Concerning the architectural layers, it was emphasized to introduce environmental aspects especially in the strategic and business layer of the enterprise.

More specifically, interviewees suggested to introduce new business roles like a Chief Sustainability Officer and new business processes for reporting and monitoring activities.

In contrast, an opposing view was presented, stating that the organization is the wrong vehicle for conducting environmental performance evaluation, consequently expressing that such an evaluation should not be an integral part of the enterprise's activities. This is due to the fact that an organization might not deliver an honest assessment when it is subject of the assessment as well as the assessor at the same time. An honest environmental performance therefore cannot be integrated in the organization's activities, but must be conducted in another way.

Table 33: Results Question 6

| **Q6: Do you think environmental performance evaluation should be an integral part of the enterprise's activities?** | # |
|---|---|
| **Yes** | 7 |
| **No** | 2 |

Table 34 presents the results to question seven (Q7) asking whether the participants are familiar with any environmental standards and frameworks. Seven of the participants were not familiar with any environmental standards and frameworks. Only two of the interviewees had experience with environmental standards/frameworks due to prior working settings. Out of the four SRTs described in this research, the GRI was familiar to one of the interviewees.

Table 34: Results Question 7

| **Q7: Are you familiar with environmental standards and frameworks?** | # |
|---|---|
| **Yes** | 2 |
| **No** | 7 |

Table 35 presents the results to question eight (Q8) asking the participants to rate the importance of environmental standards and frameworks for organizations to improve their environmental performance. Seven participants rated the utilization of those frameworks and standards as important as they provide guidelines for the organizations. However, being rated as important means to improve corporate environmental sustainability, participants raised concerns about the actual marginal usage of those means nowadays as well as the lack of comparability regarding the variety of standards and frameworks available.

In contrast two participants stated that environmental standards and frameworks are not important for organizations to improve their environmental performance. One view shared in the interview was the opinion about standards only being used as marketing tools rather than real meaningful environmental performance evaluations. Another argument presented is their limited effect when only adopted on a voluntary basis instead being enforced by law as companies nowadays are driven by growth and market-pressure. Further, adoption and implementation of frameworks and standards only lead to additional bureaucratic overhead rather than real practical value, meaning that assessment scores do not really reflect environmental performance of the organization but create additional workload.

Table 35: Results Question 8

| Q8: How do you rate the importance of environmental standards and frameworks for organizations to improve their environmental performance? | # |
|---|---|
| **important** | 7 |
| **Not important** | 2 |

### Evaluation of Part C

This part evaluates the proposal of the mapping of environmental concepts to the ArchiMate language as well as the proposed usage of attributes as described in Section 3.1. As experts in the field of EA and knowledgeable in the ArchiMate language, practitioners were asked to evaluate the proposed mappings. Table 37 summarizes the results. For a consistent and objective evaluation of the results an evaluation scheme has been used as presented in Table 36. According to the scheme, the answers of the participants have been classified in four categories and labeled with either *agree*, *partly agree*, *disagree* or *no answer*. An answer was labelled *agree* where the participants approves the proposed mapping. In some cases, interviewees provided additional ideas, for instance to also add properties to a certain element. An answer was labelled *partly agree* where the participant agrees with the mapping to a certain extent, but suggest minor changes which are not necessarily needed but could be more appropriate for certain contexts. Examples include the removal or usage of specializations of an element. In case the participant argues with the proposed mapping, the answer was labeled *disagree*. In some occasions, participants suggested an alternative mapping instead.

For some mappings no answer could be retrieved. For one interviewee this was due to time constraints of the interview session itself extending the scheduled 60 minutes. These answers were labelled as *no answer*. In contrast, in other cases, participants expressed doubts about a mapping, but could not provide an alternative proposal. Nevertheless, the fruitful discussion and arguing of the mappings provided valuable insights for the design of the final artifact. In this case, column five of Table 37 indicates where participants did not provide answers.

Table 36: Evaluation Scheme employed in the Study

| Label | Explanation |
|---|---|
| **agree** | The participant agrees with the mapping and might also suggest additional information, e.g. relationships |
| **Partly agree** | The participant agrees with the mapping to a certain ArchiMate element, but suggest minor changes which are not necessarily needed but could be more appropriate for certain contexts. Examples are: remove/add specialization, alternative elements in a specific context |
| **Disagree** | The participant disagrees with the mapping and might suggest another element instead. |
| **No answer** | The participant does not agree, partly agrees and neither disagrees with the mapping. This could be, for instance, due to time constraints. |

**Environmental Objective**

The initial proposal suggests the mapping of an environmental objective to a goal element. This was approved by eight of the participants. Only one participant disagreed with the proposal and suggested to map the environmental objective as a high-level requirement instead.

**Environmental Target**
In the initial proposal an environmental target was mapped as a specialization of a goal element. Six of the participants agree, while three of the interviewees disagree with the mapping. The latter ones argue not to introduce specializations but to rather use the existing ArchiMate elements. Further, two of the them suggest to use an outcome element instead of a goal element to distinguish the environmental target form the environmental objective without using a specialization. Another suggestion is the mapping of a requirement, as the environmental target is measurable by definition (see Section 3.1.3).

**Environmental Policy**
In the initial proposal an environmental policy was mapped as a specialization of a principle element. This mapping is approved by four participants. However, it is argued that the specialization of the Principle element is not required here to depict the environmental policy. It is recommended to use the specialization of the concept only in lower levels of details while being aware that too many details may not be useful to be included into the architecture. Further, this concept started discussions about where to place it in the architecture. On one hand it was argued to use the principles to guide goals, while on the other hand it was argued to derive the environmental policy based on the environmental goals in order to reach certain outcomes. An opposing view was presented, where the usage of principles in architectures was not recommended, instead it was suggested to depict the environmental policy as a goal.

**Environmental Condition**
In the initial proposal an environmental condition was mapped as a specialization of an *Assessment* element. Four participants agree with the proposed mapping. The discussion of the concept revealed its inherent ambiguity which results from the word “condition” which consequently leads to misinterpretation of the concept. For instance, the mapping to a driver element was suggested based on the perception of an environmental condition as a general fact about the environments state. In contrast the environmental condition describes in which state the environment is at a point in time when this particular state is measured. It therefore provides the reference point for all following assessments which can then be compared to the state of the first measurement. Similarly, the mapping to a requirement or a constraint was suggested based on the misleading word condition. Further, it was suggested to use a generic assessment concept instead of the specialization. It can be concluded that the labelling of the concept needs to be revised to avoid misinterpretation.

**Reporting Principle Content**
In the initial proposal a Reporting Principle Content was mapped as a specialization of a *Principle* element. Three participants agree with this mapping. However, while agreeing to the usage of the *Principle* element in this case, two participants reject the specialization of the principle, but rather recommend to utilize the generic principle element. Further, it is stated to ensure that the usage of the Reporting Principle Content actually adds value when introducing it in a model. This is to avoid an overload of the model itself, by adding superfluous elements that do not serve the purpose of communicating meaningful information. However, while it could be unnecessary information in a high-level view of a model, the Reporting Principle content might be needed in a more detailed, lower level view. In general, practitioners recommend the usage of principle elements in EA models following the rule of explain or comply, meaning that when making design decisions in the architecture, compliance to respective principles is obligatory. In contrast, non-compliance requires an explanation of why a principle is not followed in a particular design decision. Following this rule, practitioners warn to add to many, possibly irrelevant principles in the architecture, as it must be feasible to check each of them when making design decisions. Thus, it is recommended to provide a

statement and rationale behind each principle. This rule also raised criticism, where the usage of principles is not recommended since it reinforced unreflected following of rules to comply to principles. Another interviewee disagrees with the mapping to a principle, arguing that principles are more abstract and high-level while the Reporting Principle Content shows more the characteristics of a guideline where instructions on content reports are provided.

**Indicator Principle**
In the initial proposal an Indicator Principle was mapped as a specialization of a Principle element. Three participants agree to the proposed mapping. For the three interviewees who partly disagree as well as the one that completely disagrees with the proposed mapping, the same argument is provided as described above for the Reporting Principle Content (see Reporting Principle Content, p. 57).

**Reporting Principle Quality**
In the initial proposal a Reporting Principle Quality was mapped as a specialization of a *Principle* element. Four participants approve this mapping. For the three interviewees who partly disagree as well as the one that completely disagrees with the proposed mapping, the same argument is provided as described above for the Reporting Principle Content (see Reporting Principle Content, p. 57). However, in contrast to the Indicator Principle and the Reporting Content Principle, this concept in hand is seen as more abstract and high-level, thus qualifying as a Principle, while the latter to principle show more the characteristics of a guideline where instructions are provided.

**Legal Compliance**
The initial proposal suggests the mapping of Legal Compliance to a *Driver* element. Five participants agree with the suggested mapping. In contrast, three other mappings are proposed. Two interviewees argue the mapping as a goal as the phrasing Legal Compliance describes a state of being a compliant, while a driver would depict the motivation to be compliant and actually state the consequences. Other suggestions include the constraint element viewing legal compliance as a constraint rather than a driver as well as the requirement. However, one interviewee claims that the need to make clear distinction is not possible with the ArchiMate grammar of the motivational layer. It is argued that there is a great overlap in the definitions of the motivational elements which do not allow a clear distinction of real-world concepts into the ArchiMate motivational layer.

**Legal Requirements, Laws and Regulations**
The initial proposal suggests the mapping of Legal Requirements as well as Laws and Regulations to a *Requirement* element. Five interviewees approve the suggested mapping. Conversely, one interviewee considers the legal requirements and laws and regulations as a constraint rather than a requirement. Another suggestion is the modelling of the legal requirements and laws and regulations as a goal in the case that the law only states what needs to be achieved but does not specify the requirements which say how the goal is realized. Similarly, one interviewee suggests to map laws and regulations itself as a driver attach the requirements by association relationship as a requirement.

**Enforcement Authority**
The initial proposal suggests the mapping of an Enforcement Authority to a stakeholder element. Six participants agree with the proposed mapping. While not arguing the proposed mapping, three interviewees suggest the mapping as a business role (2) or a business actor (1) in the context of assigning the enforcement Authority to a particular business process. One interviewee argued that the purpose of modelling lays is the fact to depict the interaction of

certain business roles with certain business processes which would not be reflected by the mapping as a stakeholder.

**Environmental Impact**

In the initial proposal the environmental Impact was mapped as a specialization of an Outcome element. While six participants agree with this proposed mapping, one counter argument was presented without rejecting the proposal entirely. It was argued that the usage of the outcome element in this mapping is counter intuitive since outcomes are usually positive rather than negative. Although the ArchiMate specification does not exclude negative outcomes, the proposed mapping is seen as problematic as it is rather uncommon in practice to use motivational elements to map outcomes that are desirable instead of those ones that are not desired.

**Environmental Performance**

In the initial proposal environmental performance was mapped as a specialization of an Outcome element. The proposed mapping was approved by six participants. The interviewee who partly disagreed, argued that the usage of the outcome element in this mapping is counter intuitive since outcomes are usually positive rather than negative. Although the ArchiMate specification does not exclude negative outcomes, the proposed mapping is seen as problematic as it is rather uncommon in practice to use motivational elements to map outcomes that are desirable instead of those ones that are not desired. In conclusion the proposal was agreed to while not being evaluated as the ideal depiction for the concept at hand. Furthermore, an alternative was presented which included the suggestion to map the concept as an assessment. Following this recommendation, it was argued that the environmental performance rather presents the documentation of an outcome which corresponds to the assessment element, than to the outcome element.

**Environmental Programme**

In the initial proposal an environmental programme was mapped as a specialization of a course of Action element. Five participants agree with the proposed mapping. Among the interviewees who partly disagreed, it was recommended to use the course of action element as a generic element instead of a specialization. Conversely, the use of a specialization to express the concept was encouraged. From the practitioners end it was understood and emphasized that the environmental programme should be linked to the environmental actions as the latter ones constitute components of the environmental programme. One practitioner disagreed and evaluated the proposed mapping as counter intuitive, but could not suggest an alternative mapping.

**Environmental Action**

In the initial proposal an environmental action was mapped as a specialization of a course of Action element. Six participants approve the proposed mapping. Two practitioners stated that the specialization is not required here as an environmental action also can be modelled with the generic course of action element provided by the ArchiMate language. This particular element reflects the variety in the interpretation and usage of the specialization mechanism as another practitioner explicitly encouraged the usage of the specialization element in this particular proposed mapping.

**Environmental Management System (EMS)**

In the initial proposal the EMS was mapped as a specialization of a capability element. Five participants approve the proposed mapping. However, three participants expressed that there is no need for the specialization of the capability element but suggest to depict the EMS as a generic capability. On one hand, it was mentioned that a specialization might be useful when the EMS is divided into sub-capabilities on a more detailed level. On the other hand, specializations were recommended to use when specific properties apply in the specialization concepts that are inherited by the more generic, parent concept, but also distinguish the specialized element from the generic element.

**Environmental Review, Planning, EMS implementation and Operation, Acting, Checking, Verification, Validation, Management Review, Environmental Performance Evaluation**

The initial proposal suggests the mapping of a variety of concepts (Environmental Review, Planning, EMS implementation and operation, Checking, Verification, Validation, Management Review) to multiple ArchiMate elements dependent on the intention of the model, the view and context. Possible elements initially suggested are a *Business Process*, a *Business Function* or a *Capability* as described in Chapter 3.1.3. This initial mapping was not entirely approved by the participants. It can be concluded that all interviewees would not use a capability to map the concepts mentioned above. Similarly, all interviewees agree to mapping those concepts as business processes. Two participants would also consider a mapping to a value stream, one proposal agrees to the mapping to a business function element. All in all, the Business Processes are the preferred way of modelling the concepts at hand. Regarding the classification in Table 37, answers that agree with one or more of the proposed mappings are labelled as *agree*, while answers agreeing with one of the proposed mappings (e.g. mapping only as a business process) but suggesting another mapping (e.g. value stream) which was not proposed in the initial mapping are classified as *partly disagree*. Lastly, answers that disagree with a mapping of the concepts to any of the proposed elements (*Business Process*, a *Business Function* or a *Capability)* are labelled as *disagree*.

**Environmental Aspect**

In the initial proposal an environmental aspect was mapped as a specialization of a service or a product element. Among all the concepts proposed, this proposal received the most critical reactions. While none of the participants agreed with the provided mapping, only four explicitly disagreed. Among the interviewees who disagreed, the argument was presented that the environmental aspect does not behave like the parent element, in this case, a product or service element and therefore, cannot be modelled as a specialization of a service or product element. It was recommended to express the environmental aspects by assigning attributes attached to service or product elements, especially in the case of quantifiable environmental aspects. For environmental aspects of qualitative nature, it was suggested to use the meaning element. Further recommendations included the mapping to a motivational element, for instance a driver, in order to be able to establish a link between environmental aspects and environmental impacts here modelled as a specialization of an outcome element. Another proposal presented during the interview was the idea to model the environmental aspect as a material in the physical layer based on the idea that environmental aspects and associated environmental impacts materialize as tangible or intangible materials in the physical world. Another alternative suggestion included the idea to model the aspect as a specific type of relationship. However, this idea needs more elaboration to identify ways to convey information inherent to an environmental aspect.

**EMAS Verifier**

The initial proposal suggests the mapping of an EMAS Verifier to a business role element. Six participants agree to this mapping. However, two practitioners acknowledge the proposed mapping, but also suggest to use the business actor element in certain situations where the business actor is known.

**Management Representative**

In the initial proposal the Management representative was mapped to a business role element. In contrast to the EMAS Verifier, most of the participants recommend the use of the business actor. However, four practitioners acknowledge the proposed mapping, but also suggest to use the business role element in certain situations where the business actor is not specified or unknown.

**Environmental Statement**

In the initial proposal an environmental statement was mapped as a specialization of a representation element. This mapping was approved by four of the participants. However, while not being entirely opposed to the proposed mapping, one interviewee suggested to map the environmental statement as an artifact as it is something to be created, more specifically referring to the comprehensive information provided for the public. In contrast, three participants rejected the proposed mapping. Instead the mapping to a business object was suggested as the environmental statement refers to the information itself rather than the type of representation of some information (e.g. the format digital/analog etc.) which is denoted by the representation element. The latter ones also refuse the introduction of a specialization element here.

