Digital Decarbonization: Design Principles for an Enterprise-wide Emissions Data Architecture

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Abstract

The need for corporate decarbonization to mitigate climate change is reflected in a growing number of political measures to transparently disclose the environmental impact of corporate activities. Due to increasing reporting obligations, companies must constantly evaluate their own as well as suppliers' products and processes with respect to emissions data. To date, guidelines on how to design a data architecture focusing on the collection, storage, transformation, distribution, and disclosure of emissions data throughout an entire company are still lacking. Working with the design science research paradigm, we develop seven design principles for an enterprise-wide emissions data architecture (EEDA). We develop and iterate these principles by performing a structured literature review and semi-structured interviews. Taking this emission-centric perspective on data architecture, we foster the active engagement for a structured enterprise-wide approach for managing emissions data and coping with the increased demand for emissions reporting.

Keywords: Decarbonization, Emissions Data, Data Architecture, Design Principles

1. Introduction

Climate change is one of the main challenges affecting society and business activities (Heffron et al., 2020; Pörtner et al., 2022). Greenhouse Gas (GHG) emissions such as, e.g., CO_2 emissions, are the primary driver of the resulting crisis and, thus, the reduction of emissions are in the focus of various policy actions (Strüker et al., 2021). For example, the proposed Directive on corporate environmental due diligence by the European Commission (2022) aims at reducing GHG emissions by enforcing stricter environmental checks on products during their life cycle. Moreover, different certification and auditing processes such as, e.g., the modified European Union (EU) non-financial reporting standards, require more detailed information regarding GHG emissions of products and processes (European Commission, 2021). In addition to these legal obligations, companies increasingly voluntarily provide environmental information of their products to investors and consumers (Cadez et al., 2019; Herold et al., 2019). This is due to, inter alia, an increasing demand by stakeholders such as consumers for more proactive corporate action to reduce GHG emissions (Massa et al., 2015; Schaltegger & Csutora, 2012).

Due to mandatory and voluntary reporting, companies need to collect, store, transform, distribute, and disclose the GHG emissions of their processes and products (Babel et al., 2022; European Commission, 2021). But, there are different challenges regarding emissions data, i.e., GHG emissions data as well as primary data to allocate CO_2 equivalents, in practice. For example, to disclose emissions of processes and products, companies often have to combine

URI: https://hdl.handle.net/10125/103342
978-0-9981331-6-4

heterogeneous primary as well as secondary data from different sources and with different time units.

With increasing need to work with emissions data, companies require a data architecture for emissions that ”describes how data is collected, stored, transformed, distributed, and consumed” (DalleMule & Davenport, 2017). Such a data architecture (DA) builds the foundation of a company´s data strategy, improving the effectiveness and efficiency of the company itself (Hevner et al., 2004). Although existing literature covers DA with respect to sustainability, the authors often focus on specific cases, e.g., smart cities, (Anthony Jnr et al., 2020; Villegas-Ch et al., 2019), or do not explicitly consider highly relevant emissions data (Dev et al., 2019; Havard et al., 2021; Hendy Tannady et al., 2020). Furthermore, literature investigating the influence of organizational aspects such as, e.g., CSR committees (Córdova Román et al., 2021) or board composition (Velte et al., 2020), mainly focus on a high-level analysis of data management. Hence, existing literature focuses on emissions key figures such as, e.g., total emissions per product, or considers carbon reporting without covering data management (Córdova Román et al., 2021; Velte et al., 2020). Consequentially, there is a lack of guidelines on how companies should manage their emissions data starting with the collection of emissions data to their disclosure. To tackle the challenge of increased need for emissions data and corresponding management within the company, the following study develops overarching design principles for an Enterprise-wide Emissions Data Architecture (EEDA). In doing so, this work aims to facilitate emissions data management by answering the following research question: *What are design principles for an enterprise-wide data architecture for emissions data?*

To address this research question, we follow the Design Science Research (DSR) paradigm to propose Design Principles (DPs) for an EEDA addressing the lack of design guidelines related to emissions data characteristics, management, and organizational aspects from a company perspective (Hevner et al., 2004). We derive and iterate the DPs by applying a systematic literature review and conduct interviews with experts in data architecture and emissions data management. Upon testing our findings through an iterative process, the DPs now represent prescriptive knowledge for the design of a DA focusing on emissions data.

Following background information on data architecture and emissions data in section 2, we explain our methodological approach in section 3. In section 4, we present the DPs and discuss our contribution in section 5. We present potential drawbacks of our approach and conclude our results in section 6.

2. Background

2.1. Enterprise and Data Architecture

The DA is the foundation of a company’s data strategy. We adopt the definition of DA as an architecture that ”describes how data is collected, stored, transformed, distributed, and consumed” by DalleMule and Davenport (2017). This definition encompasses the five key processes of data management, i.e., data collection, storage, transformation, distribution, and consumption, within a company and, therefore, takes an enterprise-wide perspective on DA. Hence, a DA describes the fundamental organization of a system combining different components as well as their relationship to each other and its governing principles (ISO/IEC/IEEE 42010, 2011). The DA of a company should not be considered in isolation but in the context of a company’s organization, i.e., the enterprise architecture (EA) (ISO/IEC/IEEE 42010, 2011). We distinguish the concepts of EA and DA following the commonly used definition offered by the The Open Group Architecture Framework (TOGAF). The TOGAF (2011) observes three architectural levels of an EA, i.e., the business, the technology, and the information architecture. The latter is divided into the DA and the application architecture. Consequentially, the company’s DA differs from a company’s EA in terms of its scope and represents the data-focused part of the EA. Principles defining the entire EA of a company, thus, may also have an impact on the company’s DA.

