Accelerating sustainability in companies: A taxonomy of information systems for corporate carbon risk management

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ACCELERATING SUSTAINABILITY IN COMPANIES: A TAXONOMY OF INFORMATION SYSTEMS FOR CORPORATE CARBON RISK MANAGEMENT

Research Paper

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Abstract

For increasing sustainability and mitigating climate change, corporate carbon risk management (CCRM) can be a key enabler. As we outline in this paper, companies currently lack processes and approaches in practice to actively manage complex risks caused by carbon emissions in the form of a comprehensive CCRM. To address this issue and to combine the contributions of currently separate research streams, e.g., corporate carbon accounting and corporate risk management, we develop a taxonomy that illustrates characteristics of IS-based solutions that foster an active CCRM. While our taxonomy builds on a systematic literature review, we evaluate our results with expert interviews. We conclude that CCRM is a complex field in which IS can provide significant support at many stages. Thereby, our taxonomy also contributes to Green IS research and acts as guidance for practitioners. Moreover, we discuss how Blockchains and Artificial Intelligence can pave the way towards target-oriented CCRM in companies.

Keywords: Carbon emission, corporate risk management, Green IS, sustainability

1 Introduction

Human-induced climate change is causing major problems for society as well as for companies (Tol, 2018; Urry, 2015). In order to mitigate climate change, businesses, civil society, governments, and scholars need to make joint efforts by reducing their impact on the climate (Sachs et al., 2019). One area that attracts considerable attention is the reduction of carbon emissions, i.e., decarbonization, to achieve the 1.5-degree target of the Paris Agreement (Dwivedi et al., 2022). While the increasing demand for decarbonization pressures companies to change and adapt their business models and behave more sustainably (Huber and Ixmeier, 2021; Schoormann et al., 2022), the research stream of Green Information Systems (Green IS) also aims at designing digital solutions to promote sustainability in companies (Elliot, 2011; Loos et al., 2011; Watson et al., 2008). Regarding the need for a holistic decarbonization in companies, regulation, customers, investors, or non-governmental organizations increasingly demand precise information about a company’s carbon emissions (Herold et al., 2019): For example, customers increasingly value sustainability while financial institutions consider sustainability in the credit approval process (Jung et al., 2018). Moreover, regulatory requirements like the European Union (EU) Emission Trading System (ETS) or the EU's corporate sustainability reporting directive (CSRD) urge companies to a more sustainable behavior in the sense of decarbonization, while some countries, such as Denmark or Norway additionally implemented carbon taxes to reduce emissions (Sumner et al., 2011). Particularly in view of the increasing regulation of emissions and a rising CO_2-price in the future, companies are trying to promote low-carbon investment strategies. To monitor, and hence, to report, as well as to control corporate carbon emissions and corresponding risks, companies require a corporate carbon risk management (CCRM). CCRM aims to manage diverse risks and negative impacts resulting from corporate carbon emissions. The risks to be managed range from reputational damage and sales losses to penalty payments and other financial risks. Therefore, it is essential to highlight the interrelations between carbon emissions and corporate risks as well as to identify the requirements for corresponding necessary digital technologies which combine corporate carbon accounting and corporate risk management, CCRM. However, so far, the management of these various risks is challenging for companies as they lack comprehensive procedures for CCRM in practice that are needed for an active management of carbon emissions (Busch, 2020; Miglionico, 2022). The emphasis here is on "active", as the focus is not merely on the recording and accounting in the sense of ERP systems for ex-post reporting, but on a truly active management of carbon emissions, i.e., to consider carbon emissions as a KPI.

While academic literature contains a research stream on corporate carbon accounting (Doda et al., 2016; Schaltegger and Csutora, 2012) and a research stream on corporate risk management (Hunziker, 2021) as well as initial literature that analyzes the role of IS for carbon accounting (Hirsch, 2018; Huang and Vasarhelyi, 2019), literature currently lacks – to the best of our knowledge – a combination of the contributions of these research streams. Further, linking these fields to enable a comprehensive view on CCRM is of particular relevance for decarbonization efforts in practice. Moreover, as we will outline in this paper, potential contributions of Green IS are manifold yet fundamental to the application of a comprehensive CCRM within companies. Nevertheless, there are initial approaches in the IS literature in the area of carbon management, which, however, are not bundled but partial islands, such as Müller et al. (2023), Zampou et al. (2022) and Babel et al. (2022a). We therefore infer that there are contributions of Green IS that still need to be explored. While digital social innovations may transform society on an individual level as well as on a company level towards sustainability (Graf-Drasch et al., 2022), research already acknowledges the central role of digital technologies on the journey towards a sustainable future (Fridgen et al., 2022; Fridgen et al., 2021; Sedlmeir et al., 2021). Additionally, academic literature states that digital technologies and information systems (IS) can facilitate the processing of large data volumes in a short time, ensure manipulation safety of the processed data, and provide intelligent monitoring and control (Șerban, 2017). This would also be necessary in the context of our research as a comprehensive CCRM may consider large amounts of carbon emission data that originate from various sources. While existing systems are not performant enough and impede precise monitoring as well as control of carbon emissions and the resulting risks, practice lacks guidance on how to design a comprehensive, and hence, target-oriented CCRM. In order to contribute to sustainable development in companies and to enable the design of a comprehensive CCRM that does not only report but actively manage carbon risks, we aim to answer the following research question:

How to structure characteristics of information systems that enable an active corporate carbon risk management?