**Management Approach Disclosure**

In the initial proposal the Management Approach Disclosure was mapped as a specialization of a representation element. The proposal received similar reactions as the mapping of the Environmental Statement. While four interviewees approve the proposed mapping, another three participants suggest the mapping to a business object for the same reasons mentioned above (see environmental statement). Similarly, these practitioners consider the specialization element as not needed.

**Material Topic Specific Disclosure**

In the initial proposal the Material Topic Specific Disclosure was mapped as a specialization of a representation element. The proposal received similar reactions as the mapping of the Environmental Statement and the Management Approach Disclosure. While four interviewees approve the proposed mapping, another three participants suggest the mapping to a business object for the same reasons mentioned above (see environmental statement). Similarly, these practitioners consider the specialization element as not needed

**Table 37: Results Part C**

| Proposed Mapping | Agree | Partly Agree | Disagree | No answer |
|---|---|---|---|---|
| ***Goal*** **Environmental Objective** | 8 | 1 | 0 | 0 |
| ***Goal*** **<Environmental Target>** | 6 | 0 | 3 | 0 |
| ***Principle*** **<Environmental Policy>** | 4 | 1 | 3 | 1 |
| ***Assessment*** **<Environmental Condition>** | 4 | 4 | 0 | 1 |
| ***Principle*** **<Reporting Principle Content>** | 3 | 3 | 1 | 1 |
| ***Principle*** **<Indicator Principle>** | 3 | 4 | 1 | 1 |
| ***Principle*** **<Reporting Principle Quality>** | 4 | 4 | 0 | 1 |
| ***Driver*** **Legal Compliance** | 5 | 1 | 3 | 0 |
| ***Requirements*** **Legal Requirements/ Laws and Regulations** | 5 | 2 | 1 | 1 |
| ***Stakeholder*** **Enforcement Authority** | 6 | 3 | 0 | 0 |
| ***Outcome*** **<Environmental Impact>** | 6 | 1 | 0 | 2 |
| ***Outcome*** **<Measured Environmental Performance>** | 6 | 1 | 1 | 1 |
| ***Course of Action*** **<Environmental Programme>** | 5 | 2 | 1 | 1 |
| ***Course of Action*** **<Environmental Action>** | 6 | 2 | 0 | 1 |
| ***Capability*** **<EMS>** | 5 | 3 | 0 | 1 |
| ***Business Process*** **Environmental Review, Planning, EMS implementation and Operation, Checking, Verification, Validation, Management Review** | 6 | 2 | 0 | 1 |
| ***Activity, Product or Service*** **<Environmental Aspect>** | 0 | 0 | 4 | 3 |
| ***Business Role*** **EMAS Verifier** | 6 | 2 | 0 | 1 |
| ***Business Role*** **Management Representative** | 1 | 4 | 3 | 1 |
| ***Representation*** **<Environmental Statement>** | 4 | 1 | 3 | 1 |
| ***Representation*** **<Management Approach Disclosure>** | 4 | 0 | 3 | 2 |
| ***Representation*** **<Material Topic Specific Disclosure>** | 4 | 0 | 3 | 2 |

**Attributes**

In the very last part of the interview the participants were asked whether they think modelling attributes to certain elements in the architecture is useful. The results are presented in Table 38. All participants encourage the introduction of quantifiable and measurable attributes in the architecture as mature EA modelling. Practitioners especially emphasized the utilization of attributes for the particular domain of environmental sustainability where metrics and quantifiable data provide valuable insights about the organization's environmental performance through the architecture. Using the viewpoint mechanism, environmental performance analysis allows different levels of detail and can be drilled down to specific environmental data to present the right type of information with the right level of detail to the intended audience. Information views can provide the data and intelligence were to find specific environmental data across the landscape of information systems which in a next step can create dashboards with relevant information. Further, it was highlighted that providing the right data in the right view is essential, to deliver meaningful insights for the addressed audience.

Table 38: Results Question 9

| Q9: Do you think modelling profiles for attributes is useful? | # |
|---|---|
| **Yes** | 9 |
| **No** | 0 |

## 3.3. Discussion

This section discusses the results of our perception-based qualitative interview study. The insights provided from the practitioners' community of Enterprise Architects challenged the entire proposal of mappings. This in turn lead to a revision of our proposal, according to the feedback collected.

As the feedback is of a qualitative and perception-based, we do not pursue any quantitative evaluation (Wieringa, 2014). In line with this, our revision is based on qualitative aspects.

Changes based on the participants' feedback can be categorized according their severity and therefore correspond to the evaluation scheme as presented in Table 36. A concept is subject to a major change, when a different element has been suggested. This is to differentiate from a concept which is subject to a minor change, where the proposed element has been approved, but specializations are recommended to be removed/added or the labelling of the concept needs to be edited. A concept is subject of no change in the case that another alternative is suggested while the proposed mapping is also accepted. Further, no changes are made to mappings where the initial mapping is rejected, but no alternative ways of modelling mappings can be proposed. Below, we describe first the major changes and then the minor changes in our revised proposal.

**Major Changes**

Reasons for major changes are:

- Use of a different element

The feedback from the practitioners indicates that for a number of mappings major changes are required. The following concepts are revised:

- *Activity, Product or Service* <Environmental Aspect>
- *Representation* <Environmental Statement>
- *Representation* <Management Approach Disclosure>
- *Representation* <Material Topic Specific Disclosure>
- *Business Role* Management Representative

The three elements proposed as *Representation*s are changed into *Business Objects*. This is due to the fact that the concepts in hand refers to the information itself rather than the type or format of the representation of the information (e.g. the format digital/analog etc.). For instance, the environmental statement could be modelled as a business object. An associated representation would indicate whether it is published as a PDF-file or a paper document.

The environmental aspect has been removed from the list of proposed concepts. This is due to the fact that the environmental aspect does not behave like the parent element, in this case, a product or service element and therefore, cannot be modelled as a specialization of a service or product element. Further, practitioners share the opinion that traceability between the environmental aspect, the environmental impact as well as the origin of those two components (e.g. a product) need to be ensured. Moreover, the most common suggestion included the usage of attributes attached to a respective element to model the environmental aspect while ensuring its linkage to the belonging element. Consequently, the recommendation is followed to express the environmental aspects by assigning attributes attached to service or product elements, especially in the case of quantifiable environmental aspects.

In the case of the management representative being mapped to a business role, the use of the *Business Actor* is recommended according to the feedback of the experts.

**Minor Changes**

Reasons for minor changes are:

- Remove or add specialization
- Change of labelling/name of the concept

Based on the evaluation of the practitioners, a number of concepts are revised. These include:

- Assessment <Environmental Condition>
- Capability <EMS>
- Driver Legal Compliance

The discussion of the specialized *Assessment* element revealed its inherent ambiguity which results from the word *condition* which consequently lead to misinterpretation of the concept. According to the definition, it is recommended to use a specialized concept of an Assessment and name it an “environmental state”.

Similarly, the *Driver* legal compliance is subject of change in regard of the name of the element. Following the recommendation of the experts, “legal compliance” corresponds to a goal element as the phrasing describes a state of being a compliant, while a *Driver* would depict the motivation to be compliant and actually state the consequences. As a result, the *Driver* is labelled “be compliant”.

In case of the specialization of a *Capability* element to represent an EMS, a minor change is recommended. Based on the argumentation of the practitioners, there is no need for the specialization of the *Capability* element. Thus, the EMS is modelled as a generic *Capability*. On one hand, it was mentioned that a specialization might be useful when the EMS is divided into sub-capabilities on a more detailed level. On the other hand, specializations were recommended to use when specific properties apply in the specialization concepts that are inherited by the more generic, parent concept, but also distinguish the specialized element from the generic element.

In the initial proposal an environmental target was mapped as a specialization of a *Goal* element. Six of the participants agree, while three of the interviewees disagree with the mapping. The latter ones argue not to introduce specializations but to rather use the existing ArchiMate elements. Further, two of the them suggest to use an *Outcome* element instead of a *Goal* element to distinguish the environmental target form the environmental objective without using a specialization. Another suggestion is the mapping of to a *Requirement*, as the environmental target is measurable by definition (see Section 2.2.1.) Since no clear recommendation for changes can be drawn from the feedback, the initial mapping is kept in the remainder of this thesis.

**No Changes**

A number of concepts are not subjected to change, including:

- *Goal* Environmental Objective
- *Principle* <Environmental Policy>
- *Business Role* EMAS Verifier
- *Business Process* Environmental Review, Planning, EMS implementation and Operation, Checking, Acting, Verification, Validation, Management Review
- *Outcome* < Environmental Impact>
- *Outcome* < Environmental Performance>
- *Course of Action* <Environmental Programme>
- *Course of Action* <Environmental Action>
- *Goal* <Environmental Target>
- *Principle* <Reporting Principle Content>
- *Principle* <Indicator Principle>
- *Principle* <Reporting Principle Quality>

We make the following notes: First, we felt that the evaluation of the two specialized *Course of Action* elements is less clear. While practitioners agree to map the environmental action as well as the environmental programme as a *Course of Action*, differences become evident in the usage of specialization or generic concepts. However, as most practitioners agree with the specializations, they are kept for the two elements environmental programme and environmental action.

The discussion with the practitioners of the specialization of the *Goal* element to depict an environmental target does not allow a clear conclusion. This concept reveals how the group of participants is divided into two groups where one group rejects the usage of specializations and the other group recommends the utilization of specializations. The alternative suggestion to use an *Outcome* is rejected since the *Outcome* can be distinguished from a *Goal* or a target. This becomes clear when considering the following explanation: An Outcome (…) is like Goal, but where Goal is about a desire, the Outcome is an actually achieved result. "(Wierda, 2017, p. 44). Similarly, the proposal of using a *Requirement* as an alternative is refused. This is due to the fact that also environmental targets can be broken down into requirements that "represent the "means" to realize goals" (The Open Group, p. 43). Nevertheless, this kind of modelling decision is characterized by inherent ambiguity depending on the intention and context of the model itself. However, as most practitioners agree with the specialization, this thesis uses the specialized *Goal* element to denote the environmental target.

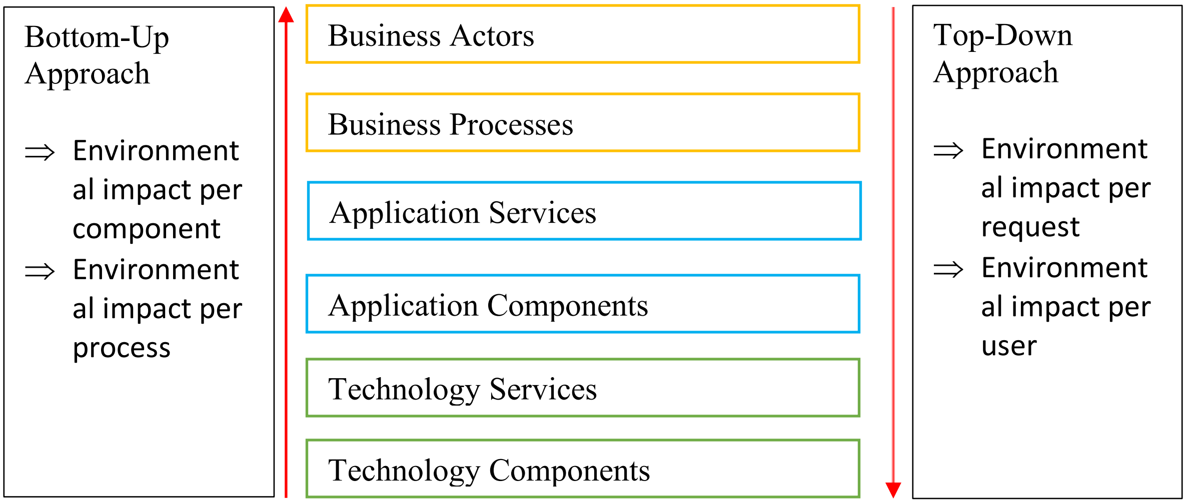
Similarly, the discussion with the practitioners of the three specialized *Principle* elements does not provide clear results concerning its final mapping. The interviews revealed the ambiguous usage and interpretation of the *Principle* elements which does not show a preference of one mapping proposal over the other. For the purpose of this thesis, the three specialized Principle elements will be kept as suggested in the initial proposal.

## 3.4. Attributes for a Quantitative Analysis

Next to the qualitative analysis and evaluation of the artifact as presented in Section 5.1 and Section 5.2., this section proposes a quantitative approach which allows the meaningful integration of the attributes in the EA models.

In order to validate the practical use of the attributes as discussed in Section 3.1 and 3.2 the approach for measuring quantitative environmental impacts is based on the work of Iacob and Jonkers (2006). According to the authors, choosing a layered view, quantities can be propagated from the lower to the higher levels enabling a bottom-up calculation. Similarly, a top-down calculation can be performed using the inputs from the bottom-up approach for further analysis from the higher levels of the model to the lower levels. Figure 16 outlines the approach.

**Figure 16: Approach for quantitative analysis of environmental attributes (adopted from Iacob and Jonkers, 2006)**




Based on Iacob and Jonkers (2006), this work assumes the following input data in order to perform the analysis:

- A weight *n* is assigned to any 'assigned by', served by' and 'accessed by' relation, depicting the average number of services/uses/accesses.
- For any *node*, the environmental aspect *ea* is defined
- For any *business process*, the number of users *u* and the number of requests *r* is defined
- Conversion Factor *c* (*ea* → ei)
- It is assumed that for every request r, a new download is started

Specifically, for the infrastructure layer, the following rules apply:

- For any node related to the network infrastructure (e.g. a Switch) a transfer energy $t_e$ is assumed. The transfer energy $t_e$ depicts the energy that is required to transfer one bit of data through a corporate network. For simplicity, the values for the power consumption of data transmission are taken from Baliga et al. (2010). Accordingly, the power consumption in the private cloud is assumed to account for 0.46 micro J/b while in the public cloud is presumed to be around 2.7 micro J/bit (Baliga et al., 2010)

- For any *Location* element representing a datacenter, a respective PUE is assumed to account for the average infrastructure efficiency regarding to the energy consumption of the datacenter infrastructure itself (without the IT equipment) (Shehabi et al. 2016, p. 3ff)

- Considering the fact that the *Location* elements depict a datacenter, the calculation of the environmental aspect of the technical infrastructure and the environmental aspect of the datacenter itself, follow the subsequent approach (Shehabi et al. 2016, p. 3ff; Posani, Paccoia & Moschettini, 2018, p. 2ff):

$$ea_{DC} = y * PUE * (\sum_{i=1}^{k} ea_i)$$

where $k$ depicts the number of technical infrastructure nodes within the datacenter and $ea$ represents the environmental aspect.

In short, the total environmental aspect for a datacenter expressed as $ea_{DC}$ is determined by adding the environmental aspect of each infrastructure node and multiply the sum with the datacenters respective Power Usage Effectiveness factor $PUE$ and its redundancy $y$.

Figure 17 and 18 depict the meta-models on which the analysis is based on.