Literature addressing DA often differs by the application field of the data, e.g., the health sector (Degele et al., 2017; Silvestri et al., 2019) or the financial sector (Soldatos et al., 2022). Even though literature on DA take sustainability into account, e.g., sustainable supply chains (Accorsi et al., 2018; Boulonne et al., 2010), there is a lack of literature elaborating on DA for emissions data to the best of our knowledge. Consequently, we aim at filling this gap by deriving DPs for a DA focusing on emissions data.With increasing significance of emissions data for companies, we take an enterprise-wide perspective describing the governing principles for emissions data within all business units from data collection to data consumption. As data consumption with respect to emissions data mainly concerns disclosing emissions in mandatory or voluntary reports, we use data disclosure and data consumption synonymously. Further, we define emissions data as data directly containing emissions information, e.g., from emissions measurements, and primary data that is used to allocate emissions to consumption, e.g., electricity consumption and carbon conversion factors.

2.2. Increasing Demand for Emissions Data

Companies need GHG emissions data, especially in form of CO_2 equivalents, for various analyses, legally required key figures, and voluntary declarations. Regarding emissions analyses, companies increasingly apply the methodology of life cycle assessment that assesses the general environmental impact of a product during its life cycle (Stewart et al., 2018). For this quantitative approach, companies must collect and process data to quantify the "relevant inputs and outputs of a product system" and allocate the GHG emissions (ISO 14040, 2006; Klöpffer, 2003). Due to pressure from stakeholders, companies additionally participate in voluntary schemes to disclose information on their environmental impact, e.g., the Carbon Disclosure Project (Hsueh, 2019) or the Science Based Targets Initiative (Science Based Targets, 2021).

Besides voluntary analyses and declarations, stricter regulations on disclosing emissions are, above all, the main drivers of an increased need for detailed emissions data of a company's products and processes. First, certification and auditing processes within Emissions Trading Systems (ETSs) require detailed information regarding CO_2 emissions (BMU, 2019). The EU ETS, for example, requires 12,000 European power and industrial plants to closely monitor and report their annual GHG emissions (Zhang & Wei, 2010). There are even further ETSs addressing other sectors than the EU ETS, e.g., the national ETS in Germany (Vollmer, 2020). Other countries also price emissions by the use of ETSs and, thus, require the participating companies to implement monitoring, reporting, and verification processes (Narassimhan et al., 2018).

Second, emissions data is required for reporting outside of ETSs for, e.g., non-financial statements or other certification. According to the Non-Financial Reporting Directive, large public interest entities from all EU member states need to publish an annual non-financial report including, inter alia, information on the environmental impact of their corporate activities (European Parliament & European Council, 2014). With the announced amendment of the European Corporate Sustainability Reporting Directive (CSRD), European companies will have to adhere to more detailed reporting requirements (European Commission, 2021). Moreover, an increasing number of European companies will be affected by the proposed new CSRD (European Commission, 2021). The approval and certification of plants for operation may also require emissions data, e.g., in the United States (U.S.), where the Cross-State Air Pollution Rule requires data on NO_2 and SO_X omitted by power plants (United States Environmental Protection Agency, 2011).

Besides the aforementioned reporting requirements, companies are required to assess their environmental impact with regard to their value chain. In 2022, the European Commission, e.g., adopted a proposal for a Directive on corporate sustainability due diligence (European Commission, 2022). According to this proposal, large companies in the EU will have to identify and closely monitor actual and potential environmental impacts from their suppliers and preliminary products, e.g., caused by omitted GHG emissions during the production. In summary, for these and further mandatory as well as voluntary disclosure of emissions information, companies must collect, store, transform, distribute, and disclose emissions data. To do so, companies need a suitable data architecture to manage emissions data across all business units and from all respective sources for application in the various disclosure requirements.

3. Method

We observe a lack of literature on how DAs should be designed to encompass the information and activities specifically for emissions data (see section 2). We aim at addressing this gap in literature by being the first to define DPs for an enterprise-wide DA focusing on emissions data, in the following referred to as EEDA. This section gives an overview on our methodological approach.

DPs are guidelines for building design artifacts in the context of DSR (Chandra et al., 2015). Researchers employ DPs to guide and constrain actions (A. Hevner et al., 2010) as well as capture knowledge about creating instances of a class of artefacts, in our case an EEDA (Sein et al., 2011). Within DSR, DPs represent prescriptive knowledge whose objective is to address current problems by providing novelty and utility (Baskerville & Pries-Heje, 2010; Gregor & Hevner, 2013). Our methodological approach follows the design science cycle suggested by Hevner et al. (2004) as well as the staged research process proposed by Peffers et al. (2007). First, we identify the problem as need for guidance in EEDA with an increasing demand for emissions data (cf. section 1 and 2). Second, drawing on existent knowledge on EA and DA, we outline our design objective relating to our formulated research question (cf. section 1). Third, in the design and development phase, we develop our key artifact, i.e., the seven comprehensive DPs for the EEDA by means of a systematic literature review. We apply stage 4 and 5 by demonstrating and evaluating the DPs with experts from practice and research and communicate the resulting DPs in this paper (stage 6). Hence, our developed DPs do not only contribute to the general knowledge in this research area but, moreover, help companies to (initially) implement and further develop their DA with respect to emissions data.To ensure the applicability of our DPs, we follow the conceptual scheme by Gregor et al. (2020).