To answer this question, we combine existing literature and knowledge from experts in the fields of corporate carbon accounting and corporate risk management. This allows us to develop a taxonomy of IS for CCRM by conducting a systematic literature review and evaluate it with eleven semi-structured expert interviews from research and practice. To the best of our knowledge, we are the first to provide a structured overview of characteristics of IS for a comprehensive CCRM. We find 18 dimensions and 53 characteristics to be relevant for CCRM in practice, illustrating the complexity of this task. Moreover, we discuss the applicability of two technologies that might foster CCRM in companies, namely the use of Blockchains and Artificial Intelligence (AI). This taxonomy shall assist practitioners in having a starting point for developing IS for CCRM by recognizing the relevant characteristics to enable CCRM-IS. In addition, our taxonomy provides a manifold basis for further research in the area of CCRM.

Our paper is structured as follows: In the next section, we introduce related literature and the research streams corporate carbon accounting and management, corporate risk management, and Green IS. In Section 3, we outline our research design and the methodological approach. The fourth section contains the presentation of our developed taxonomy of IS for CCRM. Based on these results, the fifth section discusses the applicability of exemplary digital technologies for CCRM and contains the contributions of the paper. In the final section, we draw main conclusions and outline limitations and future research.

2 Background and related literature

New regulatory requirements as well as stakeholder pressure from the market and consumer side oblige companies to adapt sustainable and decarbonizing business activities and establish carbon information flows (Humbert, 2019; Schreck and Raithel, 2018). In the context of our research, we identify three topics to be relevant for understanding the paper and for recognizing the IS relevance of the topic, which we outline in the following: (1) Corporate Carbon Accounting and Management, (2) Corporate Risk Management, and (3) Green IS. To the best of our knowledge, literature lacks a combination of these research streams that may hold a plethora of contributions for enabling CCRM.

2.1 Corporate carbon accounting and management

Carbon emission data and information flows are a relevant topic in corporate accounting and management as companies are either required from the regulatory side or the market, i.e., other companies or consumers (Qorri et al., 2018), to determine their corporate carbon footprint. The carbon footprint illustrates "the carbon […] emissions related to the activity or products of a certain company" (Harangozo and Szigeti, 2017, p. 4). In some countries, specific industries have to compensate their emissions, i.e., their carbon footprint, with specific allowances on carbon emission markets, see, e.g., the EU-ETS. Companies face the challenge of emission limitation and trading either with carbon footprint reduction strategies (Berger et al., 2022), or they are willing to pay for carbon offsets, the purchase of "verified emission reductions from other parties" (Chen et al., 2021, p. 1).

According to the Greenhouse Gas Protocol (GHG Protocol) by World Business Council for Sustainable Development (WBCSD) and World Resource Institute (WRI), there are three different groups of emissions. Scope 1 covers all direct GHG emissions, meaning emissions that "occur from sources that are owned or controlled by the company" (WBCSD and WRI, 2004, p. 25). Scope 2 includes indirect GHG emissions from "the generation of purchased electricity consumed by the company" (WBCSD and WRI, 2004, p. 25). All other indirect emissions that "are a consequence of the activities of the company, but occur from sources not owned or controlled by the company" (WBCSD and WRI, 2004, p. 25) are assigned to scope 3. Especially the determination of scope 3 carbon emissions is complex as various up- and downstream activities have to be considered (WBCSD and WRI, 2004) and supply chains are usually long and hard to manage (Huang et al., 2009). Nevertheless, companies need a sound data basis for carbon accounting which is the basis for purposeful carbon management. Besides the Science Based Targets initiative (SBTi), which aims to support companies in setting emission reduction targets for themselves and their suppliers (Mahmoudian et al., 2021; SBTi, 2021), various standards aim to foster sustainable and carbon-neutral behavior of companies and carbon emissions reporting. Hereby, the basis of corporate sustainability targets are usually the 17 Sustainable Development Goals (SDG) of the United Nations (UN) Global Compact in conjunction with several standards of the International Organization for Standardization (ISO) like ISO 14001, ISO 14031, or ISO 26000 (Brooks et al., 2012; United Nations General Assembly, 2015). Carbon emission reporting, which may be part of the annual sustainability report, primarily follows the Global Reporting Initiative (GRI) standard (Marimon et al., 2012; Roca and Searcy, 2012). To account and actively manage a company's carbon emissions, fine-granular and easy-to-disclose emission data is required (Strüker et al., 2021). This data and the beforehand mentioned sustainability report can be a basis for decision-making for CCRM (Adams and Frost, 2008).

2.2 Corporate risk management

Companies usually have to manage a wide variety of risks, for example, financial risks, supply chain risks, and sustainability risks (Aven, 2016; Hunziker, 2021; Villamil et al., 2022). According to the Committee of Sponsoring Organizations of the Treadway Commission (COSO), which is a renowned standard-setter, risk management is “the culture, capabilities, and practices, integrated with strategy-setting and its execution that organizations rely on to manage risk in creating, preserving, and realizing value” (COSO, 2017, p. 10). The ISO published a second well-known standard in risk management. According to ISO 31000, risk management activities are “coordinated activities to direct and control an organization with regard to risk” (ISO, 2018). According to Moeller (2011), the process of risk management consists of four iterative steps: “(1) risk identification, (2) quantitative and qualitative assessment of the documented risks, (3) risk prioritization and response planning, and (4) risk monitoring” (Moeller, 2011, p. 32). Risk management is essential for corporate success, as highly performant risk management enables for example reduced performance variability, decreased cost of capital, or a wider range of (new) opportunities (COSO, 2017; Hunziker, 2021).