**Figure 17: Metamodel for quantitative analysis**

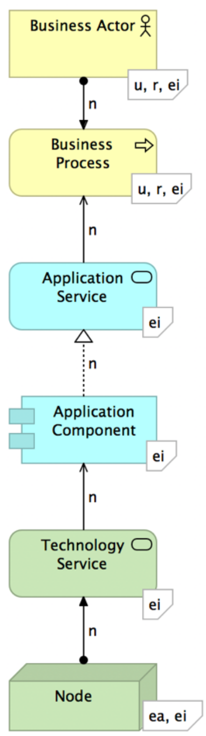


Figure 18: Metamodel for Analysis: Technical Infrastructure

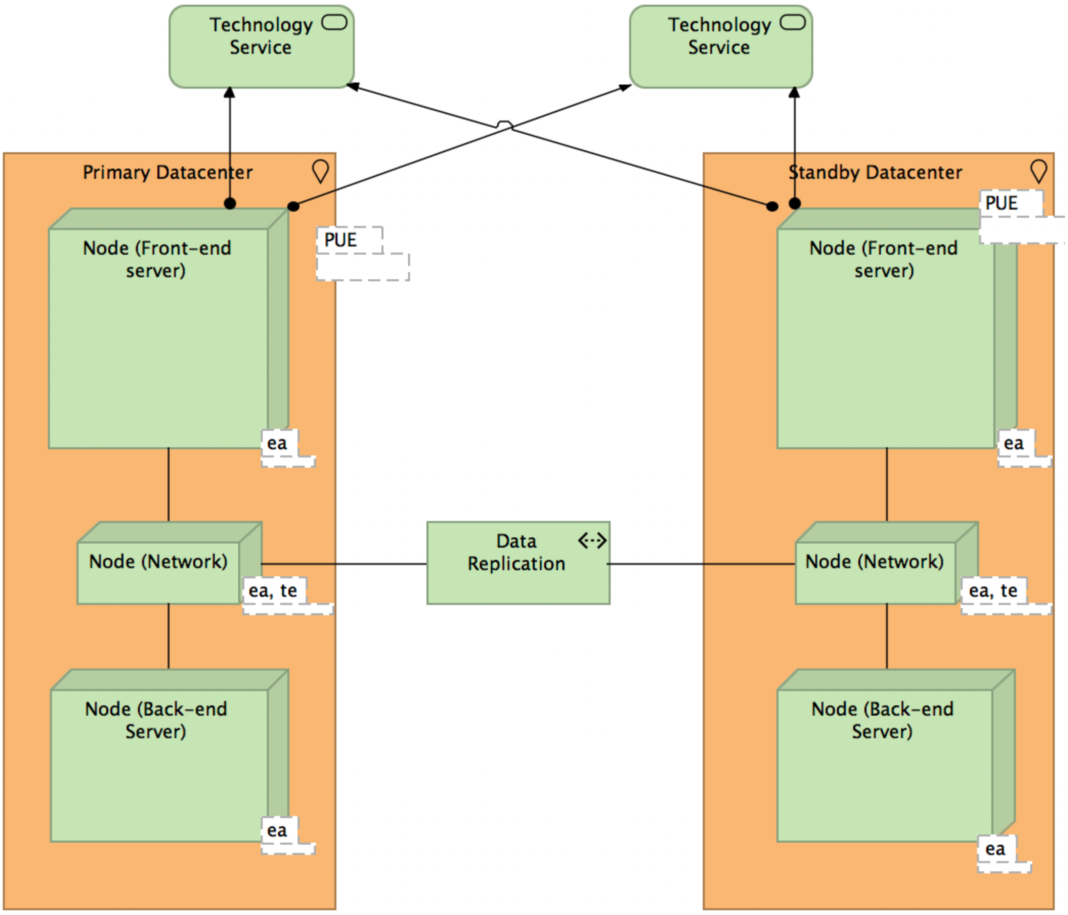



Table 39 presents a summary of the aforementioned variables.

Table 39: Summary of Variables

| Variables | Description | Metric in the example |
|---|---|---|
| **n** | Number of uses/accesses | - |
| **m** | Number of elements outside the datacenter | |
| **ea** | Value of Environmental aspect | W/h |
| **ei** | Value of Environmental impact | $CO_2$ Emissions |
| **u** | Number of users | - |
| **r** | Number of requests | - |
| **C** | Conversion factor from *ea* to *ei* | One W/hour produces 0,0836 Kg of $CO_2$ (Cavaleiro, Vasconcelos & Pedro (2016) |
| $\mathbf{t_e}$ | Transfer energy | b/J |
| **PUE** | (Power Usage Effectiveness) "total energy required by the data center in relation to the energy needed for the IT equipment" (Shehabi et al. 2016, p. 23) | - |
| **k** | Number of infrastructure nodes within the datacenter | - |
| **y** | Redundancy | - |

The quantitative analysis aims to determine the environmental impact *ei* based on the environmental aspect *ea* and is assigned to the respective element. In line with the proposal of Iacob and Jonkers (2006) the following analysis steps are suggested:

(1) Selection of a layered view and conversion to be conform with the structure in Figure 17. This includes the elimination or conversion of elements which do not fit in the structure described above.
(2) Performance of a bottom-up calculation.
(3) Performance of a top-down calculation

**Bottom-up Approach**

The goal of the bottom-up approach is twofold. It allows the calculation of:

- the environmental impact per component ($ei_x$)
- the environmental impact per business process ($ei_m$)

The environmental aspect of each node $ea_x$ is added up from the lowest to the highest layer where it is multiplied with the number of accesses/uses denoted as *n* for each relation from $ea_{x-1}$ (parent element in the lower layer) to the next element from $ea_x$ (children element of next higher layer).

This can be described as a sequence by recursion where an enumerated collection of elements is based upon each other in a specific order:

(1) $ea_m = ea_1 + ea_2 + ea_3 + \cdots + ea_x$
where $ea_m$ denotes the sum of all $ea_x$

(2) $ea_x = ea_{x-1} * \frac{1}{n}$
where x = $\{1,2,3,\ldots,m\}$ and
where n depicts the number of uses/accesses (see Table 39)

<u>Exception</u>: if $ea_1$ with x = 1, $ea_1 = ea_{DC}$

As is $ea_{DC} = y * PUE * (\sum_{i=1}^{k} ea_i)$ as described above

For each value of $ea_x$ a value $ei_x$ can be calculated by multiplying $ea_x$ with the respective conversion factor *c*. Consequently, the environmental impact can be calculated not only for each business process, but also for each component. Note: the bottom-up approach requires input data of the lowest later to allow the calculation which is given by $ea_{DC}$.

(3) $ei_x = ea_x * c$ and

(4) $ei_m = ea_m * c$
Where c denotes the conversion factor to transform $ea_x$ in $ei_x$ as well as $ea_m$ in $ei_m$.

**Top-down Approach**

The bottom-up approach provides the required inputs for the top-down calculation. It aims to calculate:

- environmental impact per request $ei_m\,(r)$
- environmental impact per user $ea_m\,(u)$

(1) $ei_m\,(r) = \frac{ei_m}{r}$
where the environmental impact $ei_m\,(r)$ of a given business process is by the number of requests *r*.

(2) $ei_m\,(u) = \frac{ei_m}{u}$
where the environmental impact $ei_m\,(u)$ of a given business process is divided by the number of users *u*.

## 3.5. Summary and Implications: Final artifact

Finalizing the artifact based on the feedback provided by the EA practitioners, the consolidated and revised list of environmental concepts and respective ArchiMate elements is presented in Table 40.

**Table 40: Summary of the Revised Concepts**

| **Initial Proposal** | **Revised Mapping** | **Changes** |
|---|---|---|
| *Activity, Product or Service* <Environmental Aspect> | Attribute | Attribute instead of element |
| *Driver* Legal Compliance | *Driver* be compliant | Alternative labelling |
| *Business Role* Management Representative | *Business Actor* | Alternative element |
| *Representation* <Environmental Statement> | *Business Object* | Alternative element |
| *Representation* <Management Approach Disclosure> | *Business Object* | Alternative element |
| *Representation* <Material Topic Specific Disclosure> | *Business Object* | Alternative element |
| *Assessment* <Environmental Condition> | *Assessment* <Environmental State> | Alternative labelling |
| *Capability* <EMS> | *Capability* EMS | Remove specialization |
| *Course of Action* <Environmental Programme> | | - |
| *Course of Action* <Environmental Action> | | - |
| *Goal* <Environmental Target> | | - |
| *Goal* Environmental Objective | | - |
| *Principle* <Environmental Policy> | | - |
| *Business Role* EMAS Verifier | | - |
| *Business Process* Environmental Review, Planning, EMS implementation and Operation, Acting, Checking, Verification, Validation, Management Review, Environmental Performance Evaluation | | - |
| *Outcome* <Environmental Impact> | | - |
| *Outcome* <Measured Environmental Performance> | | - |
| *Principle* <Reporting Principle Content> | | - |
| *Principle* <Indicator Principle> | | - |
| *Principle* <Reporting Principle Quality> | | - |
| *Requirements* Legal Requirements/ Laws and Regulations | | - |
| *Stakeholder* Enforcement Authority | | - |

In summary, the process of interviewing practitioners, discussing the proposed artifact and the final revision of the artifact has led to a list of 30 environmental concepts that can be modelled by using nine original ArchiMate elements (*Stakeholder, Goal, Requirement, Driver, Business Object, Business Actor, Business Role, Business Process, Capability*), ten new ArchiMate elements (Specializations: *Assessment* <Environmental State>, *Course of Action* <Environmental Programme>, *Course of Action* <Environmental Action>, *Goal* <Environmental Target>, *Principle* <Environmental Policy>, *Outcome* <Environmental Impact>, *Outcome* <Measured Environmental Performance>, *Principle* <Reporting Principle

Content>, *Principle* <Indicator Principle>, *Principle* <Reporting Principle Quality>) as well as the profiles to create attributes.

The treatment design phase led to the development of the artifact in hand that is based on a theoretical fundament and challenged through practical insights from experts in the EA domain.

A number of general remarks and lessons learned from the experience of Enterprise Architects can be drawn. To begin with, as already seen with the scarce literature base resulting from the literature review (Section 2.2.2), the participants of the interviews confirm the novelty of the topic of EA and environmental performance. Although respective research is still in its infancy and yet to mature, a great interest has been expressed in modelling environmental performance. According to practitioners, this does not only hold true for the subject of environmental sustainability, but also for other domains like ethical issues and social sustainability. It can be concluded that EA has a very IT-centric view with the sole purpose of achieving Business and IT alignment. Nevertheless, practitioners encourage this research in taking the bigger picture and a holistic view on the enterprise and all the issues and concerns, transcending the boundaries of the IT domain to other relevant, but yet new domains, including the environment and integrating it in the organization's enterprise architecture.

From this point of view, the potential of ArchiMate as the modelling language of choice has been expressed repeatedly. Moreover, the discussion about modelling environmental concepts with ArchiMate revealed its inherent ambiguity around the language's usability. This is, on the one hand, its extensive scope of expressiveness which has been matured over the years with every release and extension of the concepts. This subsequently allows to transcend the boundaries of the IT domain, to other domains. On the other hand, this great variety of scope comes with the burden of modelling decisions which became evident in the discussions about how to model the environmental concepts. Even with the experience of practitioners working in the EA field for many years, the interviews revealed a great variety of interpretation and modelling decisions. The practitioners also state that there is not only one right way of modelling a concept. Additionally, while acknowledging the usability of the ArchiMate language, the concern about the rather unclear and ambiguous grammar of the motivational extension has been raised. This includes especially the overlap in the definitions of the motivational elements in the ArchiMate language which can be seen in the discussions around the modelling of concepts like the environmental target as described in Section 3.2.2 and 3.3.

Another striking observation to be made at that point, deals with the utilization of the language customization mechanism, specifically the introduction of specialized elements derived from generic elements as described in Section 3.1.2. While some of the practitioners strictly refused to use any specializations, a number of practitioners encouraged this in some cases. On the one hand, this language customization was claimed as very useful for the elaboration and creation of clearly defined concepts. For instance, practitioners encouraged the specialization to distinguish the environmental goal from the environmental target. In contrast, introducing new concepts was entirely refused by some practitioners stating the modification leads to confusion where ArchiMate as a language is supposed to be understandable to a wide audience. It cannot be rejected, that with the introduction of specialized elements, the scope of concepts extends and consequently leads to reduced usability and ease of comprehension, introducing new efforts to communication.

Lastly, the introduction of attributes has been widely encouraged by the practitioners. This has been stated especially for the particular domain of environmental sustainability where metrics and quantifiable data provide valuable insights about the organization's environmental performance through the architecture. At the same time, practitioners support the utilization of attributes under consideration of the overall purpose of the EA model, ensuring that it adds value to the model, so that the right information with the right level of detail is conveyed, without overloading the model and therefore impeding communication. After the participants positive feedback of using attributes into the architecture models, this research also provides a quantitative side of the artifact. It has been shown that the concept of the environmental aspect can actually be used as an attribute where it has been originally mapped as a specialized element (*Activity, Product or Service* <Environmental Aspect>). This demonstrates the value of the two-step approach where the initial mapping has been revised leading to an improved artifact. The evaluation of the artifact's usefulness is subject of Chapter 4.

# 4. TREATMENT VALIDATION

***This chapter presents the validation of the proposed artifact designed in the previous chapter. As the last part of the design cycle, the validation aims at verifying the artifact's contribution to the addressed target group and intends to predict how it would interact in a real-world problem context (Wieringa, 2014, p. 31).***

To validate the artifact, the newly proposed and mapped environmental concepts as well as the quantitative approach are demonstrated in an example case study. Afterwards, the example case is presented to two experts who are interviewed to verify the usability and usefulness. Section 4.1 presents the design of the interview as well as the case study as a single-case mechanism experiment which is further presented in Section 4.2. Subsequently, Section 4.3 discusses the results of the validation in detail.

## 4.1. Methodology

For the treatment validation a two-method approach is chosen combining a single-case mechanism experiment with expert opinion interviews. Based on the presentation of the ArchiSurance case, the experts evaluate the artifact in a realistic context.

### 4.1.1. Single-Case Mechanism Experiment

The case of the fictional company ArchiSurance has been chosen for a single-case mechanism experiment as the validation method of choice. With the ArchiSurance case a controlled and well-established scenario is provided which allows to expose the artifact to a controlled environment where the interactions of the artifact in a realistic context can be analyzed and studied (Wieringa, 2014, p. 64). In this case, the usefulness and practicality of the artifact was subject of evaluation.

### 4.1.2. Expert Opinion Interview

For validating the usability and usefulness of the proposed artifact, the expert opinion interview is the method of choice. The interview design follows the approach of the RAND National Defense Research Institute for collecting data with semi-structured interviews as described in detail in Section 3.2.1. Table 49 presents the interview design for the treatment validation in detail.

Table 41: Interview Design for Treatment Validation

| Phase | Item | Description |
|---|---|---|
| **Framing the research** | Research question | How is the artifact evaluated? |
| | Information source | Available experts |
| | # Respondents | 2 |
| **Sampling** | Convenience | Available experts knowledgeable of EA and ArchiMate |
| **Designing questions & probes** | Descriptive and structural questions | See questions in appendix (Chapter 8.2) |
| **Developing the protocol** | Introduction | Introduction of the researcher, the purpose of the interview and the research |
| | | Establish rapport |
| | | Explain ground rules |
| | Ground rules | The interview aims at validating the research findings. |
| | | With permission of the interviewee the interview will be audio recorded. |
| | | The interview will take about 30 minutes. |
| | | The interview is confidential. |
| | | The interview will only be used within the context of the research |
| | | Responses will be anonymized in this thesis. |
| | Questions and probes | • Could this approach help organizations to improve their environmental performance?<br>• Is the use of the new environmental concepts and quantitative analysis intuitive and understandable?<br>• How do you evaluate the usefulness of the proposed artifact?<br>• How do you evaluate the usability of the proposed approach?<br>• Do you see any weaknesses in using the approach?<br>• Do you see benefits and strong points of using the approach?<br>• How does the approach allow to derive opportunities for improving the environmental performance based on the design of the to-be-EA? |
| | Closing | No follow-up required |
| **Preparing the interview** | | Prepare presentation |
| **Conducting the interview** | | Conduct interview following this protocol. |
| **Capturing the data** | | Summarize interviews and analyze results |

## 4.2. Single-Case Mechanism Experiment: Example of a Fictional Case Study

To show the practical use of the proposed artifact to introduce environmental concepts into the architecture of an organization, this section illustrates an example. The example is based on the case study of the fictional enterprise ArchiSurance as described by The Open Group (2012-2017). The goal of this example is twofold: First of all, the integration of environmental concepts as mapped and reviewed in Section 3.1 and 3.2 into the ArchiSurance architecture should be shown. Secondly, the usage of attributes to measure the environmental impacts should be demonstrated. In order to achieve both goals, the ArchiSurance case study has been adapted by introducing slight changes to the EA models provided in the case study (The Open Group, 2012-2017). For the purpose of demonstration, it is assumed that ArchiSurance plans the adoption of the EMAS regulation as described in Section 2.2.1.