In order to elaborate DPs for an EEDA in stage 3 of our research process, we conduct a systematic literature review following the guidelines of Webster and Watson (2002) and Vom Brocke et al. (2015) to identify the body of knowledge regarding existing frameworks for EA and DA. As stated in section 2, findings with respect to the EA of a company have impact on the DA and can, therefore, be transferred to the DA. Hence, we derive a search string complementing these relevant topics related to our research question with synonyms. This results in the following search string: (”enterprise” OR ”organization”) AND (”architecture” OR ”information system” OR ”information technolog*” OR ”data standard*” OR ”data management”). Regarding the database, we choose Scopus as well as journals and conference proceedings in the AIS eLibrary not contained in Scopus. We consider the last five years, i.e., from 2018 to 2022, to account for the fast-moving nature of this emerging field of research. Besides, we involve only articles written in English language. Regarding the subject area, we specify on Scopus to solely consider articles with a focus on computer science, business, management and accounting.We apply the search string to the title, abstract, and keywords, obtaining 1,198 articles as a result of our initial search. To narrow the number of eligible articles, we proceed with the article selection process consisting of title, abstract, and full-text screening. In each of these steps, we refer to defined exclusion and inclusion criteria: First, we exclude publications that do not address an EA or DA. Second, we eliminate literature that focus solely on information technology for the implementation of enterprise-wide DAs. As inclusion criteria, we only consider peer-reviewed papers where a full text is available. After screening the titles, we reduce the number of papers to 405, for which we additionally screen the abstract. Afterwards, 150 papers remain for full-text screening. As a result of the full-text screening and forward and backward literature search, we obtain 38 articles that are relevant to developing our DPs.

To iterate and evaluate the DPs, we derive from the selected literature (stage 4 and 5), we conduct semi-structured interviews with experts from research as well as practice due to their competence in EA, DA, and/or emissions data (Kvale, 2007; Schultze & Avital, 2011; Vogelsang et al., 2013). Table 1 gives an overview of the seven conducted interviews. The interviews lasted between 60 and 75 minutes. We audio-recorded as well as transcribed the interviews with the consent of each interview partner and took notes of relevance during the interviews. We conducted the interviews in the native language of the interview partners, however, keeping the object of the interviews, i.e., the formulated DPs, in their communicated English language. Our guideline for the semi-structured interviews follows the order of presented DPs (see table 2) as well as our evaluation criteria, i.e., ease of use, elegance, simplicity, understandability, and completeness of our DPs (Sonnenberg & Brocke, 2012).

4. Results

In this section, we present our seven DPs, which we derived from the structured literature review and iterated through semi-structured interviews. We mark the feedback on the DPs by the interview experts during the evaluation with an ”E” in combination with the interview ID (see Table 1). Table 2 gives an overview of the final DPs following the conceptual scheme for DPs proposed by (Gregor & Hevner, 2013). This scheme structures each DP in terms of title, aim, context, mechanism, and rationale. The aim denotes *what* we want to achieve with the DP whereas the mechanism describes *how* the DP wants to achieve this aim. The context clarifies the stage of the EEDA development cycle, i.e., initiation, development, implementation, and operation, at which a given DP receives the greatest attention (Alter, 2013). Within the rationale, we describe *why* we should consider this DP and which area of the literature is currently most relevant to it.

DP 1 – A Center of Intelligence (CoI) helps coordinate and manage the stakeholders of an EEDA which highly influences the success of an EEDA in a target-oriented manner (Trishan et al., 2022). The CoI for an EEDA bundles all relevant aspects from legal requirements to customer demands as well as know-how about the emissions data itself. The CoI can either be derived as a new department, team, or person, or, respectively, assigned to an existing entity (cf. E.4, E.1). To derive such a CoI, the company should identify the key stakeholders of an EEDA. Within our work, we define key stakeholders as employees that must actively work within the main EEDA processes, i.e., data collection, storage, transformation, distribution, and disclosure, today or in the foreseeable future (cf. E.3, E.7). The identification of key stakeholders is crucial to understand the existing expertise, requirements towards an EEDA as well as potential interfaces to other business units and their respective information systems (cf. DP 3, E.5). Exemplary action regarding this DP may include communication with every unit to derive the

Table 1: Iteration and evaluation of design principles: Participants of the expert interviews

ID	Business domain	Employees worldwide	Expertise interview partner(s)
1	Research & information systems engineering	>100	Industry 4.0 & data platforms
2	Research & information systems engineering	>100	Process management & business intelligence
3	Chemical industry	>10,000	Environmental & CSR reporting
4	Automotive industry	>100,000	Energy management
5	Research	>100	Machine learning & platforms
6	Chemical industry	>1,000	Energy & sustainability management; Digitalization
7	Research	>100	Knowledge management systems

key stakeholders with expertise on the requirements and the well-functioning of an EEDA. Communication is an important aspect for successfully managing the EEDA (cf. E.6) (Al-Kharusi et al., 2020; Trishan et al., 2022). By networking contact persons, the CoI may increase the acceptance of an EEDA which is an important factor as well (Anthony Jnr et al., 2021). Additionally, organizational aspects such as, e.g., defining responsibilities and coordinating tasks for the individual EEDA processes within the company, can be challenging. Hence, a CoI may reinforce consistent responsibility during, e.g., the process of collecting, storing, and transforming data, to avoid inefficient data management and even false statements about GHG emissions of a product due to inconsistencies (van den Hoven, 2003).

DP 2 – Institutionalize standardized and automated processes are essential to use resources and produce results, e.g, emissions key figures, in the best possible way (Nardello et al., 2020). While implementing standardized and automated processes, the focus should be on most frequently executed EEDA processes (cf. E.3, E.1). Possible actions, for example, are the implementation of sensors with IoT solutions to automatically collect and directly store GHG data in a database and increase data quality (cf. E.2) (Khan et al., 2022). In cases where devises such as smart meters are not yet installed, visual scanners with visual recognition can be used to automatically collect the data as well and record standardized data units. Moreover, the storage and the access to data can be simplified by applying Structured Query Language (SQL). With respect to the processes of data transformation and disclosure, companies may implement automated calculations for important key figures, i.e., automated data transformation, as well as utilize automated fill-ins for different reports, i.e., automated data disclosure (cf. E.6).