Carbon risk is an emerging topic with dynamic development and adjustment. Increasing regulatory requirements, such as the EU-ETS, constitute a risk for companies (Clarkson et al., 2015). In addition to regulatory risks, a company’s carbon emissions can lead to physical, financial, or business risks (Labatt and White, 2007). These manifold risks force companies to set up a carbon risk management system (Jung et al., 2018). At the moment, companies often lack the right (green) IS solutions to determine the carbon risks, even though they are aware of it and have started to integrate it into their corporate risk management (Busch, 2020; Miglionico, 2022).

2.3 Green IS

The research stream of Green IS builds an interdisciplinary subset of IS research and is concerned with “the design and implementation of information systems that contribute to sustainable business processes” (Watson et al., 2008, p. 2). While Green IS encompasses topics like the management of information about environmental issues, the change of behaviors towards climate change, or the support of a sustainable development – often with an eye to energy systems –, the use of Green IS can, among others, be in the area of carbon emissions monitoring, green production, or fulfillment of corresponding compliance requirements (Babel et al., 2022a; Graf et al., 2018; Hanny et al., 2022; Sarkis et al., 2013; vom Brocke et al., 2013). Besides that, Butler (2011) and Seidel et al. (2013) state that applications of Green IS may also reduce the long-term expenses of a company and improve its reputation, as pollution can be tracked and measured more easily. Lima et al. (2021), Müller et al. (2023) and Zampou et al. (2022) argue that carbon emissions should be reduced to deal with climate change and that IS may provide assistance. As well as in carbon emission management, IS can support corporate risk management as they enable for instance automated audit processes or real-time monitoring (Babel et al., 2022b; Huang and Vasarhelyi, 2019). Because carbon emissions as one aspect of sustainability represent an increasing risk for companies, the use of digital technologies might foster the management of these risks.

Concerning the monitoring of carbon emissions, there is a wide range of IS literature that applies technologies for digital solution approaches. As Blockchain-based solutions, for example, can enable trust, privacy, and transparency (Körner et al., 2022; Roth et al., 2022), Blockchain is already used in different business cases where companies want to ensure the privacy of sensitive data, such as revenue or balances (Babel et al., 2023; Sedlmeir et al., 2022). While the probably best-known use case of Blockchain is in the area of crypto-currencies (Nakamoto, 2008), literature also considers the use of Blockchains in carbon emission management (Babel et al., 2022a; Pan et al., 2019). Nevertheless, there are no IS solutions with wide market penetration that actively manage carbon risks. According to Babel et al. (2022a), IS solution approaches that are based on decentralized technologies, like Blockchain or decentral digital identities, may also ensure a tamper-proof end-to-end transfer of data by specific verification schemes. In this case, Blockchain may enable verification of emissions along the supply chain, which fosters the trust of end-consumers and other stakeholders (Qorri et al., 2018).

Green IS research also considers another technology to be used in the context of carbon emission monitoring, namely, AI applications (Nishant et al., 2020). According to Rai et al. (2019), AI is "the ability of a machine to perform cognitive functions that we associate with human minds" (Rai et al., 2019, p. iii). AI applications enable process automation of time-consuming tasks, structure big amounts of data, and can solve complex problems (Nishant et al., 2020). Among others, federated learning is an increasingly important sub-topic of AI and machine learning research (Qin et al., 2021). Carbon emission data is highly sensitive and the transmission should therefore only happen via secure communication. The use of federated learning avoids the transmission of original data and ensures the privacy of carbon emission data (Zhang et al., 2021). Currently, there are already IS available for carbon emission monitoring that aim to support the measurement of carbon emissions but a holistic IS that can process carbon emission data and calculate the resulting risks is lacking.

3 Research design and methodological approach

As carbon risk is an emerging topic and the digitalization of business processes is becoming increasingly important (Bolton and Kacperczyk, 2021; Denner et al., 2018), we recognize the need for a taxonomy as a first but relevant foundation that structures the characteristics of IS for CCRM. A foundation is of particular relevance as practice currently lacks structured knowledge about how to design IS for CCRM (Busch, 2020). As taxonomies aim to "structure or organize […] knowledge" (Glass and Vessey, 1995), they enable a better understanding of a field of research. In IS research, Nickerson et al.'s (2012) method is one of the most widely spread approaches for taxonomy development (Kundisch et al., 2021). Oberländer et al. (2019) provide an overview of different taxonomies in the IS domain. The taxonomy builds on an initial literature review, searching for articles in the field of IS, sustainability and corporate risk management that exist but have not been bundled and structured yet. Then, we conduct a forward and backward search to identify relevant citations and references. After the taxonomy development process, we evaluate the taxonomy. We use semi-structured expert interviews as suggested by Kundisch et al. (2021) and Szopinski et al. (2019).