In order to identify meaningful viewpoints, the questions are presented that are intended to be answered by the respective EA model. Due to the limited scope of this thesis, only selected viewpoints for each layer are depicted to demonstrate the approach.

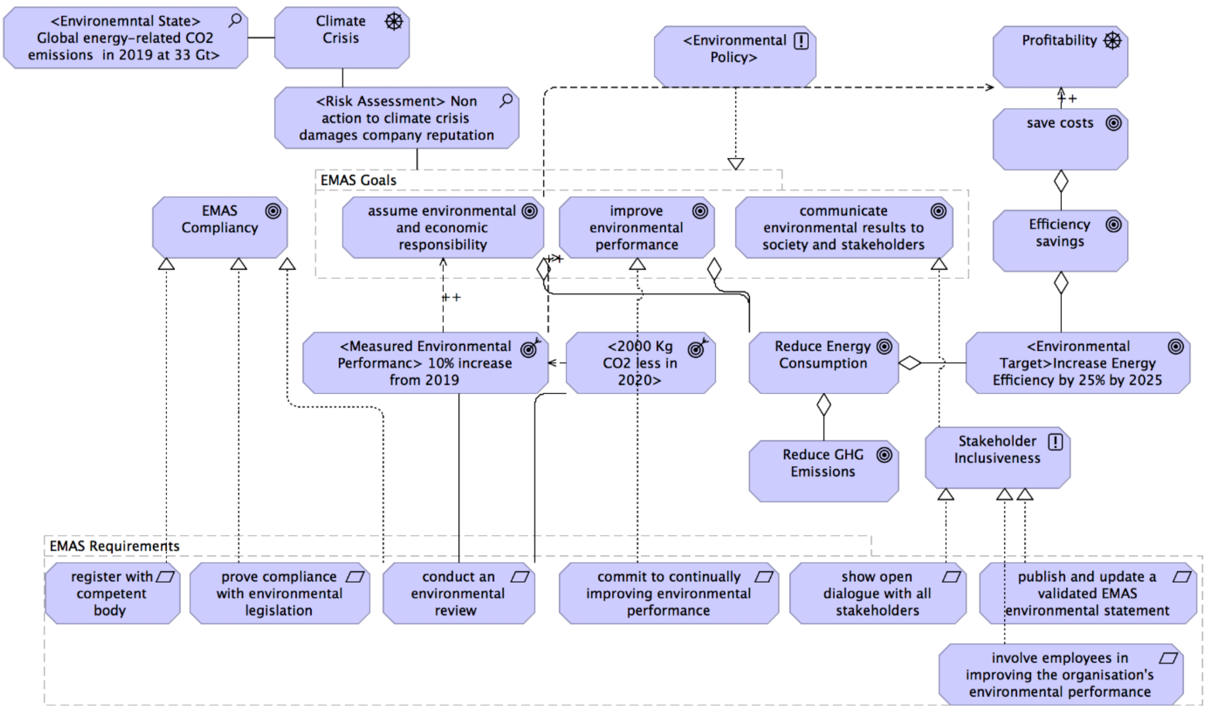
| Viewpoint | Required Environmental Elements | Questions |
|---|---|---|
| **Motivation** | Goals (Environmental Target; Environmental Objective), Outcome <Environmental Performance>, Principle <Environmental Policy>, Assessment <Environmental State>, Driver, Reporting Principles | What are the environmental goals of ArchiSurance? |
| | | Do environmental goals conflict with other goals of ArchiSurance? |
| | | What are the requirements to achieve environmental goals? |
| **Capability Map** | Capability EMS | What are the capabilities of ArchiSurance? |
| | | Are there already existing capabilities that could realize the environmental goals? |
| **Capability Realization** | Capability EMS, Business Function | What business functions are required to support existing and new capabilities? |
| **Outcome Realization** | Capability (EMS), Course of Action <Environmental Programme>, Course of Action <Environmental Action> | What capabilities are required to achieve the environmental goals? |
| **Business Process Cooperation** | Business Process, Business Actor EMAS Verifier, Business Object Environmental Statement, Capability EMS | What high-level processes are needed to realize the EMS capability? |
| **Layered View** | Environmental Aspect, Environmental Impact | What is the environmental impact for the business process “claim handling” and “claim submission”? |
| | | What is the environmental impact per request for the business process “claim handling”? |
| | | What is the environmental impact for the business process “claim submission”? |

### Motivation Viewpoint

The model intents to answer the following questions:

- What are the drivers for adopting environmental goals?
- What are the environmental goals of ArchiSurance?
- Do environmental goals conflict with other goals of ArchiSurance?
- What are the requirements to achieve environmental goals?

Figure 19: Motivation View



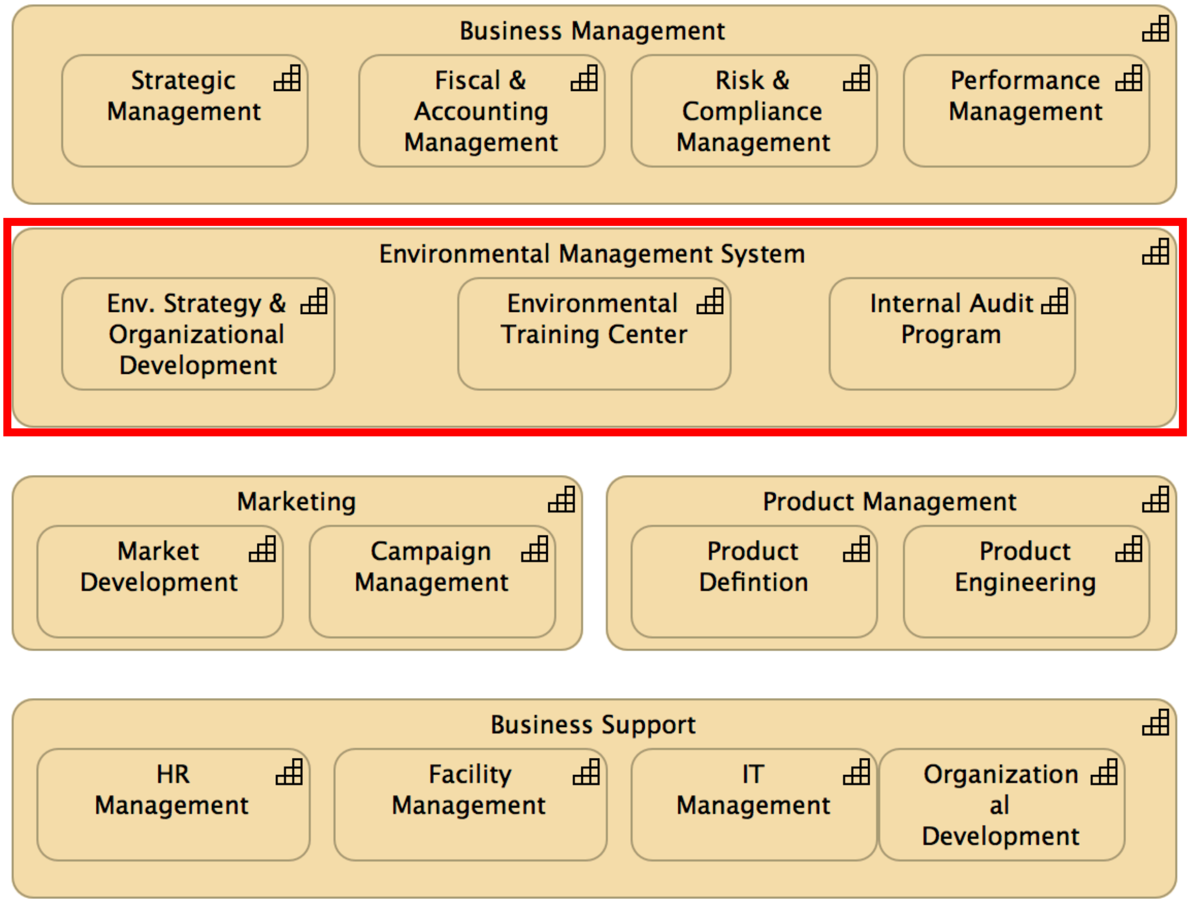

ArchiSurance is driven by profitability. Furthermore, the company recognizes the climate crisis as an external driver since an assessment showed that taking no environmental action represents a risk of damaging the company's representation. The external driver "Climate Crisis" is associated to the actual environmental state with global energy-related $CO_2$-emission being measured about 33 Gt in 2019. To ensure commitment, ArchiSurance drafts an environmental policy guiding the environmental goals inherent to the EMAS regulation. Next to those goals the company aims to achieve full EMAS compliance. In order to achieve all these goals, the EMAS regulation states a number of requirements that specify how the goals can be realized. At the same time, being driven by profitability, ArchiSurance aims at saving costs where possible. The company specifies another goal "efficiency savings" in order to save costs. The company recognizes the potential synergies of increasing energy efficiencies to realize cost savings and environmental goals at the same time. Therefore, an environmental target "Increase Energy Efficiency by 25% by 2025" is defined which at the same time supports the goal to reduce the company's overall energy consumption that in turn effects the EMAS goals "assume environmental and economic responsibility" and "improve environmental performance". To begin with, ArchiSurance wants to focus only on two of the mandatory performance indicators, namely, energy and emissions. Thus, the goal "reduce GHG emissions" is aggregated by the goal "reduce energy consumption within the company". To be able to prove energy and emission efforts, environmental performance reviews are performed showing the organizations environmental impacts and overall environmental performance. These reviews are associated with the outcome of a 10% higher environmental performance compared to the previous year as well as a decreased environmental impact of 2000 kg less $CO_2$. The decreased environmental impact directly influences the organization's overall environmental performance which positively affects the goal "assume environmental and economic responsibility" and "improve environmental performance". Further, the model depicts all the requirements formulated by the EMAS regulation and which of those requirements need to be fulfilled to achieve the goals. While all requirements need to be fulfilled to achieve the goal of EMAS compliancy, specific requirements state what needs to be done to achieve certain goals. For instance, the goal "communicate environmental results to society and stakeholders" comes with the requirement to publish and update a validated EMAS environmental statement.

**Capability Map Viewpoint**

The model intents to answer the following questions:

- What are the capabilities of ArchiSurance?
- Are there already existing capabilities that could realize the environmental goals?

Figure 20: Capability Map View



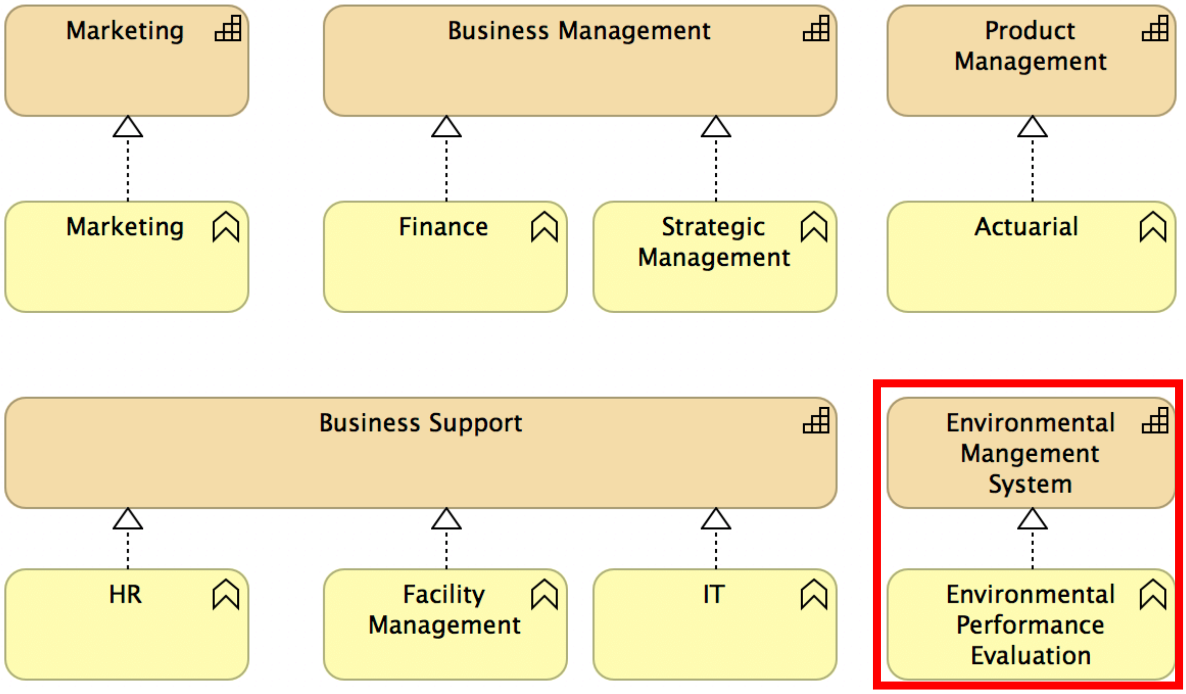

The capability map viewpoint provides an overview of existing capabilities in the organization. Based on this, missing capabilities can be identified. It may address strategic concerns pointing out gaps were capabilities are required to address certain organizational goals. ArchiSurance has several capabilities which are further divided into sub-capabilities. In order to achieve the intended goals, the company introduces a new capability which complies with the EMAS regulation for the introduction of an Environmental Management System. Examples for sub-capabilities within the EMS are the environmental strategy and organizational development, the environmental training center and the internal training program. Newly introduced elements that are not yet available in the ArchiSurance are marked in red in the model.

**Capability Realization Viewpoint**

The model intents to answer the following questions:

- What business functions are required to support existing and new capabilities?

Figure 21: Capability Realization View



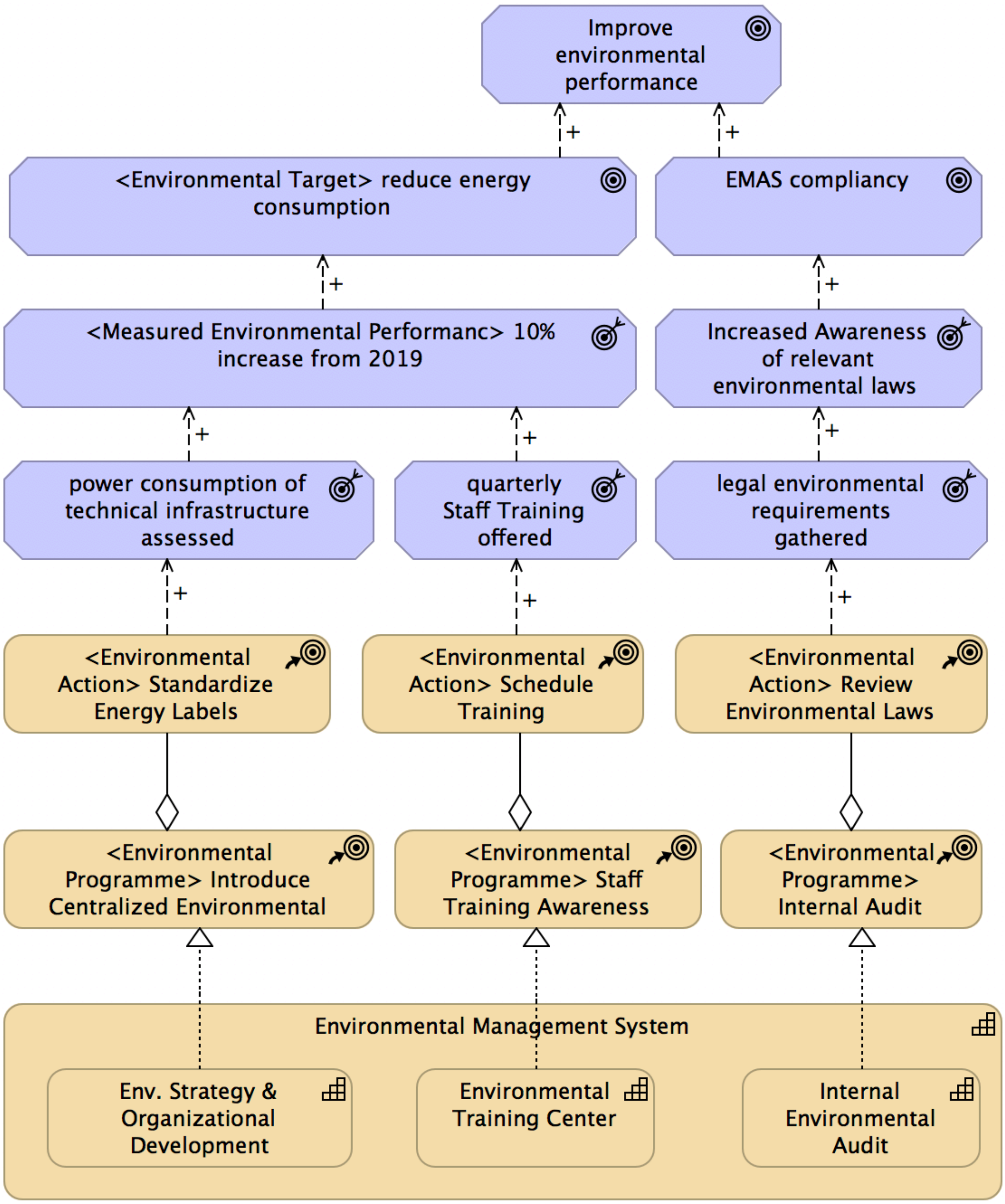

From the high-level overview of existing and required capabilities as shown in the capability viewpoint (Fig. 21) the capability realization viewpoint allows to see what business functions realize the respective capabilities. The ArchiSurance company aims at introducing a new organizational unit to set up the EMS (capability) where required skills, resources and knowledge for the environmental performance evaluation are united. Newly introduced elements that are not yet available in the ArchiSurance are marked in red in the model.