DP 3 – With the increasing demand for decarbonization of processes, products, and services, companies do not only need to process emissions data within a sustainability unit (In et al., 2019; Olson, 2010). Hence, emissions data need to be integrated into already existing information systems in other units of the company (Gimpel et al., 2018; Perdana et al., 2020; Santos et al., 2020). For example, sales units should be enabled to share emissions data of specific products along with technical features and performance indicators to the customer (cf. E.7). In the finance unit, financial key figures need to be linked to sustainability indicators stemming from emissions data, e.g., with respect to investment decisions. This increasing interrelation between different kinds of data require standardized interfaces between information systems that manage data like, e.g., financial or sales information, and, consequently, make them available within the EEDA (cf. E.4) (Nardello et al., 2020). Especially for the main information systems and corresponding data that must be linked to emissions data, standardized interfaces would enable an automated provision and integration of emissions data with other, unit-specific data (cf. E.6) (Qomariyah & Priandoyo, 2020). Exemplary actions for this DP include the identification of data, e.g., with respect to frequency of use (cf. E.3), data format, and data granularity, that has to be processed in relation to emissions data to define foremost the main data distribution (cf. E.6) and transformation processes connecting different information systems (cf. E.7).

DP 4 – For the applicability in practice, the EEDA must be aligned with the core business model and the respective business processes of the company. Then, the EEDA helps achieve key business objectives as well as formulated sustainability objectives (cf. E.1) (Foorthuis et al., 2016; Qomariyah & Priandoyo, 2020). In contrast, contradictory goals or incompatible logics need to be avoided (Dang, 2021; Foorthuis et al., 2016). Clearly formulating the sustainability-orientated objectives, e.g., the total CO_2 emissions in specific scopes, helps to monitor and achieve them (Gallotta et al., 2016). Moreover, companies may define and implement quarterly up to real-time monitoring of CO_2 objectives depending on what processes are the core business processes of the company and/or which are subject to EEDA processes, e.g., emissions data collection (cf. E.3). Further compliance guidelines that encompass economic as well as emissions objectives can be developed within workshops (cf. E.2, E.5). These monitoring concepts, implemented via an EEDA, must be aligned with the core business model and

Table 2: Overview of Design Principles for an Enterprise-wide Emissions Data Architecture

DP	Title	Aim	Context (Stage)	Mechanism	Rationale	Supporting Literature
1	Center of Intelligence	To derive a center of intelligence for an EEDA	Initiation Development Implementation	To define key stakeholders of emissions data	Clear allocation of expertise and responsibilities improve application (Vilminko-Heikkinen & Pekkola, 2019)	Al-Kharusi et al., 2020; Anthony Jnr et al., 2021 Chuang and van Loggerenberg, 2010 Dang, 2021; Trishan et al., 2022 van den Hoven, 2003
2	Standardization and automation	To efficiently and effectively manage emissions data	Implementation Operation	To institutionalize standardized and automated processes for emissions data collection, storage, transformation, distribution, and disclosure	EEDA processes require high effort in time and resources (Csutora & Harangozo, 2017)	Ahlemann et al., 2021; Al-Kharusi et al., 2020 Foorthuis et al., 2016; Gong and Janssen, 2021 Khan et al., 2022 Nardello et al., 2020
3	Interfaces to other systems	To make related data available to key stakeholders	Development	To define key interfaces of emissions data with data from other enterprise-wide information systems	Emissions data need to be related to other data of interest (Apergis et al., 2013)	Gimpel et al., 2018; In et al., 2019 Nardello et al., 2020; Olson, 2010 Perdana et al., 2020; Santos et al., 2020 Qomariyah and Priandoyo, 2020
4	Alignment to processes	To monitor the formulated sustainability objectives and compliance	Implementation Operation	To align the EEDA with the company's core emissions-relevant business processes	Business model(s) and goals, i.a., define corporate processes (Rosemann et al., 2008)	Dang, 2021; Foorthuis et al., 2016 Gallotta et al., 2016 Perdana et al., 2020 Qomariyah and Priandoyo, 2020
5	Empowerment of employees	To efficiently operate and utilize the EEDA	Initiation Operation	To enable employees by providing required know-how and intuitive user interfaces	Involvement and empowerment of employees fosters acceptance and performance (Roslin et al., 2019)	Gong and Janssen, 2021 Rehring et al., 2019 Tajul Urus et al., 2020 Yayla and Lei, 2020
6	Data security and privacy	To maintain the company's data sovereignty and prevent leakage of its sensitive emissions data	Development Implementation Operation	To safeguard data security and privacy measures	Emissions data are highly sensitive company data (Terzi et al., 2020)	Al-Turkistani et al., 2021 Ebo et al., 2020 Gupta and Agrawal, 2021 Mirsalari and Ranjbarfard, 2020
7	Flexibility	To successfully cope with the fast-changing regulatory requirements and further external factors	Initiation Development	To construct the EEDA flexible and modular	Increased pressure for decarbonization and corresponding policy and corporate action (Herold et al., 2019)	Mirsalari and Ranjbarfard, 2020 Kawtar et al., 2022 Wissal et al., 2020

business activities in a target-oriented manner (cf. E.4) as management of emissions data is mostly not part of a company's core business (cf. E.6) (Perdana et al., 2020).