3.1 Taxonomy development

Our research follows the taxonomy design process of Nickerson et al. (2012). According to Nickerson et al. (2012), the first step is the determination of the meta-characteristic, as all other characteristics should be related to it. The meta-characteristic is "the most comprehensive characteristic that will serve as the basis for the choice of characteristics in the taxonomy" (Nickerson et al., 2012). In line with our research question, we define the following meta-characteristic: *Characteristics of IS solutions that foster CCRM*.

The second step of the taxonomy development is the definition of ending conditions. When we meet these conditions, the iteration process of the taxonomy development stops. In line with Nickerson et al. (2012), we select both, objective and subjective ending conditions, which are listed in Table 1.

Objective ending conditions	Subjective ending conditions
• No new characteristics or dimensions were added in the last iteration • No new characteristics or dimensions were merged or split in the last iteration • Each characteristic is unique within its dimension • Each dimension is unique and not repeated within the taxonomy	• Concise • Robust • Comprehensive • Extendible • Explanatory

Table 1: Objective and subjective ending conditions

After the determination of the meta-characteristic and the ending conditions, the iterations of the taxonomy development process start. According to Nickerson et al. (2012), researchers can choose between two approaches, depending on the available data and existing knowledge: The empirical-to-conceptual approach first identifies a new subset of objects and identifies common characteristics afterwards. In contrast, the conceptual-to-empirical approach conceptualizes new characteristics or dimensions and then examines objects for these characteristics. At the end of an iteration, we check the fulfillment of the defined ending conditions. The taxonomy development process ends, when we meet both, the subjective and objective ending conditions. Otherwise, we continue with another iteration. Our taxonomy development process consists of five iterations before we meet our ending conditions. We alternate between a total of three iterations using the conceptual-to-empirical approach and two iterations using the empirical-to-conceptual approach. In the first iteration (conceptual-to-empirical), we conduct a systematic literature review and develop a first draft of the taxonomy. Afterwards, we use the experience and knowledge of the authors in the second iteration to extend and improve the taxonomy (Nickerson et al., 2012). In our third iteration, we examine the references of the literature review's relevant articles (backward search) and refine the taxonomy. Afterwards, we conduct another iteration with general knowledge and experience of the authors. As we add new characteristics and dimensions in our fourth iteration and therefore don't meet our objective ending conditions, we perform a fifth iteration by doing a forward search of the literature review's relevant results. During the fifth iteration, we make no more changes to the existing taxonomy. We meet the objective and subjective ending conditions and obtain our taxonomy, which we evaluate afterwards.

3.2 Systematic literature review

The systematic literature review following Webster and Watson (2002) and Wolfswinkel et al. (2013) represents the first iteration in order to get scientifically substantiated knowledge (vom Brocke et al., 2015). We select three databases for our literature review. With Web of Science, Science Direct, and AIS eLibrary we use one database with a focus on IS topics and two wide-ranged databases that cover IS as well as other relevant research fields. The search string used for the databases is: *("Carbon" OR "GHG" OR "Green House Gas*" OR "Greenhouse Gas*" OR "CO2" OR "Emission*" OR "Sustainab*") AND ("Risk" OR "Accounting") AND ("Information System*" OR "Digital*" OR "Technolog*" OR "Data*") AND ("Business*" OR "Compan*" OR "Enterprise*" OR "Corporate") NOT ("Geologic*" OR "Storage" OR "Energy" OR "nano*" OR "Construct*" OR "bio*" OR "agri*" OR "chemical" OR "chemistry" OR "power" OR "health")*.

As suggested by Wolfswinkel et al. (2013), we exclude duplicates and irrelevant research domains. We solely consider articles with a focus on accounting, business, IS, and management. Afterwards, the author team screens and winnows the remaining articles' titles and abstracts. Articles that provide information on the use of IS for corporate sustainability actions are included, whereas articles with a focus on, e.g., environmental science, are excluded. Figure 1 illustrates the literature review process that results in 27 relevant articles after the full-text screening.

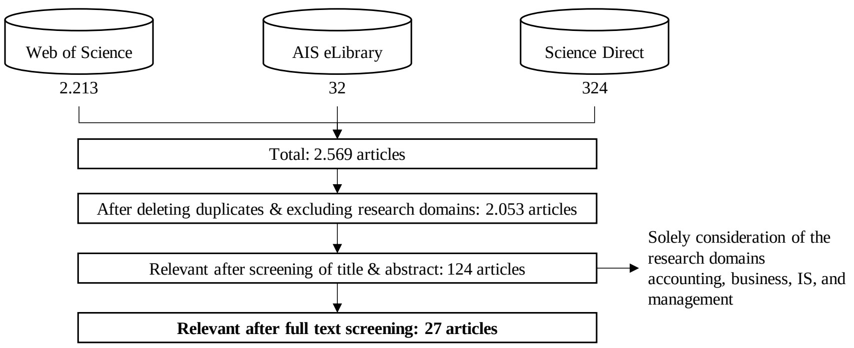

Figure 1: Structure of the systematic literature review

After the initial literature review, we perform a backward and forward search to determine relevant references and citations (Webster and Watson, 2002; Wolfswinkel et al., 2013) and enlarge the number of considered articles. The backward search reveals 13 relevant articles and the forward search four relevant articles. We use the additional results of our backward search in the third iteration and the additional results of our forward search in the fifth iteration, which, as aforementioned, is the last iteration of our taxonomy development process.