**Outcome Realization View**

The model intents to answer the following questions:

- What capabilities are required to achieve the environmental outcomes?
- What capabilities and course of actions are required to achieve the environmental goals?
- How are strategic actions related with outcomes and goals?

Figure 22: Outcome Realization View




The view (Fig. 22) intents to show how capabilities of the enterprise can be used to achieve the environmental goals and desired outcomes as specified by ArchiSurance. For this reason, the Outcome Realization Viewpoint is selected. It addresses business managers and architects and support them in the design and decision-making processes. Specifically, the model depicts which capabilities realize certain Course of Actions which the company has decided to do. Finally, decision-makers can see which capabilities and actions influence the outcomes. In this case, for instance, ArchiSurance introduce the EMS which is divided in three sub-capabilities. One of those is the Environmental Training center where actions are planned to train staff in their awareness in energy consumption behaviour. Due to this programme, ArchiSurance is able to provide quarterly staff trainings which positively affected the outcome of a 10% increase regarding the environmental performance compared to the last year. This also contributes to the environmental target of reducing the energy consumption which in turn positively affects the overall goal of improving the organization's environmental performance. Similarly, the EMS organized a sub-capability in charge of company's overall environmental strategy and organizational development regarding environmental issues. This capability introduces a new programme to implement a centralized environmental record system which will be the place where environmental performance measurements are kept and therefore form the basis for all environmental performance measurements and audits. To start with, the company launches the environmental action to standardize all energy labels that exist in the company. This action led to the successful assessment of power consumption of technical infrastructure in the organization which positively affected the outcome of a 10% increase regarding the environmental performance compared to the last year. This outcome contributes to the environmental target aiming to reduce the energy consumption which in turn positively influences the overall goal of improving the organization's environmental performance. Another sub-capability is concerned with internal auditing aligned with the EMAS regulation. A programme has been introduced to conduct internal audits regarding environmental issues. This includes the review of environmental laws and regulations in order to know which laws the company needs to comply with. This particular action led to the successful gathering of all applicable environmental laws which in turn resulted in an increased awareness of those laws. This helped the company to work towards its goal of achieving EMAS compliancy and consequently improving their environmental performance.

**Business Process Cooperation**

The model intents to answer the following questions:

- What high-level processes are needed to realize the EMS capability according to the EMAS regulation?

Figure 23: Business Process View

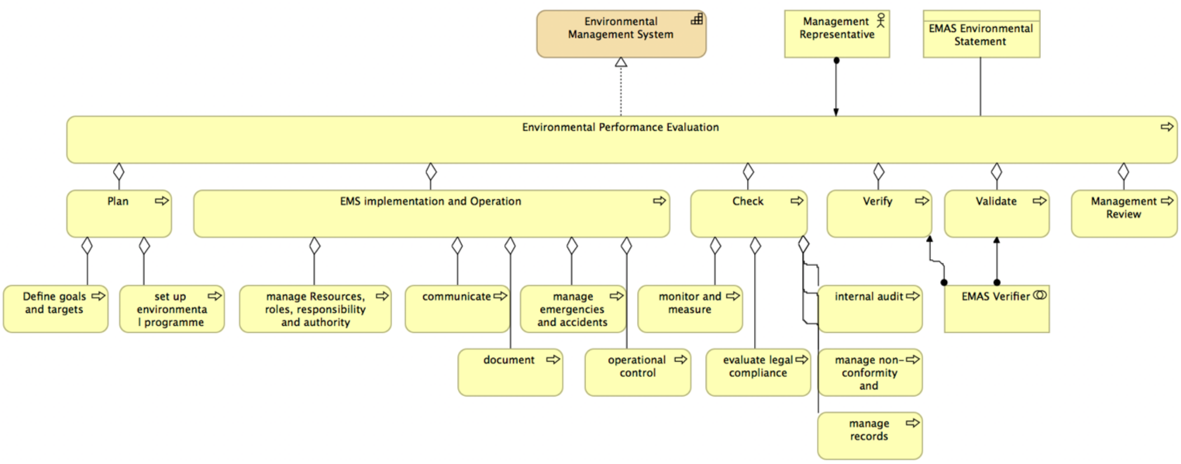



Figure 23 presents the Business Process View. The EMS is realized by the environmental performance evaluation process. As defined by the EMAS regulation, a management representative is assigned to this process which is associated with the formulation of the EMAS environmental statement. The environmental performance evaluation consists out of a number of sub-processes which are realized in sequence. To begin with the plan process is in charge of defining environmental objectives and targets and the setting up of the environmental programme. Afterwards, the EMS implementation and operation process is concerned with managing resources, roles responsibility and authority, communicating, documenting managing potential emergencies and accidents as well as the operational control which are defined as further sub-processes. The subsequent checking process deals with a number of sub-processes as the monitoring and measurement of defined parameter and core performance indicators, (2) the evaluation of legal compliance, (3) the procedures in case of non-conformity and need for corrective and preventive actions, (4) the control of records and (5) the internal audit (EEC, 2017). In the following verification process the conformity with the regulations' requirements concerning the overall set-up of the EMS by the organization is evaluated. The verification process is conducted by the EMAS verifier. In the subsequent validation process the verifier confirms the reliability, credibility and correctness of the environmental information provided by the organization (e.g. in its environmental statement) and its fulfilment of the requirements of the regulation. Furthermore, the management review is a re-occurring process of top management revising the management system in place regarding its effectiveness and value. A Management review can lead to modifications in the EMS including its objectives or the environmental policy.

**Layered View**

The model intents to answer the following questions:

- What is the environmental impact for the business process "claim handling" and "claim submission"?
- What is the environmental impact per request for the business process "claim handling" and "claim submission"?
- What is the environmental impact per user for the business process "claim submission" and "claim submission"?
- What is the environmental impact of potential to-be architectures for the business process "claim handling" and "claim submission"?

In order to perform a quantitative analysis to determine the environmental impact of a certain business process, the layered viewpoint is selected. This viewpoint intents to offer an overview across all layers in one diagram. According to the ArchiMate specification "The structural principle behind a fully layered viewpoint is that each dedicated layer exposes, by means of the "realization" relationship, a layer of services, which are further on "serving" the next dedicated layer" (The Open Group, 2012-2017, p. 146). Consequently, the internal structure of a dedicated layer can be distinguished from the externally observable behaviour represented as the service layer which is realized by the dedicated layer.

The following example extracts two main business processes from the ArchiSurance Case. The diagram as presented by The Open Group (2012-2017), has been slightly modified in order to fit in the attributes and allow a quantitative analysis of the environmental impacts.

Looking at the claim handling process, the administrator can search and view damage reports by accessing the respective applications. In contrast, the damage expert is entitled to access the report scanning application in order to digitize and store damage reports.

The report scanning application is supported by the underlying Document Management System (DMS) and the Database (DB) system, two application components that allow to enter new data into the database and store documents in the DMS. The same holds true for the view and search components which also access the DMS and DB application components to retrieve documents form the DMS and query data in the database.

The application components, DB and DMS are supported by the underlying technology layer. Usually, the DMS accesses documents by using the front-end server in the primary Datacenter (Location A) of ArchiSurance. Similarly, does the DB system access data by using the front-end server in the primary Datacenter (Location A) of ArchiSurance. The Front-end server is connected via a Switch to the Back-end server where the relational Database Management System is located.

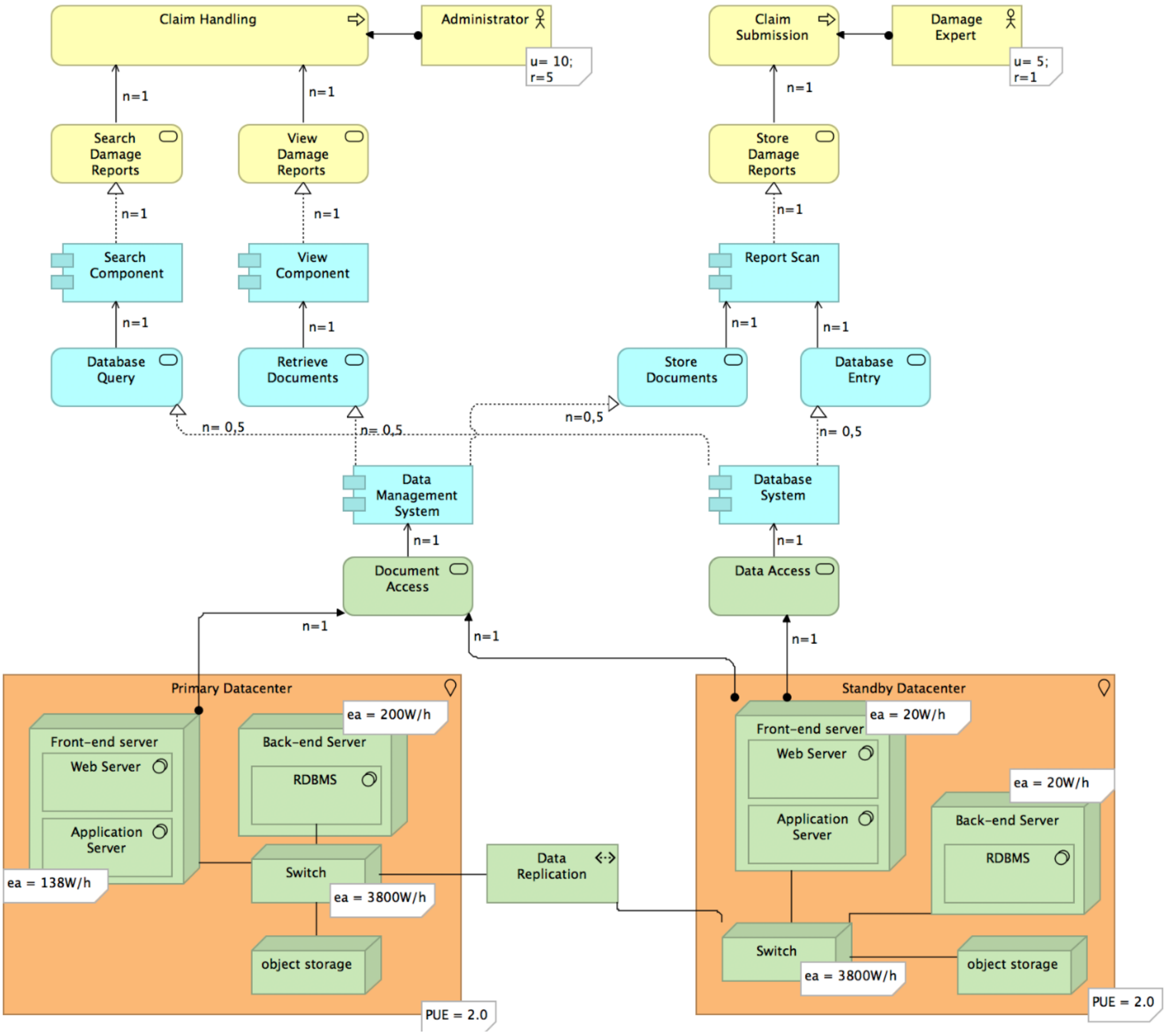
To mitigate the risk of data loss in case of a down-time of the servers or similar events in the primary Datacenter (Location A), ArchiSurance adopted a backup strategy. This includes a complete replication of the data into a secondary Front-End Server (B) and Back-end (server) in another Datacenter in another location (B). This allows ArchiSurance business continuity even in the event of down-times of servers in the primary datacenter as in this case the DMS and DB application will automatically access the Front-end server B.

For the purpose of analyzing the impacts, the following assumptions are made:

- On a regular basis, Front-end Server (A) and Back-End Server (A) work with a 50% load
- On a regular basis, Front-end Server (B) and Back-End Server (B) work with an idle load since application components are using servers in the primary Datacenter (Location A)
- Although the servers have virtualized servers (Application Server, Web Server, Database Servers) running on the physical front- and back end servers, calculations do not consider energy consumption of virtualization strategies
- Power consumption of user equipment (e.g. laptops, printers) are not taken into account
- The average number of requests per hour in the claim handling process is $r = 10$
- The average number of requests per hour in the claim submission process is $r = 2$
- The average number of users per hour in the claim handling process is $u = 5$
- The average number of users per hour in the claim handling process is $u = 1$
- ArchiSurance currently operates in a corporate network
- Datacenter A is located on-Premises of the ArchiSurance enterprise and can be described as a Server Room, consequently a PUE = 2.0 is assumed (Shehabi et al. 2016, p. 24)
- Datacenter B is located on-Premises of the ArchiSurance enterprise and can be described as a Server Room, consequently a PUE = 2.0 is assumed (Shehabi et al. 2016, p. 24)
- One W/h produces 0,0836 Kg of $CO_2$ (Cavaleiro, Vasconcelos & Pedro (2016)

Figure 24 depicts the current architecture as a transformed model according to the presented metamodel in Section 3.3.2.

Figure 24: Transformed Layered Model




## Bottom-Up Approach ($CO_2$ Impact per component/Location)

The bottom-up approach allows to calculate the $CO_2$ emissions for each component as well as for each datacentre depicted in the model. Table 41 shows the parameters used in the calculations based on the specifications of hardware components according to recent industry-standards. Calculations are performed as presented in Section 5.4 for the bottom-up approach.

Table 42: Specifications of Infrastructure Components according to SPEC measurements

| Component | Estimated Load | W/H |
|---|---|---|
| Front-End Server (A) (SPEC_1, 2020) | 50% Load | 138 |
| Front-End Server (B) (SPEC_2, 2019) | Idle Load | 20 |
| Back-End Server (A) (SPEC_2, 2019) | 50% Load | 200 |
| Back-End Server (B) (SPEC_2, 2019) | Idle Load | 20 |
| Switch (A) (Posani, Paccoia & Moschettini, 2018) | Peak Load | 3800 |
| Switch (B) (Posani, Paccoia & Moschettini, 2018) | Peak Load | 3800 |

For each component the environmental aspect $ea_x$ is mapped into the model, with $ea_x$ depicting the power consumption (kw/h). The respective values are shown in Table 41. For each *served by* and *realized by* relation, the number of uses n is mapped into the model. Starting from the lower level each value $ea_x$ is multiplied by the respective value $n$ to the linked element in the upper level, resulting in the mapping of an $ea_x$ for each component. The multiplication of the value $ea_x$ with the conversion factor results in the $ei_x$ for each element.