DP 5 – Even if many processes within an EEDA should be automated with increasing reporting obligations and, thus, a higher volume of emissions data (cf. DP 2), the EEDA should still be designed and operated in such a way that it can be handled by the responsible employees (Gong & Janssen, 2021). An efficient operation and utilization of the EEDA by the employees should increase acceptance and reduce the necessary time an employee spends on managing EEDA processes (cf. E.3), e.g., data collection, while maintaining or improving the required quality of the output, e.g., emissions key figures and reports (Tajul Urus et al., 2020). Managers can help to successfully implement the EEDA by providing employees with the know-how required to execute or accompany the processes within the EEDA (cf. E.4) (Yayla & Lei, 2020). Moreover, employees should have an overview of the whole process to better understand their task and its importance to the company (cf. E.4). To facilitate the interaction with implemented information systems (cf. DP 4 and 5), intuitive user interfaces should be a key element of EEDA instantiations. Exemplary action with respect to this DP may include the development of user interfaces that are understandable and customizable for both EEDA experts and top management (cf. E.7). Furthermore, the CoI (cf. DP 1) may develop and provide specific training for employees, e.g., in form of workshops or visualizations, with respect to emissions data and the employee's role within the EEDA (cf. E.1, E.2, E.5) (Rehring et al., 2019).

DP 6 – Emissions data of a company are sensitive data as competitors within the same sector can derive information about specific process operations from location and/or product-specific emissions data (cf. E.1). Consequentially, companies with sensitive emissions data mostly have comprehensive data privacy measures in place to prevent leakage of emissions data and corresponding information and insights to competitors, or in general, the external stakeholders (cf. E.4) (Mirsalari & Ranjbarfard, 2020). For an EEDA, these existing data security as well as data privacy measures have to be safeguarded to maintain the company's data sovereignty (Al-Turkistani et al., 2021; Ebo et al., 2020; Gupta & Agrawal, 2021). This DP especially applies to listed companies where leakages could have severe effects on the stock market value. Data privacy measures that companies should safeguard include, e.g., employee training with respect to data security, guidelines for cases of data leakages and hardware and software components (cf. E.6).

DP 7 – Due to the fast-changing external environment, i.e., regulatory requirements as well as other social, environmental, or technological developments, an EEDA should be designed in such a way that it is not rigid, but flexible to react to the changing external factors if necessary (cf. E.2, E.5) (Kawtar et al., 2022). Also, the possibility for revisions and improvements can be considered (cf. E.6)

(Wissal et al., 2020). By using modular elements within the EEDA, standards (cf. DP 2, E.7) can be implemented while simultaneously granting flexibility for adjustments and scalability (Mirsalari & Ranjbarfard, 2020). Flexible adjustments of the EEDA may range from, e.g., structural changes of data collection and transmission to adapting report calculation rules for data disclosure. Furthermore, the flexible development of an EEDA enables the company to react to innovations and other changes within the company's competitor field. Exemplary action to apply this DP includes the specification of decision-making responsibilities within the EEDA with respect to, e.g., the five elements of DA, i.e., data collection, storage, transformation, distribution, and disclosure. Transparently communicated responsibilities would allow for fast decision-making processes given a changed external condition and the need to (fundamentally) changing the EEDA.

5. Discussion and Contribution

The DPs presented in section 4 advance the practical development of EEDAs and extend the existing literature on DA by taking an enterprise-wide perspective on emissions data. The initiation, development, implementation, and operation of an EEDA can be an essential part of the corporate decarbonization process. Provided a sufficient data basis, structured EEDA processes, i.e., data collection, storage, transformation, distribution, and disclosure, are a starting point for dealing with the increasing multiplicity of reporting requirements. As such, an EEDA outlined by our DPs may support companies in coping with new and distinct reporting requirements. Furthermore, an EEDA forms the basis for active carbon performance steering of products by making data actionable to gain insights on the company's direct emissions, i.e., scope 1 emissions (cf. DP 4). However, regarding the company's scope 2 and 3 emissions, a company may have only limited influence on the data quality of suppliers and preliminary products. In this case, an EEDA may still foster transparent tracking of the use of emissions as recorded by third parties throughout the company's processes (cf. DP 3). For example, with the increasing use of batteries at company sites, the electricity consumption from a battery and its carbon footprint could be put in relation to the electricity mix during battery charging. For practitioners, the formulated DPs illustrate which problems in existing emissions data management processes need to be eliminated or improved in contrast to the status quo. Further, the DPs provide a forward-looking agenda for linking emissions data and sustainability objectives more closely to economic activities of the company and generating benefits from this (cf. DPs 3, 4, 7).

6. Conclusion

With an increasing demand for emissions data, companies need to look more closely at how they manage the growing amount of emissions data and how a corresponding EEDA should be designed. Consequently, we answer our research question by presenting guidelines for the design of an EEDA in form of prescriptive design knowledge. Even though our resulting DPs are subjected to limitations, these limitations also indicate starting points for future research. First, we conducted seven interviews with experts from research and practice to iterate and evaluate our DPs. Since we conducted our systematic literature review based on the time range of the recent five years and two data bases, extending the literature search on additional sources and years may lead to other relevant concepts for an EEDA and further support of our DPs. Moreover, an evaluation with experts from further industry branches and backgrounds, hence, might enhance the quality of DPs by taking in additional perspectives and further challenging the DPs with respect to our evaluation criteria. Second, our DPs are especially supportive for larger companies, e.g., listed companies, as they already have business units that deal with emissions data and require a well-designed DA to deal with increasing reporting requirements. Thus, differences regarding the relevance and application of our DPs may occur depending on company size and reporting obligations, e.g., for small to medium-sized companies that are currently not subject to emissions reporting requirement. Since we have not yet evaluated the DPs within real-world conditions, future research may evaluate the DPs by applying them to real-world companies with varying size and reporting requirements and, thus, provide real-world demonstrations of an exemplary EEDA following the presented DPs. Additionally, researchers may analyze in which sequence these DPs should be implemented by a company and which dependencies exist when transforming existing processes to an EEDA. In summary, our DPs form guidelines for practitioners taking an emissions data perspective on DA and, thus, indicate starting points for improving current company emissions data management towards a structured EEDA.