3.3 Evaluation: Semi-structured interviews

After the taxonomy development process with five iterations, we evaluate the results. There are various possibilities to evaluate a taxonomy, but Szopinski et al. (2019) find that the two most common are expert interviews and the classification of real-world objects. Due to the insufficient number of market-ready IS for CCRM in companies, we conduct semi-structured interviews based on Adams (2015) and Myers and Newman (2007). The experts critically analyze the taxonomy, bring a new perspective to it, and complement our findings. We interview eleven experts with expertise in the field of sustainability (risk) management and digitalization (see Table 2). To account for the importance of the perspective from practice, we focus on industry partners from the authors' network as interviewees. The interviews last 60 minutes on average and are recorded and transcribed. After that, we analyze the transcripts to identify potential new dimensions or characteristics, rearrange characteristics, change the wording, and refine our taxonomy.

No.	**Job Title**	**Years of experience**	**Industry**	**Employees (2021)**
01	Environmental and Energy Management Officer	> 10	Precision engineering	< 1,000
02	Sustainability Manager	5-10	Energy supply	1,000-100,000
03	Consultant ESG & Technology	> 10	Auditing & consulting	1,000-100,000
04	Researcher	< 5	Research	< 1,000
05	Management Accountant Sustainability	> 10	Conglomerate	> 100,000
06	Corporate Communications CSR	5-10	Food retailing	> 100,000
07	Sustainability Manager	5-10	Conglomerate	> 100,000
08	Responsibility & Sustainability Manager	< 5	Online mail order	1,000-100,000
09	Researcher	< 5	Research	< 1,000
10	Enterprise Risk Manager	> 10	Smart infrastructure	> 100,000
11	Researcher	< 5	Research	< 1,000

Table 2: Details on the semi-structured expert interviews

Following Myers and Newman (2007), we start the interviews with a short introduction to the research topic. To get practitioners' insights, the second part of the interview contains questions about CCRM. Then the experts evaluate the taxonomy of IS for CCRM (Schultze and Avital, 2011). The evaluation allows us to challenge the characteristics we identified based on the literature review and general knowledge and points out missing or irrelevant characteristics and dimensions. After adding the new findings, we obtain our final taxonomy.

4 Taxonomy of information systems for corporate carbon risk management

Our taxonomy of information systems for corporate carbon risk management is structured in two layers that we build through three conceptual-to-empirical iterations, two empirical-to-conceptual iterations, and an evaluation with semi-structured expert interviews. We present the final taxonomy in Table 3 (cf. end of the section). Due to page restrictions, we refrain from providing detailed information on the results of the individual iterations. In the following, we illustrate the meaning and relevance of each characteristic and dimension and explain, whether they originate from the literature review or the expert interviews. In line with Berger et al. (2020), Oberländer et al. (2018), and Roeglinger et al. (2016) the characteristics can either be mutually exclusive (E) or mutually non-exclusive (NE).

Data input and processing requirements

The first layer describes the data input and processing requirements. The *frequency of data updates* can either be in real-time or not in real-time. A frequent updating of input data enables a faster risk management process and consequently faster reactions. In line with Tiwari and Khan (2020), we note that a future-oriented IS for a comprehensive CCRM would be able to handle real-time capable input systems (Thöni et al., 2013). According to Lewis and Young (2019), the *data format of input data* should be machine-readable to be processed by the CCRM-IS. We distinguish between structured, semi-structured, and unstructured data. Groth and Muntermann (2011) postulate that risk management should use unstructured data as well as structured or semi-structured data. Most IS are only able to proceed structured or semi-structured data but by using AI applications or machine learning applications unstructured data may be processed, too (Groth and Muntermann, 2011). The *data collection transmission* of the CCRM-IS represents another dimension of our taxonomy. Connected IS that provide data to the CCRM system can either push their information into the CCRM system or the CCRM system pulls data from the connected IS (Thöni et al., 2013). To adapt to already existing connected systems and their capabilities, the CCRM-IS would be able to pull data and have data pushed in from other systems. Since carbon emission data originates from different sources, we identify the *origin of processed data* as a relevant dimension. The emission data can either be internal or external (Žigienė et al., 2019). Internal data originates from the company's sources whereas external data is provided by consulting companies, suppliers, or other external service providers (Žigienė et al., 2019). Especially scope 3 emissions, typically the largest share of a company's total carbon emissions, are mostly external data as they include various indirect emissions such as transport, waste, or purchased goods (SBTi, 2021). The *data collection automation* can either be full, partial, or manual. Process automation is important for the CCRM as it can accelerate the risk management process and reduce errors (Aziz and Dowling, 2019). Interviewees 06 and 08 highlight that manual data input and corrections are time-consuming. Some tasks still need to be performed by employees because the existing input system is not compliant with the CCRM-IS or the automation and the interfaces are not yet completely developed (Chan and Vasarhelyi, 2011), but we note that an IS for a comprehensive CCRM would be able to collect the required data automatically. The *data aggregation automation*, our sixth dimension in this layer, includes the characteristics full, partial, and manual. Since there is a large amount of emission data, especially from scope 3 emissions, data aggregation should be fully automated to enable an effective use of the data (Satoh, 2011). In addition to that, the data can origin from different *data sources.* Companies can directly process primary data or use secondary data that, for instance, originates from a company's Enterprise Ressource Planning system (Thöni et al., 2013). This dimension can be differentiated from the dimension *origin of processed data* as internal and external data can be both, raw primary and already processed secondary data. The penultimate dimension in this layer, the *responsible party for data verification*, is important because emission data origins from various sources with different credibility and consistency (Satoh, 2011). According to interviewee 03, the quality of carbon emission data is challenging for many companies. For this, the data should be verified. The data verification can be done by a third party or internally (Doda et al., 2016). According to interviewees 06 and 08, most companies do not verify the carbon emission data but perform plausibility checks only. Interviewee 03 adds that data verification solely takes place in the case of high potential level of damage. Against this background, there also exist cases where no verification is performed at all. As emission data origins from different sources, e.g., suppliers, verification is key to process correct data. Data verification increases data quality as fraud might be detected faster (Woo et al., 2021). Processing incorrect data might have harmful effects as decisions are typically made based on the results of the CCRM system. Our last dimension in this layer is *data verification automation*. Similar to the other dimensions talking about automation, there are three types of automation: full, partial, and manual. A fully automated verification process implies that the system verifies all incoming data immediately, or in other words, in real-time (Peters et al., 2017). If only predefined points in time cause data verification, we consider this as partial automation. The verification, for instance, takes place before the report is generated. If there are anomalies in carbon emission data, the employees can also initiate the data verification manually.