This corresponds to the formulas (1) to (4) as explained in Section 3.4.

The results are shown in Table 42 and Table 43.

**Figure 25: As-Is Architecture**

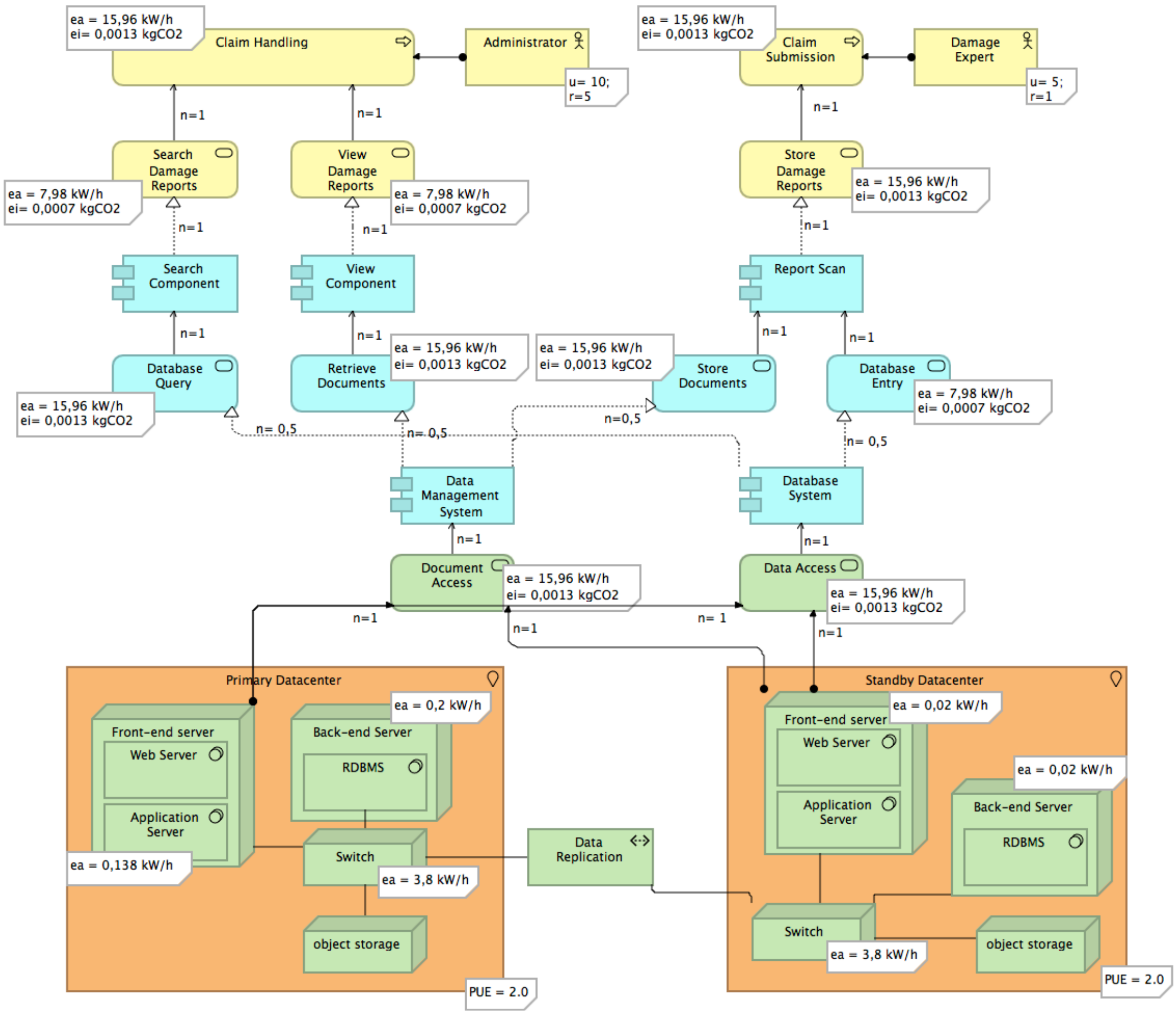


Table 43: Results environmental aspect and environmental impact per component

| Layer | Component | Underlying Service | Power Consumption (kW/h) | n | Emissions (Kg $CO_2$) |
|---|---|---|---|---|---|
| **Application** | Search Component | Search Damage Reports | 7,98 | 1 | 0,0007 |
| **Application** | View Component | View Reports | 7,98 | 1 | 0,0007 |
| **Application** | Report Scan | Store Reports | 15,96 | 1 | 0,0013 |
| **Application** | DMS | Retrieve Documents | 7,98 | 0,5 | 0,0007 |
| | | Store Documents | 7,98 | 0,5 | 0,0007 |
| **Application** | Database system | Database Entry | 7,98 | 0,5 | 0,0007 |
| | | Database Query | 7,98 | 0,5 | 0,0007 |
| **Technology** | Location A+B | Data Access | 15,96 | 1 | 0,0013 |
| | | Document Access | 15,96 | 1 | 0,0013 |

Table 44: Environmental aspect and environmental impact per process

| Process | Underlying Service | Power Consumption (kW/h) | n | Emissions (Kg $CO_2$) |
|---|---|---|---|---|
| **Claim Handling** | View Damage Report<br>Search Damage Report | 15,96 | 1 | 0,0013 |
| **Claim Submission** | Store Damage Report | 15,96 | 1 | 0,0013 |

**Top-Down Approach ($CO_2$ Impact per Request/User)**

The values $ea_m$ and $ei_m$ of the claim handling process and claim submission process provide the input data for the top-down calculations. The results presented in Table 44 are obtained by the calculations presented in Section 5.4 for the top-down approach.

Table 45: Power Consumption/$CO_2$ Emissions per Request and User

| Process | Power Consumption per Request (kW/h) | Power Consumption per User (kW/h) | Emissions per Request (kg $CO_2$) | Emissions per User (kg $CO_2$) |
|---|---|---|---|---|
| **Claim Handling** | 1,6 | 3,19 | 0,00013 | 0,0003 |
| **Claim Submission** | 7,98 | 15,96 | 0,00067 | 0,0013 |

For compliance reasons of storing claim requests for a long time period, ArchiSurance needs to replicate its data and wants to take the environmental impact for its data replication strategy into account. Therefore, the company wants to evaluate the environmental performance of two potential solutions. In the first option, data will be replicated from the primary datacentre (Location A) to the secondary datacentre (Location B). In the second option, the company uses the storage service of an external public cloud service provider for a backup of the data from the primary datacentre.

**Assumptions**:

- The required amount of storage is 16TB
- PUE On-Premises = 2.0
- Redundancy *y* on Premises = 2
- One w/h accounts for 0,0836 Kg of $CO_2$ denoted as *c*

Table 45 below shows the specifications of the storage devices.

Table 46: Specification of Storage Devices according to Oracle (2009-2014) and Posani, Paccoia and Moschettini (2018)

| | Storage Device | Disks (d) | TB per Disk | Peak W/h |
|---|---|---|---|---|
| **On-Premise** | Oracle ZS3-2 | 2 | 8 | 890 |
| **Public Cloud** | HP SO | 2 | 8 | 607 |

**Option 1: Storage Replication in the Private Cloud (on-premise)**

The calculations are based on the work of Posani, Paccoia and Moschettini (2018).

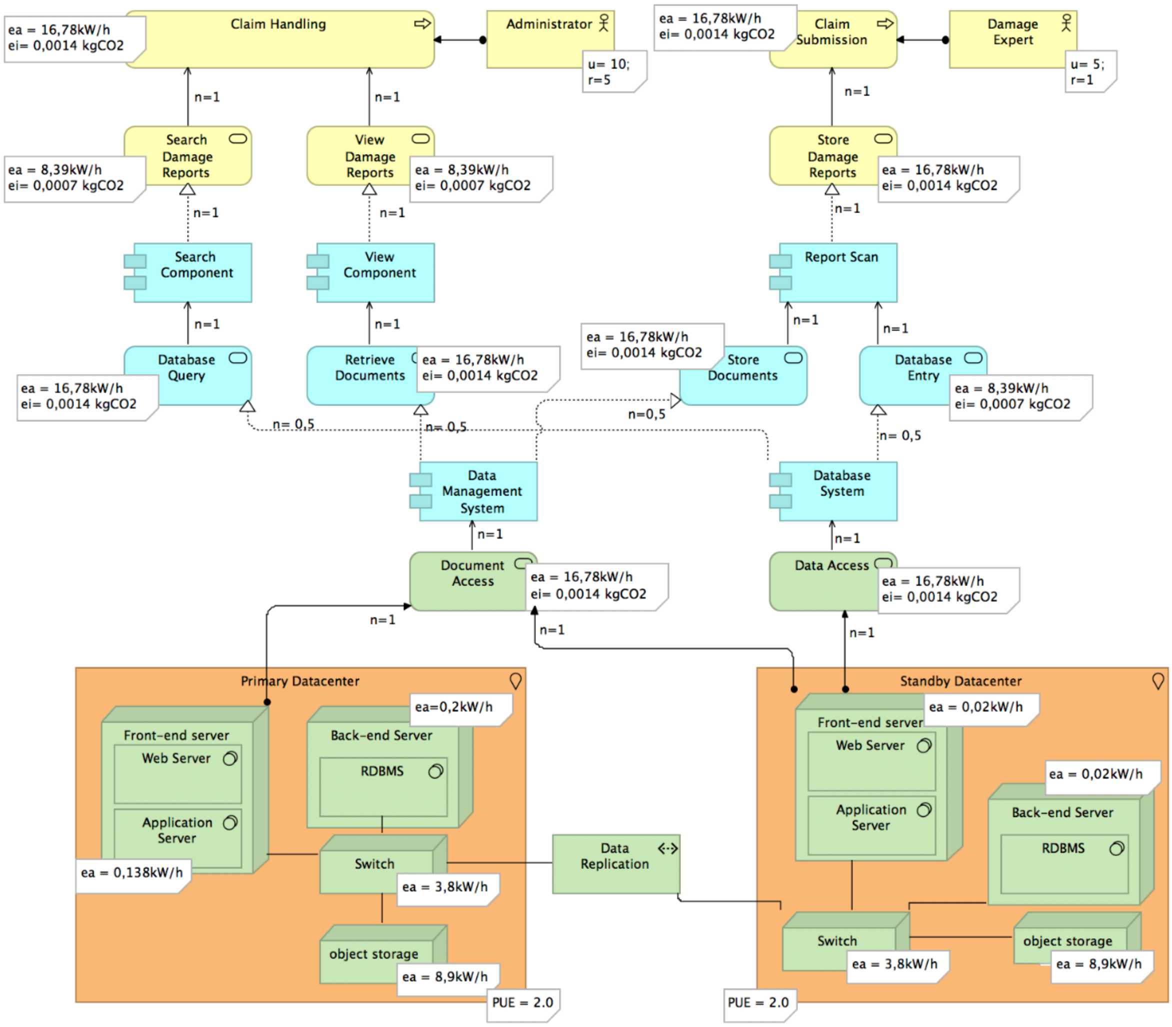
Power Consumption for storage solution in the Private Cloud:

$$(1)\ ea_{private\ cloud} = \text{PUE} \times \text{y} \times \frac{\text{peak w/h}}{\text{d} \times \text{TB of d}}$$

$CO_2$ Emissions for storage solution in the Private Cloud:

$$(2)\ ei_{private\ cloud} = ea_{private\ cloud} \times \text{c}$$

Figure 26: To-be Architecture Option 1




**Option 2: Storage Replication in the Public Cloud**

The calculations for the public cloud are based on the work of Posani, Paccoia and Moschettini (2018).

Power Consumption of the storage in the public Cloud:

$$(1)\ ea_{public\ cloud} = \mathrm{PUE} \times 1 \times \frac{\text{peak w/h}}{\text{d} \times \text{TB of d}}$$

Power Consumption of the storage in the primary datacentre (Location A):

$$(2)\ ea_{datacentre\ A} = \mathrm{PUE} \times 1 \times \frac{\text{peak w/h}}{\text{d} \times \text{TB of d}}$$

Therefore, option 2 results in a power consumption of:

$$(3)\ ea_{option2} = ea_{datacentre\ A} + ea_{public\ cloud}$$

The $CO_2$ emissions result in

(4) $ei_{option2} = ea_{option2} \times c$

**Comparison: Private Cloud (Option 1) vs. Public Cloud (Option 2)**

The results are presented in Table 47. Comparing the energy consumption for 16 TB of storage with the current deployment, the results show that the public cloud storage saves 50,55 W/h accounting for 4,22 kg $CO_2$ when compared to the private cloud storage solution.

(1) $\Delta\, ea_{storage} = ea_{option1} - ea_{option2} = 50{,}55\ \frac{W}{h}$

(2) $\Delta\, ei_{storage} = ei_{option1} - ei_{option2} = 4{,}22\ kg\ CO_2$

Table 47: Comparison of Power Consumption and $CO_2$ Emissions for storage

| | Power Consumption for 16TB storage only (W/h) | $CO_2$ Emissions (kg per W/h) for 16 TB storage only |
|---|---|---|
| **Option 1** | 222,5 | 18,6 |
| **Option 2** | 171,95 | 14,38 |

For simplicity, the values for the power consumption data transmission are taken from Baliga et al. (2010). Accordingly, the power consumption in the private cloud is assumed to account for 0.46 micro J/b while in the public cloud is presumed to be around 2.7 micro J/bit.

Table 48 shows the results when taking the power consumption per bit of transmission into account. The results are based on the following formulas:

(3) $ea_{option1} = 3{,}95\frac{kJ}{GB} \times 16000\text{GB}$

(4) $ea_{option2} = 23{,}19\frac{kJ}{GB} \times 16000\text{GB}$

Note: the formula employs $\frac{kJ}{GB}$ transformed from $\frac{J}{B}$.

Table 48: Comparison of Power Consumption and $CO_2$ Emission per Bit of Transmission

| | Transfer Power Consumption W/h for 16 TB | Transfer $CO_2$ Emissions (kg) for 16TB |
|---|---|---|
| **Option 1** | 0,0176 | 0,00147 |
| **Option 2** | 0,1031 | 0,00862 |

Table 49 shows the results of the total power consumption and $CO_2$ emissions for storage and transfer for both options. The results do not consider the power consumption of the whole deployment as presented in the as-is architecture.

The comparison of the transfer power consumption of both options shows that the private cloud option saves about 0,0855176 W/h for a 16TB storage. Thus, in terms of $CO_2$ emissions, the private Cloud deployment saves 0,00714927 kg of $CO_2$.

(5) $\Delta\, ea_{(transfer)} = ea_{\ (option\ 1)} - ea_{(option\ 2)} = 0{,}0855176\ \frac{W}{h}$

$$(6)\ \Delta\, ei_{(transfer)} = ei_{(option\ 1)} - ei_{(option\ 2)} = 0{,}00714927\ kg\ CO_2$$

**Table 49: Total Power Consumption and $CO_2$ Emissions**

| | Total Power Consumption W/h for 16 TB storage | Total $CO_2$ Emissions (kg) for 16 TB storage |
|---|---|---|
| **Option 1** | 222,5175616 | 18,60146815 |
| **Option 2** | 172,0530792 | 14,38861742 |

Comparing the total amount of power consumption and $CO_2$ emissions, the public cloud solution saves 50,4644824 W/h corresponding to 4,21285073 kg $CO_2$.