7. Acknowledgments

The authors thank the Graduate School of the Bavarian Center for Battery Technology (BayBatt) for ongoing support.

References

Accorsi, R., Cholette, S., Manzini, R., & Tufano, A. (2018). A hierarchical data architecture for sustainable food supply chain management and planning. *Journal of Cleaner Production*, *203*, 1039–1054.

Ahlemann, F., Legner, C., & Lux, J. (2021). A resource-based perspective of value generation through enterprise architecture management. *Information & Management*, *58*(1).

Al-Kharusi, H., Miskon, S., & Bahari, M. (2020). Enterprise architects and stakeholders alignment framework in enterprise architecture development. *Information Systems and e-Business Management*, *19*(1), 137–181.

Alter, S. (2013). Work system theory: Overview of core concepts, extensions, and challenges for the future. *Journal of the Association for Information Systems*, 72.

Al-Turkistani, H. F., Aldobaian, S., & Latif, R. (2021). Enterprise architecture frameworks assessment: Capabilities, cyber security and resiliency review. *2021 1st International Conference on Artificial Intelligence and Data Analytics (CAIDA)*, 79–84.

Anthony Jnr, B., Abbas Petersen, S., Ahlers, D., & Krogstie, J. (2020). Big data driven multi-tier architecture for electric mobility as a service in smart cities. *International Journal of Energy Sector Management*, *14*(5), 1023–1047.

Anthony Jnr, B., Petersen, S. A., & Krogstie, J. (2021). A model to evaluate the acceptance and usefulness of enterprise architecture for digitalization of cities. *Kybernetes*.

Apergis, N., Eleftheriou, S., & Payne, J. E. (2013). The relationship between international financial reporting standards, carbon emissions, and R&D expenditures: Evidence from european manufacturing firms. *Ecological Economics*, *88*, 57–66.

Babel, M., Gramlich, V., Körner, M.-F., Sedlmeir, J., Strüker, J., & Zwede, T. (2022). Enabling end-to-end digital carbon emission tracing with shielded NFTs. *Energy Informatics*, *5*(1).

Baskerville, R., & Pries-Heje, J. (2010). Explanatory design theory. *Business & Information Systems Engineering*, *2*(5), 271–282.

BMU. (2019). Environmental information for products and services: Requirements - tools - examples (BMU, Division G II 2, S. 1. UBA III, & BDI, Environment and Technology Division, Eds.).

Boulonne, A., Johansson, B., Skoogh, A., & Aufenanger, M. (2010). Simulation data architecture for sustainable development. *Proceedings of the 2010 Winter Simulation Conference*, 3435–3446.

Cadez, S., Czerny, A., & Letmathe, P. (2019). Stakeholder pressures and corporate climate change mitigation strategies. *Business Strategy and the Environment*, *28*(1), 1–14.

Chandra, L., Seidel, S., & Gregor, S. D. (2015). Prescriptive knowledge in is research: Conceptualizing design principles in terms of materiality, action, and boundary conditions. *Proceedings of the 48th Hawaii International Conference on System Sciences*, 4039–4048.

Chuang, C.-H., & van Loggerenberg, J. (2010). Challenges facing enterprise architects: A South African perspective. *Proceedings of the 43rd Hawaii International Conference on System Sciences*.

Córdova Román, C., Zorio-Grima, A., & Merello, P. (2021). Economic development and CSR assurance: Important drivers for carbon reporting... yet inefficient drivers for carbon management? *Technological Forecasting and Social Change*, *163*.

Csutora, M., & Harangozo, G. (2017). Twenty years of carbon accounting and auditing–a review and outlook. *Society and Economy*, *39*(4), 459–480.

DalleMule, L., & Davenport, T. H. (2017). What's your data strategy? *Harvard Business Review*, *May-June*, 112–121.

Dang, D. (2021). Institutional logics and their influence on enterprise architecture adoption. *Journal of Computer Information Systems*, *61*(1), 42–52.

Degele, J., Hain, J., Kinitzki, V., Krauß, S., Kühfuß, P., & Sigle, N. (2017). Data architecture for digital health insurances. In A. Rossmann & A. Zimmermann (Eds.), *Digital Enterprise Computing (DEC 2017)* (pp. 107–116). Gesellschaft für Informatik e.V.

Dev, N. K., Shankar, R., Gupta, R., & Dong, J. (2019). Multi-criteria evaluation of real-time key performance indicators of supply chain with consideration of big data architecture. *Computers & Industrial Engineering*, *128*, 1076–1087.

Ebo, I. O., Falana, O. J., Taiwo, O., & Olumuyiwa, B. A. (2020). An enhanced secured IOT model for enterprise architecture. *Proceedings of the International Conference in Mathematics, Computer Engineering and Computer Science*, 1–6.

European Commission. (2021). A proposal for a Directive of the European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting.

European Commission. (2022). Just and sustainable economy: Commission lays down rules for companies to respect human rights and environment in global value chains. https://ec.europa.eu/commission/presscorner/detail/en/ip_22_1145

European Parliament & European Council. (2014). Directive 2014/95/EU of the European Parliament and of the Council - of 22 October 2014 - amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups. *Official Journal of the European Union*, 1–9.