Output used for CCRM and application

The output used for CCRM and the application represent the second layer of our taxonomy. The first dimension includes possible *content of the reports* that the CCRM generates. The CCRM reports provide an overview and support decision-makers. Risk management matrixes, as suggested by Pačaiová et al. (2017), can provide an overview of occurring risks and their probability or consequences. The same applies to key performance indicators (KPIs). They support the monitoring of relevant carbon emission data and guide when to react. Another important output content is future cost calculations (Busch, 2020). ETSs require companies to purchase emission allowances whose prices increase and fluctuate. The forecast of future carbon emissions and their costs should therefore be addressed by the CCRM-IS. Overall, an IS for a comprehensive CCRM would also highlight areas that require greater risk management in order to keep future costs low and to ensure corporate success (Pačaiová et al., 2017). In corporate reporting, there are two *types of reports* that are typically generated. Standard reports are generated in regular intervals, e.g., weekly, monthly, or annually, whereas ad-hoc reports are generated on request. These ad-hoc requests may require new report content that was not needed before. We note that an IS for a comprehensive CCRM would be able to generate both types of reports to fulfill managers' demands and ensure an effective and user-friendly CCRM. Similar to data input in the second layer, the *frequency of report generation* can either be in real-time or not in real-time (Thöni et al., 2013). A real-time capable CCRM reporting enables faster notifications or alerts and consequently faster responses to emerging risks. This, in turn, can lower the costs of risk elimination or management. Like the input process, the *reporting process automation* can be full, partial, or manual. Fully or partially automated processes can foster corporate compliance as human intervention is limited (Miglionico, 2022). Consequently, the quality of the output from the CCRM-IS increases through full or partial reporting process automation. As mentioned in layer two, process automation might not be fully in the implementation phase because the CCRM-IS needs to be adapted to downstream systems with possibly different requirements. Interviewee 03 adds that with increasing regulatory requirements and effort the automatization might also increase. Interviewee 10 remarks that companies usually conduct a *document classification*. Public documents are accessible to the public via the company's homepage because they do not contain sensitive information. Internal documents are only shared within the company. All employees can access the documents, regardless of their assigned business unit or team. Both, confidential and strictly confidential documents are accessible only to authorized employees. The classification of CCRM reports ensures the privacy of sensitive data and limits unauthorized information access and information procurement. The dimension of *customizability* illustrates the various customization options that a CCRM-IS would be able to present. Among different levels of (local) aggregation, there are various product types, topics, grouping of risks, business units, or suppliers and customers that might require different reports of the CCRM-IS (Gibson, 1997). Interviewees 08 and 10 state that reports have to be customizable as not all receivers should get and need all information that the CCRM-IS can provide. As mentioned previously, not all information is shared with all internal or external stakeholders. For this purpose, not only the data storage must have different classifications but also the generated reports of the CCRM must be adaptable to the recipient groups and their authorizations. The dimension *targeted emissions* lists the carbon emission scopes 1, 2, and 3, which may be addressed by a CCRM-IS. All interviewees confirm that their companies consider scope 1, scope 2, and relevant scope 3 emissions. An IS for a comprehensive CCRM would be able to capture all scopes, as decarbonization initiatives urge companies to reduce all carbon emissions, not only scope 1 or scope 2 carbon emissions (Harangozo and Szigeti, 2017; SBTi, 2021). Conversely, this means that all scopes represent a potential risk for companies and should be monitored and controlled by the CCRM. The *connected GHG regulation* consists of two characteristics. Mandatory requirements, e.g., ETS or sustainability reporting requirements, limit the emissions of high-polluting industries (European Parliament, 2003; Weng and Xu, 2018) and enable the monitoring of a company's sustainability actions. Currently countries all over the world pass laws that aim to limit global warming and decrease carbon emissions. For this, the CCRM has to be aware of the different regulations and their effects on the company's financial situation. Interviewee 03 notes that the CCRM should be integrated in financial reporting systems. The same applies to voluntary regulation. Even though they are not legally required, companies may publish sustainability reports. The CCRM-IS might be closely linked to that voluntary regulation as, according to interviewees 02, 08, and 10, identified risks are briefly mentioned in the annual reports of companies. The last dimension in the second layer is *compliance with standards*. There are various standards that structure and regulate risk management, reporting, GHG emissions, or sustainability in companies. The SDGs, the SBTi, the GHG Protocol, the carbon disclosure project (CDP), the GRI, ISO 14031, ISO 26000, and the task force on climate-related financial disclosures (TCFD) are relevant sustainability or carbon-orientated standards (Olson, 2010). These standards' requirements should be considered in the CCRM-IS development process as a company's environmental management system and the CCRM-IS may be closely linked to each other. According to interviewee 07, companies consider carbon risk as one part of sustainability risks in the sustainability report and the corporate sustainability strategy. In contrast to the aforementioned standards, the COSO standard and ISO 31000 give guidance for risk management (Shad et al., 2019). A CCRM-IS has to be compliant with these standards if companies want to be or stay certified correspondingly. The certification of risk management is also important to credit approval processes (Mathiesen, 2018).