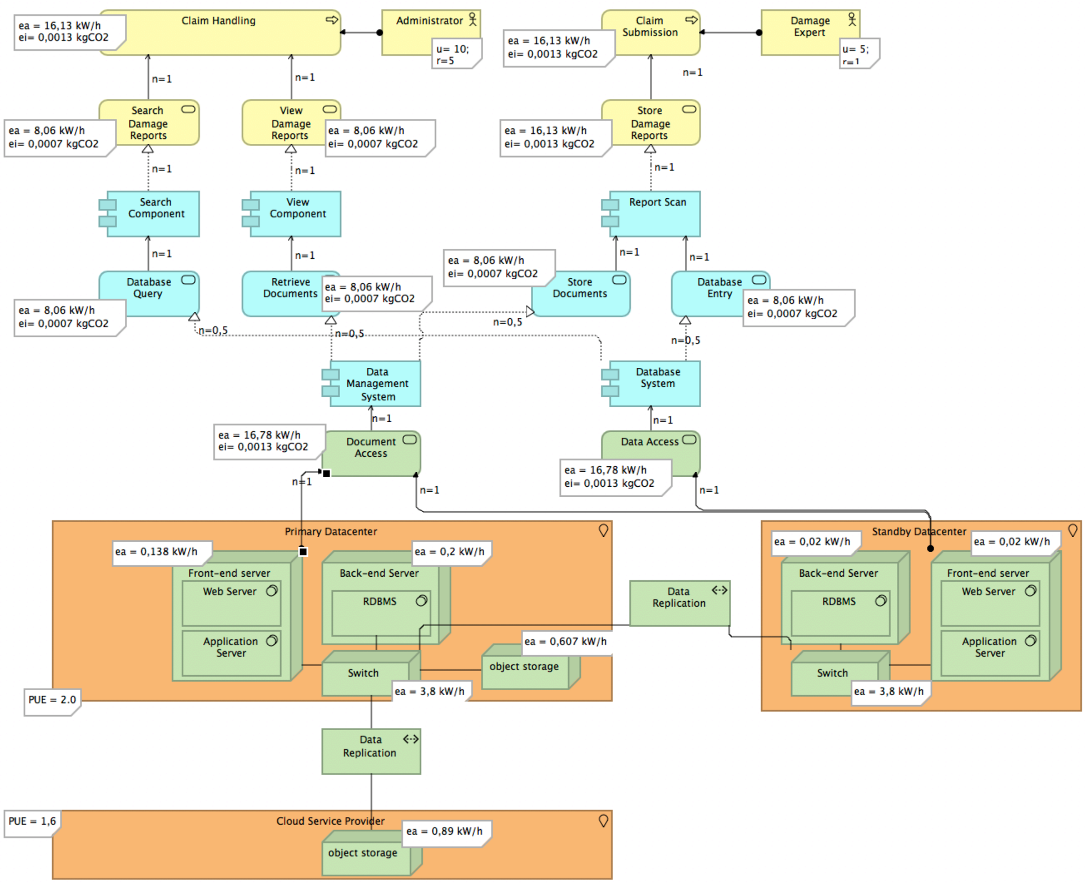
$$(7)\ \Delta\, ea_{(storage+transfer)} = ea_{(option\ 1)} - ea_{(option\ 2)} = 50{,}4644824\ \frac{W}{h}$$

$$(8)\ \Delta\, ei_{(storage+transfer)} = ei_{(option\ 1)} - ei_{(option\ 2)} = 4{,}21285073\ kg\ CO_2$$

Based on the previous calculations the public cloud solution saves 442,82 kW/h corresponding to 37,02 kg $CO_2$ each year in comparison to the private cloud solution.

However, when transferring this to the current architecture (Fig. 27), it can be seen that the savings are only marginal when compared to option 1. While the Claim Handling Process accounts for 16,13 kW/h in option 2, the same process accounts for 16,78 kW/h in option 1 (power consumption per process per hour).

**Figure 27: To-be Architecture Option 2**



## 4.3. Results

The expert opinion interviews aim at evaluating the artifact including the semantic concepts as well as the quantitative analysis which are demonstrated in the single case experiment. To begin with, the artifact was well received and evaluated as a valuable contribution for organizations. In general, with the proposed approach, the participants see an opportunity to actually improve an organization's environmental performance. Experts recognize the value of this approach as it allows to utilize a familiar and established practice like EA to discover and address new concerns like environmental performance in the organizational context. According to the interviewees, this lowers significantly the threshold for organizations to take action concerning environmental assessments within the enterprise. This comes with the condition that enterprises already have EA in place. Further, it was emphasized, that with EA as a significant part of enterprise planning and organizing business, the proposed artifact not only provides organizations with the tools to incorporate environmental performance evaluation in their EA models, but also makes environmental performance parameters a part of default processes in EA modelling. In short, the experts agree that the proposed approach allows companies an easier access to environmental performance evaluation by combining it with familiar and everyday EA practice. In this sense, the artifact was evaluated as useful as it directly takes up the way many larger organizations organize their business. Similarly, the usability and understandability were rated rather high. It was argued that the approach uses the familiar semantics and grammar of the ArchiMate language which makes it easily accessible for Enterprise Architects and does not require any additional learning efforts. All in all, the experts were able to read and comprehend the presented EA models without perceiving any difficulties in understanding the newly introduced concepts.

Despite all the positive feedback, also weaknesses of the artifact have been uncovered. It was mentioned that in the quantitative analysis, the utilization of exact numbers quantifying the environmental impacts and aspects is not adequate as it does not meet realistic conditions. Based on experience, one interviewee argued that it is not feasible to measure exact values of environmental aspects and impacts in heterogenous datacenters were power consumption can only be estimated and accuracy is probably impossible to achieve. While encouraging the quantitative analysis in EA models, it was suggested to account for uncertainty by utilizing a range of values for the environmental aspects and impacts rather than unrealistic estimated exact values.

In contrast, the potential automation of the quantitative analysis was highlighted as an advantage. According to one participant, the automation of the top-down and bottom-up calculations with the right tool support for EA modelling would enable organizations to quickly assess environmental performance of business processes, components and the whole organization. This opportunity was emphasized as very helpful. Consistent with this observation, the experts consider the proposed artifact as an opportunity to improve the organizational environmental performance for multiples reasons. For instance, it was mentioned that EA models would enable to assess and demonstrate the current state of the organization's environmental performance, helping the enterprise to evaluate its as-is situation and identify critical components of the architecture which are accountable for high environmental impacts. As one of the benefits of EA models, the architecture shows not only the environmental impacts of a certain architectural component, but also shows the component's place and therefore its significance and relevance in the whole architecture. This is important in decision-making were components with great environmental impact might be crucial for the organization's business. As a result, this would allow to identify the environmental harming components that are the least significant and thus the easy ones to tackle without compromising the functionality of the architecture. Great potential was seen in using different views and the creation of scenarios which would allow to assess different potential architectures including factors like the significance of the components and environmental impact parameters. Consequently, with the right tool support, the creation of scenarios could help to identify the best solution under consideration of environmental performance parameters, among others, and guide the design of the to-be architecture.

Further, several opportunities for future work were recognized and potential ideas for further research was recommended. Section 5.3 discusses future work of this thesis.

# 5. DISCUSSION

***With the presentation of the final artifact and its validation in the previous chapters, this chapter aims at discussing limitations, implications and future work. First of all, it provides a retrospective to critically assess the limitations of this work by looking back on the applied methods. Secondly, it offers a perspective for future research based on this thesis.***

## 5.1. Limitations

This section discusses the limitations of the methods applied in this research. The thesis at hand follows the Design Cycle Methodology. Therefore, this section follows the stages of Wieringa's design cycle.

### 5.1.1. Limitations pertaining to problem investigation

In the first phase a SLR has been conducted to investigate the state of the art in research and investigate the problem. The SLR follows the approach of Webster and Watson (2002) and has been documented in all steps from the query to the literature selection. This allows to avoid a subjective selection of the researcher and reduces bias which could steer the results in one or another direction. Thus, the SLR can be reproduced and would provide the same results independent from the researcher performing the review.

However, looking back very critically on the search strategy and selection process, it might be the case that a potentially relevant publication has been left out due to the fact that authors may have used different keywords to describe their scientific output. To counter this risk, different keywords have been tried and preliminary searches performed. Especially due to the fact that there are no established and common keywords for the joint topic of EA and environmental sustainability, the lack of standard terminologies might pose a validity thread.

Similarly, publications might not be considered in the SLR due to lack of access as specified in the exclusion criteria 2 (EC 2).

In regard to inclusion criteria 2 (IC2) limiting the search to the English language, it can be assumed that part of the publication output may well be in other languages. Hence, empirical studies not published in English might have ended up unincluded in the SLR. This is a limitation.

As defined in inclusion criteria 3 (IC3) studies were elected published from 2009 to 2020 as the preliminary search indicated that the topic only become prominent after 2009. Thus, publications before that date are not presenting the information relevant for this research. The excluded publications may affect the generalizability of the result.

Furthermore, the selection of the databases might be regarded as a risk as other databases might lead to other results. However, we believe that with the selected databases a sufficient and reasonable coverage is achieved.

Regarding internal validity, it could be possible that the author might have been biased in the application of the inclusion and the exclusion criteria. However, the clear documentation of the process enables the reproduction of the process for other researchers to reproduce the SLR and verify the objectiveness of the selection process.

In regard of the literature used in this work, it is to acknowledge that the university of the actor is very active in the area of EA research and that there is one paper included which is written by a teacher of the author. This paper (Iacob, Quartel & Jonkers, 2012) however was included because of its explicit relevance to the subject of this research.

Further, the fact that certain publications could not be accessed fully poses a limitation to this work. This is the case for the publications from the website of the International Organization for Standardization where limited access to the information has been encountered. However, the lack has been balanced out by using other sources reviewing the same topic, so that a correct representation can be ensured and misinterpretation through lack of completeness be eliminated as much as possible.

### 5.1.2. Limitations pertaining to treatment design

Moving on in the design cycle, the treatment design phase comes with a number of limitations. To begin with, only a handful of SRTs has been selected for the mapping to the ArchiMate language. The main reason for this are time constraints and the limited scope of this research. However, the selection of the SRTs has been performed in a systematic manner and is not subject of bias or randomness. In regard of the mapping process itself, the methodology of Wand & Weber (2002) as well as the rules for the classification of architectural concepts ensure a systematic and rational mapping process and guarantee the conformity and interoperability with the existing ArchiMate metamodel. Further, to ensure that the mapping in not based on the subjective perception of the researcher, the discussion of the results with experts of the field with a subsequent revision process assures the objectiveness of the proposal (see Section 5.2).

Concerning, the study design of the interview, the experts can be considered a reliable source. Given the carefully designed interview protocol following the approach of the RAND National Defense Research Institute, semi-structured interviews can be reproduced and are expected to provide the same results assuming the same participants and context of research. Concerning the interviews and the availability of the experts, another limitation of this research is perceived due to time constraints. In some cases, the interview could not be conducted fully, leaving open unanswered questions due to the limited availability of some participants.

Another important concern in qualitative studies pertains to the question if we would get different results if we interview a different set of practitioners. Following Seddon and Scheepers (2012), we think that in companies that share the contextual settings of the organizations employing the interview participants, it might well be possible to observe similar findings as those presented in this thesis. Examples of companies that share the contextual settings of our included practitioners are those operating in the same business sectors (see Table 29), having similar business processes and supporting applications.

Moreover, regarding the completeness of the mapping proposal, it can be stated that the concept mapping as presented in Section 5.1 has been completed before performing the interviews (Section 5.2) to guarantee that all concepts are evaluated by experts. This contributes towards the goal of objectives and avoid bias.

Considering the selection process of the participants for the interviews in the treatment design phase, a convenience sample has been described in Section 5.2.1. The sample shows that most participants work in the field of IT and consultancy which is due to the fact that this is the domain of Enterprise Architects. Demographics of the sample show also the heterogeneity of the participants backgrounds as the interviewees came from all over the world.

### 5.1.3. Limitations pertaining to treatment validation

Moving on to the treatment validation phase of the Design Cycle, a fictional case study has been chosen for a single-case mechanism experiment as the validation method of choice. With the ArchiSurance case a controlled and well-established scenario is provided which allows to expose the artifact to a controlled environment where the interactions of the artifact in a realistic context can be analyzed and studied. In this case, the usefulness of the artifact was subject of evaluation. In combination with the expert opinion to assess the artifact applied to the ArchiSurance case, valuable insights have been gained. In can be concluded, that the case study offers a great opportunity for the purpose of validation as it offers a realistic validation model that has been acknowledged by the EA practitioners' community. However, since the topic of environmental performance is very novel, many assumptions had to be made (e.g. ArchiSurance adopts the EMAS regulation) which in turn requires some adoptions of the original EA models of the case study. Nevertheless, the expert opinion interviews confirm the meaningful use of the presented EA models with the intention of presenting the integration of environmental performance in EA modelling. Further, in order to prevent a subjective selection of viewpoints, the purpose of the models was defined beforehand by posing questions that the EA models were intended to answer. To sum up, the fictional case study in combination with the expert interviews allow the validation of the artifact where valuable insight concerning the usability and usefulness of the artifact have been gained.

## 5.2. Implications

A number of implications can be drawn from this research. This part outlines implications for three target groups: (1) practitioners, (2) teachers and (3) researchers.

(1) The results from Chapter 3 and Chapter 4 and their validation clearly indicate the need for making the topic of environmental sustainability more accessible to organizations. Here, this research has shown how EA modelling can be used to overcome this barrier. Throughout the interviews with the practitioners, it became evident that environmental sustainability is not a well-known topic among Enterprise Architects and while all of them expressed great interest in the topic, only one interviewee actually had experience in modelling sustainability. This represents the first barrier to approach environmental sustainability in the organizational context. Practitioners striving for the integration of environmental sustainability in the organization's enterprise architecture need to be familiar with the concepts as presented in this thesis (see Section 3.5). Further, it is recommended to follow a holistic approach where environmental sustainability is supported from top management which should be visible in the mission and vision of the organization. Consultants familiar with modelling environmental sustainability can be advisors on how to represent and measure environmental performance for their client's organizations. Depending on the selected viewpoint, different parties of an enterprise can benefit from modelling environmental sustainability. For instance, on a small scale a project manager planning to introduce a new system in the IT landscape of an organization, can also consider the new system's environmental performance by comparing the as-is and potential to-be architectures. This way, environmental performance can be taken into account as a default when looking on how enterprises organize their business. This does not only apply for the whole enterprise but is also applicable for single business processes or complex services. In contrast, until now, EA as a domain did not consider to account for environmental performance in any way. With this approach however, also practitioners can benefit from the means that EA and ArchiMate provide to approach the topic of environmental sustainability. With the given approach based on ArchiMate as presented in this thesis, assumingly a large number of organizations can already start modelling their environmental performance initiatives and measures. As ArchiMate is well-integrated with TOGAF, enterprises using other EA frameworks must assess the transferability and usability of the proposed approach and evaluate individually how it fits with other EA frameworks. However, since this research does not focus on EA frameworks, but emphasizes the use of ArchiMate, other EA frameworks are not explicitly excluded.

(2) With sustainability being a more relevant issue nowadays, it is recommended and necessary to integrate the topic in the student's curriculum. Especially, with regard to the subject of Business and IT, students should also be allowed to gain knowledge about how to address environmental sustainability in organizations and how technology can be employed to do so. Concerning the "how" question, teachers should highlight common practices which can also offer the means to address the topic of environmental sustainability. For instance, in the Business Information Technology programme of the University of Twente, existing courses about EA offer teachers the opportunity to integrate environmental sustainability. For example, when discussing analysis methods in EA, instead of explaining a basic cost analysis, an environmental impact analysis could be performed. Regarding the technology aspect, it is recommended to teach about the potentials of technology to contribute to environmental sustainability. In this aspect, e.g. courses in requirements engineering could also highlight the benefit for the business when environmental aspects are taken into account for systems engineering.

(3) While this thesis focusses on EA modelling languages with ArchiMate in particular, the suitability of EA frameworks for environmental performance evaluation is recommended for future research. In line with this, researchers are recommended to look into the following research questions:

- How can EA frameworks support and guide organization's environmental performance evaluation?
- What further environmental concepts need to be integrated to enable organizations to fully express their environmental concerns and issues in EA models?
- How can SRTs and environmental performance evaluation methods (e.g. Life Cycle Assessments) be integrated in EA models?
- What kind of tool support is required to allow automation and analysis for better decision-making in EA-model-based environmental performance evaluation?
- How can the business benefit from requirements management in systems engineering when taking environmental aspects into account?

The future lines of research are elaborated in more detail in the next section.