Foorthuis, R., van Steenbergen, M., Brinkkemper, S., & Bruls, W. A. G. (2016). A theory building study of enterprise architecture practices and benefits. *Information Systems Frontiers*, *18*(3), 541–564.

Gallotta, B., Garza-Reyes, J. A., Anosike, A., Lim, M. K., & Roberts, I. (2016). A conceptual framework for the implementation of sustainability business processes.

Proceedings of the Conference by Production and Operations Management Society.
Gimpel, H., Hosseini, S., Huber, R., Roeglinger, M., Probst, L., & Faisst, U. (2018). Structuring digital transformation - a framework of action fields and its application at ZEISS. *Journal of Information Technology Theory and Application*, *19*.
Gong, Y., & Janssen, M. (2021). Roles and capabilities of enterprise architecture in big data analytics technology adoption and implementation. *Journal of Theoretical and Applied Electronic Commerce Research*, *16*(1), 37–51.
Gregor, S., Chandra Kruse, L., & Seidel, S. (2020). Research perspectives: The anatomy of a design principle. *Journal of the Association for Information Systems*, *21*(6), 2.
Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly*, *37*(2), 337–355.
Gupta, B. B., & Agrawal, D. P. (2021). Security, privacy and forensics in the enterprise information systems. *Enterprise Information Systems*, *15*, 445–447.
Havard, V., Sahnoun, M., Bettayeb, B., Duval, F., & Baudry, D. (2021). Data architecture and model design for industry 4.0 components integration in cyber-physical production systems. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *235*(14), 2338–2349.
Heffron, R., Körner, M.-F., Wagner, J., Weibelzahl, M., & Fridgen, G. (2020). Industrial demand-side flexibility: A key element of a just energy transition and industrial development. *Applied Energy*, *269*, 115026.
Hendy Tannady, Johanes Andry, Bernadus Gunawan Sudarsono, & Yuliawan Krishartanto. (2020). Enterprise architecture using zachman framework at paint manufacturing company. *Technology Reports of Kansai University*, *62*(4), 1869–1883.
Herold, D. M., Farr-Wharton, B., Lee, K.-H., & Groschopf, W. (2019). The interaction between institutional and stakeholder pressures: Advancing a framework for categorising carbon disclosure strategies. *Business Strategy & Development*, *2*(2), 77–90.
Hevner, A., Chatterjee, S., Gray, P., & Baldwin, C. Y. (2010). *Design research in information systems: Theory and practice* (Vol. 22). Springer.
Hevner, March, Park, & Ram. (2004). Design science in information systems research. *MIS Quarterly*, *28*(1), 75–105.
Hsueh, L. (2019). Opening up the firm: What explains participation and effort in voluntary carbon disclosure by global businesses? An analysis of internal firm factors and dynamics. *Business Strategy and the Environment*, *28*(7), 1302–1322.
In, S. Y., Rook, D., & Monk, A. (2019). Integrating alternative data (also known as ESG data) in investment decision making. *Global Economic Review*, *48*(3), 237–260.
ISO 14040. (2006). Environmental management-life cycle assessment-principles and framework national standard understanding.
ISO/IEC/IEEE 42010. (2011). Systems and software engineering - architecture description.
Kawtar, I., Karim, D., & Salah, B. (2022). Algorithms to analyze the impact of change on enterprise architecture. *Procedia Computer Science*, *196*, 356–363.
Khan, A., Bhowmick, A., Das, A., & Majumdar, D. (2022). Towards standardization of data–focusing on data quality as a service. *Journal of Positive School Psychology*, 1032–1039.
Klöpffer, W. (2003). Life-cycle based methods for sustainable product development. *The International Journal of Life Cycle Assessment*, *8*(3), 157–159.
Kvale, S. (2007). *Doing interviews* (Vol. Pt. 2). SAGE.
Massa, L., Farneti, F., & Scappini, B. (2015). Developing a sustainability report in a small to medium enterprise: Process and consequences. *Meditari Accountancy Research*, *23*(1), 62–91.
Mirsalari, S. R., & Ranjbarfard, M. (2020). A model for evaluation of enterprise architecture quality. *Evaluation and Program Planning*, *83*, 101853.
Narassimhan, E., Gallagher, K. S., Koester, S., & Alejo, J. R. (2018). Carbon pricing in practice: A review of existing emissions trading systems. *Climate Policy*, *18*(8), 967–991.
Nardello, M., Han, S., Møller, C., & Gøtze, J. (2020). Incorporating process and data heterogeneity in enterprise architecture: Extended AMA4EA in an international manufacturing company. *Computers in Industry*, *115*.
Olson, E. G. (2010). Challenges and opportunities from greenhouse gas emissions reporting and independent auditing. *Managerial Auditing Journal*, *25*(9), 934–942.
Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77.
Perdana, E. G., Sitohang, B., Sastramihardja, H. S., & Candra, M. Z. C. (2020). A strategy framework for incorporating sustainability into enterprise architecture. *Proceedings of the 8th International Conference on Information and Communication Technology*, 1–6.
Pörtner, H.-O., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., & Rama, B. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
Qomariyah, N. N., & Priandoyo, A. (2020). Sustainable internet of things: Alignment approach using enterprise architecture. *2020 8th International Conference on Information and Communication Technology*, 1–4.
Rehring, K., Greulich, M., Bredenfeld, L., & Ahlemann, F. (2019). Let's get in touch - Decision making about enterprise architecture using 3D visualization in augmented reality. *Proceedings of the 52nd Hawaii International Conference on System Sciences*, 1769–1778.
Rosemann, M., Recker, J., & Flender, C. (2008). Contextualisation of business processes. *International*

Journal of Business Process Integration and Management, *3*(1), 47–60.