<table>
<tr><th>Layer</th><th>Dimensions</th><th colspan="12">Characteristics</th><th>E/ NE</th></tr>
<tr><td rowspan="9">Data input & processing require-ments</td><td>Frequency of data update</td><td colspan="6">Real-time capability</td><td colspan="6">No real-time capability</td><td>E</td></tr>
<tr><td>Data format of input data</td><td colspan="4">Structured</td><td colspan="4">Semi-structured</td><td colspan="4">Unstructured</td><td>NE</td></tr>
<tr><td>Data collection transmission</td><td colspan="6">System push</td><td colspan="6">System pull</td><td>NE</td></tr>
<tr><td>Origin of processed data</td><td colspan="6">Internal</td><td colspan="6">External</td><td>NE</td></tr>
<tr><td>Data collection automation</td><td colspan="4">Full</td><td colspan="4">Partial</td><td colspan="4">Manual</td><td>E</td></tr>
<tr><td>Data aggregation automation</td><td colspan="4">Full</td><td colspan="4">Partial</td><td colspan="4">Manual</td><td>E</td></tr>
<tr><td>Data source</td><td colspan="6">Primary data</td><td colspan="6">Secondary data</td><td>NE</td></tr>
<tr><td>Responsible party for data verification</td><td colspan="4">Third party</td><td colspan="4">Internal</td><td colspan="4">No</td><td>NE</td></tr>
<tr><td>Data verification automation</td><td colspan="4">Full/ Immediate verification of all incoming data</td><td colspan="4">Partial/ Verification of all incoming data at predefined points in time</td><td colspan="4">Manual/ Verification of all incoming data after manual initiation</td><td>E</td></tr>
<tr><td rowspan="6">Output used for CCRM & application</td><td>Content of report</td><td colspan="3">Risk matrix</td><td colspan="3">KPI</td><td colspan="3">Future costs</td><td colspan="3">Areas that require greater risk management</td><td>NE</td></tr>
<tr><td>Type of report</td><td colspan="6">Ad-hoc report</td><td colspan="6">Standard report</td><td>NE</td></tr>
<tr><td>Frequency of report generation</td><td colspan="6">Real-time capability</td><td colspan="6">No real-time capability</td><td>E</td></tr>
<tr><td>Reporting process automation</td><td colspan="4">Full</td><td colspan="4">Partial</td><td colspan="4">Manual</td><td>E</td></tr>
<tr><td>Document classification</td><td colspan="3">Public</td><td colspan="3">Internal</td><td colspan="3">Confidential</td><td colspan="3">Strictly confidential</td><td>E</td></tr>
<tr><td>Customizability</td><td colspan="2">Levels of (local)</td><td colspan="2">Product types</td><td colspan="2">Topics</td><td colspan="2">Groups of risks</td><td colspan="2">Business units</td><td colspan="2">Suppliers</td><td>NE</td></tr>
</table>

<table>
<tr><td rowspan="4"></td><td></td><td colspan="2">aggrega-
tion</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2">&
customers</td><td></td></tr>
<tr><td>Targeted emissions</td><td colspan="4">Scope 1</td><td colspan="4">Scope 2</td><td colspan="4">Scope 3</td><td>NE</td></tr>
<tr><td>Connected GHG regulation</td><td colspan="6">Mandatory</td><td colspan="6">Voluntary</td><td>NE</td></tr>
<tr><td>Compliance with standards</td><td colspan="3">Sustainability</td><td colspan="3">Reporting</td><td colspan="3">Emission trading</td><td colspan="3">Risk management</td><td>NE</td></tr>
</table>

Table 3: Taxonomy of IS for CCRM, (E = Mutually exclusive, NE = Mutually non-exclusive)

5 Discussion and contribution

While current IS solutions in practice mainly focus either on carbon management, on carbon accounting, or on environmental impact calculation, our research outlines the relevant characteristics that an IS for an active CCRM should incorporate. Thereby, we also illustrate the currently existing lack of considerations on an IS for CCRM, which is, among others, in line with the interviewed practitioners, who emphasize the significant need for IS solutions that enable an active management of a company's carbon emission risks. To date, CCRM in many companies would be thwarted by slow processes with many manual steps and inaccurate scope 3 carbon emission data. The companies solely perform plausibility checks and data verification. In addition, most reports come in the form of manual excel files that are not performant as the amount of data and calculations are too complex – making them inefficient and non-sufficient tools. An IS for CCRM has to address these current issues as corresponding processes have to become verifiable, more accurate, and more automated. In the following section, we discuss the potential of different technologies – that are mentioned in literature for being applicable to sustainability and risk management – for CCRM to show the taxonomy's utility. Moreover, we also illustrate the contribution of our research in Section 5.2.