## 5.3. Future Work

Throughout the design and validation of the artifact, the importance of integrating environmental concerns into the organizational context has become clear. Additionally, the dialogue with experts has shown the value of combining the topics of environmental performance and EA creating new opportunities for more awareness for environmental issues when it comes to enterprise planning and business organization. Lastly, with the finalization of the artifact and its validation, the potential of the presented approach presents itself with numerous prospects for future research. Potential research questions already raised in the previous section are elaborated here.

To begin with, it is recommended to verify that all SRTs and the according environmental concepts can be represented in EA models. It is therefore suggested to perform a similar semantic analysis as performed in Section 3.1 for other SRTs which might be adopted by organizations that wish to address environmental reporting and assessments. Similarly, the quantitative analysis approach needs to be tested with other attributes to verify whether the approach itself also is useful when other environmental aspects are considered in the calculations.

Moreover, further investigations should analyse whether relationships in ArchiMate could be utilized to express environmental concepts or could be used to convey environmental parameters.

Also, future research could explore how environmental performance evaluation methods could be integrated in EA models. For instance, Life Cycle Assessments (LCA) could be incorporated in the environmental impact calculation.

Further, as already raised in the interviews, future research should look into the automation of the calculations. This could be achieved by providing EA modelling tools with analysis features where environmental aspects can be assigned to architectural components and environmental impacts are calculated automatically.

Based on this idea, tool support can also be considered for future research where environmental costs are combined with other parameters which help in decision-making and creating scenarios to identify the best to-be architecture. Concretely, other parameters that could be relevant for design decisions for the to-be architecture include monetary costs or significance of architectural components. The enriched architecture models would allow better decision-making as a holistic view of the enterprise is provided.

Additionally, tool support and automation should also be subject for further investigation concerning compliance checking through EA models. This includes research on verifying regulatory compliance concerning environmental laws based on EA models. For instance, automated checking processes could assess how much GHG emissions are produced in a certain production process and its verification against national and international determined restrictions.

Furthermore, research in enhanced analyses and visualization are recommended for future work. For instance, based on analysis and calculation of environmental impacts, heat maps could show ‘big polluters’ in the architecture while also indicating the relative relevance concerning their functionality for the whole architecture.

Lastly, the artifact needs further validation in real-world companies to verify its usefulness.

# 6. CONCLUSION

***This research presents how to introduce environmental sustainability to the enterprise using EA and the EA modelling language ArchiMate. Guided by common SRTs, the systematic analysis and mapping of environmental concepts to the ArchiMate language and its subsequent expert evaluation demonstrates how ArchiMate provides the ideal vehicle for introducing environmental sustainability in the organizational context. With the combined knowledge from literature and practice, this research offers both a qualitative and quantitative approach to environmental performance modelling and assessment. This has been evaluated as a valuable and useful contribution for organizations aiming to improve the organizational environmental performance from an architectural perspective.***

This chapter revisits the research objectives stated in Section 1.3 and answers the main research question:

*How can environmental performance be modelled in enterprise architecture (EA)?*

The results of the sub-research questions as answered in this research are summarized below.

**(RO1) Research Objective 1: Identify current approaches and means how organizations measure environmental performance**

*RQ1a: What are the most common frameworks and standards to address environmental performance of organizations?*

Our researched literature reveals a variety of SRTs that support organizations in the reporting and evaluation of environmental performance on a corporate level.

In Section 2.1.1 a general overview has been provided about the different types of corporate SRTs that are available. The retrieved results provided a starting point for this research which successfully achieved a consent for a consolidated set of essential concepts to represent environmental performance.

The most common SRTs found in literature are the ISO 14001, the ISO 14031, the Eco-Management and Audit Scheme and the Sustainability Reporting Guidelines G3. These SRTs are taken into account for the extraction and mapping process to the ArchiMate language.

**(RO2) Research Objective 2: Identify the state-of-the-art of the relation of EA practices and environmental performance?**

*RQ2a: How do existing EA-based approaches measure environmental performance in literature?*

In regard of RQ 2a asking for EA-based approaches to measure environmental performance, it can be held that only one study (Cavaleiro, Vasconcelos & Pedro (2010) can be found in literature that investigates EA-based measurement of EP. The approach presented, uses the EA language ArchiMate for modelling the technology infrastructure in order to measure energy consumption and $CO_2$ emissions with the goal of assessing the overall environmental performance of ICT. However, the paper only focusses on single infrastructure components in the technology layer and does not take any other layers of the organization's architecture into account.

*RQ2b: Which languages and frameworks allow to model environmental performance?*

Similar to RQ2a, we found that literature on environmental performance and EA languages and frameworks is fairly scarce. Based on the findings from the SLR as presented in Section 2.2.2, literature suggests the usage of the EA-modelling language ArchiMate as well as the GERAM to approach environmental performance from an EA perspective. Further, new EA frameworks are proposed supporting organizations in aligning environmental strategies and embracing green technologies in the overall EA (Scholtz et al. (2014), Gill, Bunker & Seltsikas, 2011). Those however, lack any references to common EA standards or do not provide complete frameworks which makes them hardly accessible for organizations. In this sense, newly proposed frameworks need to nurture compatibility with already established standards such as The Open Group Architecture Framework (TOGAF). This would make novel approaches significantly usable, allowing them to be embraced by others who have already embarked on TOGAF.

In summary, the EA practice has not yet contemplated, but rather disregarded environmental performance modelling. Therefore, literature does not suggest established best practices where frameworks and languages suitable for EA-based environmental performance modelling have stayed unnoticed by the researchers' and practitioners' community so far.

**(RO3) Research Objective 3: Map and Integrate environmental performance into the EA practice and ArchiMate modelling language.**

*RQ3a: To what extent can environmental performance be represented in EA and ArchiMate?*

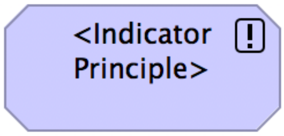
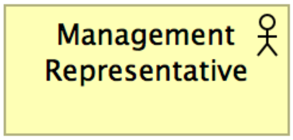
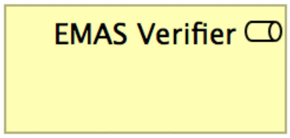
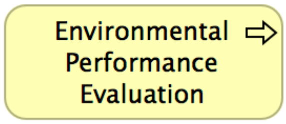
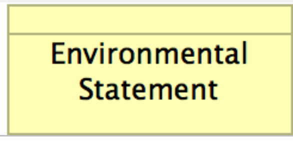
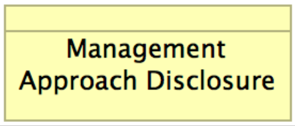
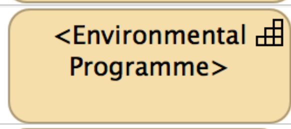
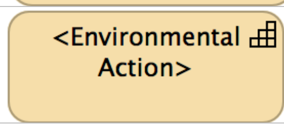
In regard to RQ3a, this research corroborates the potential of ArchiMate as the modelling language of choice, specifically in its ability to express environmental concepts in architectural terms. Moreover, the expert evaluation of modelling environmental concepts with ArchiMate revealed its inherent ambiguity concerning the language's usability. This is, on the one hand, its extensive scope of expressiveness which has been matured over the years with every release and extension of the concepts. This subsequently allows to transcend the boundaries of the IT domain, to other domains. On the other hand, this great variety of scope comes with the burden of ambiguous modelling decisions where a great range of interpretation and modelling decisions has been uncovered. Additionally, while acknowledging the usability of the ArchiMate language, the concern about the rather unclear and ambiguous grammar of the motivational extension has been raised.

*RQ3b: How can ArchiMate be adopted to achieve full expressiveness in order to model environmental performance in EA?*

Acknowledging the potential of ArchiMate for modelling purposes, adoptions were required in order to achieve full expressiveness to represent environmental concepts with ArchiMate. Regarding RQ3b, the combined methodological approach from literature and practice has led to a list of 22 environmental concepts that can be modelled by using nine original ArchiMate elements, ten new ArchiMate elements (Specializations) as well as the profiles to create attributes. The final mapping of environmental concepts is presented in Table 50. The careful and systematic mapping process guided by the methodology of Wand & Weber (2002), guarantees the conformity and interoperability with existing ArchiMate models. Furthermore, the adoption of the profiling specialization mechanism enables the introduction of attributes to the architecture and consequently introduces a quantitative side to the presented approach. Insights from practice confirm that the adoption of quantitative metrics and data valorize architectural modelling endeavors in the context of environmental performance evaluation with EA.

**Table 50: Final Artifact**

| **Environmental Concept** | **ArchiMate Elements** | |
|---|---|---|
| Environmental Aspect | Attribute | - |
| Be compliant | *Driver* | be compliant |
| Environmental Target | Specialization of a *Goal* | <Environmental Target> |
| Environmental Objective | *Goal* | Environmental Objective |
| Environmental Policy | *Specialization of a Principle* | <Environmental Policy> |
| Environmental Impact | *Specialization of an Outcome* | <Environemental Impact> |
| Measured Environmental Performance | *Specialization of an Outcome* | <Environemental Performance Measurement> |
| Environmental State | *Specialization of an Assessment* | <Environmental State> |
| Enforcement Authority | *Stakeholder* | Enforcement Authority |
| Legal Requirements/ Laws and Regulations | *Requirement* | Legal Requirements/ Laws and Regulations |
| Reporting Principle Content | *Specialization of a Principle* | <Reporting Principle Content> |
| Reporting Principle Quality | *Specialization of a Principle* | <Reporting Principle Quality> |

| Environmental Concept | ArchiMate Elements | |
|---|---|---|
| Indicator Principle | *Specialization of a Principle* |   |
| Management Representative | *Business Actor* |   |
| EMAS Verifier | *Business Role* |   |
| Environmental Review, Planning, EMS implementation and Operation, Acting, Checking, Verification, Validation, Management Review, Environmental Performance Evaluation | *Business Process* |   |
| Environmental Statement | *Business Object* |   |
| Management Approach Disclosure | *Business Object* |   |
| Material Topic Specific Disclosure | *Business Object* |   |
| EMS | *Capability* |   |
| Environmental Programme | Specialization of a *Course of Action* |   |
| Environmental Action | Specialization of a *Course of Action* |   |

*RQ3c: How can EA models be used for quantitative analysis of environmental performance?*

The single case experiment in combination with the expert opinion interviews demonstrates not only the value of the integration of semantic aspects of environmental performance in the architecture, but also shows the usefulness of the quantitative analysis. In analogy to the EA-based cost analysis as presented by Iacob and Jonkers (2006), the proposed approach allows the calculation of the organization's overall environmental performance composed of individual environmental aspects and impacts of single components and business processes. In the bottom-up approach the environmental impact for every business process and architectural component (e.g. business service or technology component) can be computed while the top-down approach allows the calculation of the environmental impact per action (e.g. request of a client) or per user/business actor. The contribution of the quantitative analysis is twofold: First of all, it allows the organization to assess the current environmental performance of the as-is architecture as well as it enables the design of a potential future to-be architecture aiming at an improved environmental performance. Secondly, the approach facilitates the discovery of heavy polluters in the architecture and assists in the process of singling out distinct components and processes that effect the environmental performance significantly in a negative way.

Thus, the EA-based quantitative analysis of environmental performance as proposed in this research equips Enterprise Architects with the right tool to integrate quantitative environmental performance assessment in architecture design spanning all organizational concerns from business process design to technology infrastructure planning.

**(RO4) Evaluate and demonstrate the artifact in an example.**

*RQ4a: How do experts evaluate the usefulness of the artifact?*

The experts participating in our evaluation study agree that the proposed approach allows companies an easier access to environmental performance evaluation by combining it with familiar and everyday EA practice. In this sense, the artifact was evaluated as useful as it directly takes up the way many larger organizations organize their business. A good usability and understandability enable an easy adoption of the proposed approach.

*RQ4b: To what extent does the artifact help to improve an organization's environmental performance?*

According to our study participants, the artifact helps to improve an organization's environmental performance as it significantly lowers the threshold for organizations to take action concerning environmental assessments within the enterprise. This is due to the fact, that with EA as a significant part of enterprise planning and organizing business, the proposed artifact not only provides organizations with the tools to incorporate environmental performance evaluation in their EA models, but also makes environmental performance parameters a part of default processes in EA modelling.

*RQ4c: How does the artifact allow to derive opportunities for improving the environmental performance based on the design of to-be-EA?*

In the perceptions of our participating experts, the proposed artifact clearly represents an opportunity to improve the organizational environmental performance with future architecture design in multiple ways. With the adoption of the proposed approach EA models enable the assessment and demonstration of the current state of the organization's environmental performance, helping the enterprise to evaluate its as-is situation and identify critical components of the architecture which are accountable for high environmental impacts. With the artifact benefitting from the inherent qualities of EA models, the architecture shows not only the environmental impacts of a certain architectural component, but also the component's place and therefore its significance and relevance in the whole architecture. This is important for decision-making where components with great environmental impact might be crucial for the organization's business. As a result, this would allow to identify the environmental harming components that are the least significant and thus the easiest to tackle without compromising the functionality of the architecture. Great potential was seen in using different views and the creation of scenarios which would allow to assess different potential architectures including factors like the significance of the components and environmental impact parameters. Consequently, with the right tool support, the creation of scenarios could help to identify the best solution under consideration of environmental performance parameters, among others, and guide the design of the to-be architecture.

**Main Research Question: How can environmental performance be modelled in enterprise architecture (EA)?**

This research shows how environmental performance can be modelled in EA in both semantic and quantitative terms. With the new set of concepts based on the ArchiMate language, enterprises are enabled to model their environmental sustainability strategies embedded and aligned in the overall Enterprise Architecture. With the careful analysis of SRTs, it has been shown that regulatory compliance in environmental concerns can be modelled and assessed in EA models. Secondly, environmental performance can be modelled in quantitative terms which allow an EA based measurement and analysis of the organization's environmental footprint, consequently providing the first step towards the design of a future architecture that considers environmental concerns in its design and operation.

This research intends to adopt the Enterprise Architecture Modelling Language ArchiMate for modelling and assessing environmental performance. The contribution is manifold: First of all, this proposal provides a new set of concepts based on the ArchiMate language that allows enterprises to model their individual environmental sustainability strategies embedded and aligned in the overall Enterprise Architecture. Secondly, a tool is provided to measure and analyze the organization's environmental performance. Therefore, it offers the means for improvement of environmental performance on all levels of the enterprise and enables a new improved design of a to-be enterprise architecture. Third, next to the novel approach, this research also offers an evaluation of the proposal and incorporates the feedback provided by domain experts reflecting the need and relevance of the topic for the practitioners community.

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# 8. APPENDICES

## 8.1. Interview Questions (Treatment Design)

**Part A**

1. (Q1) What is your current job role?
2. (Q2) What does the organization do that you work for?
3. (Q3) What is your professional experience with EA and ArchiMate?

**Part B**

4. (Q4) Are you interested/experienced in modelling sustainability with ArchiMate?
5. (Q5) How do you rate the importance of evaluating the environmental performance of an organization?
6. (Q6) Do you think environmental performance evaluation should be an integral part of the enterprise's activities?
7. (Q7) Are you familiar with environmental standards and frameworks?
8. (Q8) How do you rate the importance of environmental standards and frameworks for organizations to improve their environmental performance?

**Part C**

9. To what extent do you agree to the following proposed ArchiMate elements that reflect environmental concepts extracted from environmental standards and frameworks?
10. To what extent do you agree to the mapping of environmental concepts as attributes of ArchiMate elements?
11. Do you think modelling profiles for attributes is useful?

## 8.2. Interview Questions (Treatment Validation)

1. Could this approach help organizations to improve their environmental performance? In what way?
2. Is the use of the new environmental concepts and quantitative analysis intuitive and understandable?
3. How do you evaluate the usefulness of the proposed approach?
4. How do you evaluate the usability of the proposed approach?
5. Do you see any weaknesses in using the approach?
6. Do you see benefits and strong points of using the approach?
7. How does the approach allow to derive opportunities for improving the environmental performance based on the design of the to-be EA?