Roslin, E. N., Ahmed, S., Ahamat, M. A., Bahrom, M. Z., & Ibrahim, N. (2019). The impact of employee involvement and empowerment in lean manufacturing system implementation towards organizational performances. *International Journal on Advanced Science, Engineering and Information Technology*, *9*(1), 188–193.

Santos, W. F., Ribeiro, M. G., Santos, S. C., de Farias Junior, I. H., & de Oliveira Rodrigues, C. M. (2020). The state-of-the-art of enterprise architecture its definitions, contexts, frameworks, benefits, and challenges: A systematic mapping of literature. *Proceedings of the 15th Iberian Conference on Information Systems and Technologies*, 1–6.

Schaltegger, S., & Csutora, M. (2012). Carbon accounting for sustainability and management. status quo and challenges. *Journal of Cleaner Production*, *36*, 1–16.

Schultze, U., & Avital, M. (2011). Designing interviews to generate rich data for information systems research. *Information and Organization*, *21*(1), 1–16.

Science Based Targets. (2021). Lead the way to a low-carbon future. https://sciencebasedtargets.org/how-it-works

Sein, Henfridsson, Purao, Rossi, & Lindgren. (2011). Action design research. *MIS Quarterly*, *35*(1), 37.

Silvestri, S., Esposito, A., Gargiulo, F., Sicuranza, M., Ciampi, M., & De Pietro, G. (2019). A big data architecture for the extraction and analysis of ehr data. *Proceedings of the IEEE World Congress on Services*, *2642*, 283–288.

Soldatos, J., Troiano, E., Kranas, P., & Mamelli, A. (2022). A reference architecture model for big data systems in the finance sector. *Big Data and Artificial Intelligence in Digital Finance*, 3–28.

Sonnenberg, C., & Brocke, J. v. (2012). Evaluations in the science of the artificial–reconsidering the build-evaluate pattern in design science research. *Proceedings of International Conference on Design Science Research in Information Systems*, 381–397.

Stewart, R., Fantke, P., Bjørn, A., Owsianiak, M., Molin, C., Hauschild, M. Z., & Laurent, A. (2018). Life cycle assessment in corporate sustainability reporting: Global, regional, sectoral, and company-level trends. *Business Strategy and the Environment*, *27*(8), 1751–1764.

Strüker, J., Weibelzahl, M., Körner, M.-F., Kießling, A., Franke-Sluijk, A., & Hermann, M. (2021). Decarbonisation through digitalisation: Proposals for transforming the energy sector (69th ed.). *Bayreuther Arbeitspapiere zur Wirtschaftsinformatik*.

Tajul Urus, S., Hasim, K., Syed Mustapha Nazri, S. N. F., & Tuan Mat, T. Z. (2020). Critical success factors of Accounting Information Systems (AIS): Empirical evidence from Malaysian organizations. *Management & Accounting Review*, *19*(1), 233–266.

Terzi, S., Savvaidis, C., Votis, K., Tzovaras, D., & Stamelos, I. (2020). Securing emission data of smart vehicles with blockchain and self-sovereign identities. *Proceedings of IEEE International Conference on Blockchain*, 462–469.

The Open Group. (2011). *TOGAF Version 9.1* (1. ed., 1. impr). Van Haren Publication.

Trishan, M., van der Alta, M., & Aurona, G. (2022). Systematic literature review of essential enterprise architecture management dimensions. In X.-S. Yang, S. Sherratt, N. Dey, & A. Joshi (Eds.), *Proceedings of 6th international congress on information and communication technology* (pp. 381–391). Springer Singapore.

United States Environmental Protection Agency. (2011). Overview of the Cross-State Air Pollution Rule (CSAPR). https://www.epa.gov/csapr/overview-cross-state-air-pollution-rule-csapr

van den Hoven, J. (2003). Data architecture: Blueprints for data. *Information Systems Management*, *20*(1), 90–92.

Velte, P., Stawinoga, M., & Lueg, R. (2020). Carbon performance and disclosure: A systematic review of governance-related determinants and financial consequences. *Journal of Cleaner Production*, *254*, 120063.

Villegas-Ch, W., Palacios-Pacheco, X., & Luján-Mora, S. (2019). Application of a smart city model to a traditional university campus with a big data architecture: A sustainable smart campus. *Sustainability*, *11*(10), 1–28.

Vilminko-Heikkinen, R., & Pekkola, S. (2019). Changes in roles, responsibilities and ownership in organizing master data management. *International Journal of Information Management*, *47*, 76–87.

Vogelsang, K., Steinhüser, M., & Hoppe, U. A. (2013). A qualitative approach to examine technology acceptance. *Proceedings of the International Conference on Information Systems*.

Vollmer, M. (2020). Das Brennstoff-Emissionshandelsgesetz (BEHG). *Natur und Recht*, *42*(4), 237–241.

Vom Brocke, J., Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., & Cleven, A. (2015). Standing on the shoulders of giants: Challenges and recommendations of literature search in information systems research. *Communications of the Association for Information Systems*, *37*(1), 9.

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly*, xiii–xxiii.

Wissal, D., Karim, D., & Laila, K. (2020). Adaptive enterprise architecture: Initiatives and criteria. *Proceedings of the 7th International Conference on Control, Decision and Information Technologies*, *1*, 557–562.

Yayla, A., & Lei, Y. (2020). Information technology implementation and organizational change: A dissipative structure theoretical lens. *Journal of the Southern Association for Information Systems*, *6*(1), 1–21.

Zhang, Y.-J., & Wei, Y.-M. (2010). An overview of current research on EU ETS: Evidence from its operating mechanism and economic effect. *Applied Energy*, *87*(6), 1804–1814.