5.1 Fields of application for digital technologies in corporate carbon risk management

Based on our literature review, we find that literature, e.g., Meiyou and Ye (2022), Miglionico (2022), Woo et al. (2021), or Žigienė et al. (2019), mentions the application of Blockchain and AI particularly frequently in the context of sustainability and risk management. We supplement the articles from our literature review with additional research to obtain a sound knowledge of the technologies' potentials.

Concerning Blockchains, for example, Alkhudary et al. (2020) and Fridgen et al. (2019) state that this technology enables a transparent, immutable, and secure collection and processing of data in risk management. Since current risk management systems often rely on analogous and manual transfer of data by employees with excel files, they lack a tamper-proof collection and an immutable storage of data (Ma et al., 2018). In the context of CCRM, the processing of current data is of inevitable relevance for decision-makers to avoid poor decisions. Hence, the quality, reliability, and transparency of data that is processed are key for a comprehensive CCRM. Especially the reporting and verification of (company-external) scope 3 carbon emission data is, according to interviewee 02, challenging for companies. Against this background, literature such as Agahari et al. (2022), Körner et al. (2022), and Strüker et al. (2021) propose decentralized technologies, like Blockchains, self-sovereign identities, or secure multi-party computation – or their combination to account for Blockchains' privacy challenges –, to share external data along supply chains. Moreover, Babel et al. (2022a) illustrate how such a data sharing may be designed in the context of carbon emissions data. Also the UN highlight Blockchains as a technology that might foster climate protection, since carbon emission data can be better verified, tracked, and reported (United Nations, 2017). By applying Blockchains, the verification of data may be done in real-time, allowing rapid responses to anomalies and trust from both sides, the data provider and the data receiver (Woo et al., 2021). Consequently, the management of carbon risks would become faster and more precise, which may reduce the costs of necessary countermeasures.

Secondly, AI and its' technological subsets have wide-ranging possible applications in CCRM (Bedi et al., 2020; Hirsch, 2018). AI applications can be used in all four stages of the risk management process (Žigienė et al., 2019) and for various types of risk (Bedi et al., 2020). It enables fast data processing, as routine steps in risk management can be automated by the application of AI (Bedi et al., 2020). In addition, AI applications can process both, structured and unstructured data (Makridakis, 2017). While through the use of cognitive computing – a subset of AI – large amounts of information can be processed in real-time (Miglionico, 2022), for example, predictions of the CCRM may be improved since the more data a risk management system can use for its calculations, the better are the predictions of future risks. According to Bedi et al. (2020), AI applications also enable previously unknown risks to be discovered and included. Moreover, literature already states that AI applications can find anomalies in carbon emission data automatically (Woo et al., 2021). Since there are usually large amounts of carbon emission data, an automatic check might reduce fraud and improve data quality. As already mentioned above, improved data quality then leads to a more accurate CCRM. While according to Duda et al. (2022), companies are concerned about privacy issues caused by AI, advances in federated learning can account for that by addressing concerns about data protection (Zhang et al., 2021).

Since carbon emission data is highly sensitive and competition-relevant, it should only be transmitted via secure communication. Especially for the processing of company-external data, it is of particular relevance to design solutions that are capable of providing specific verification schemes for transmitted data as well as that they are capable of preserving the privacy of the data-providing company. While we note that IS research is in charge to analyze such solutions, we see that this may not be accomplished by one technology alone but with a specific interplay of, e.g., Blockchains and AI, only.

5.2 Contribution to practice and theory

Our developed taxonomy presented in Section 4 provides a structured overview of the characteristics of IS for CCRM that can foster corporate decarbonization, illustrates which technologies can support corporate decarbonization, and is relevant for both, researchers and practitioners. To the best of our knowledge, we are the first to combine corporate carbon accounting and corporate risk management and identify the requirements for supporting IS solutions for CCRM.

For practitioners, our taxonomy contributes as an initial step for the development of CCRM-IS in practice. Our expert interviews illustrate that companies lack solutions for CCRM. Due to increasing regulatory requirements and stakeholder pressure, there is a significant need for CCRM. We structure the complex field of CCRM, and thus, support the development of IS solutions in this field. Second, our results highlight that there is a need for data verification in CCRM in practice, especially when processing company-external data. The interviewed experts note that their companies do not verify the incoming emission data accordingly but carry out plausibility checks only. Our taxonomy can support an increasing transparency of carbon emission data as we emphasize the relevance of data verification in the CCRM process. Third, the developed taxonomy provides a solution for legacy systems. The common data formats and systems used for carbon emission reporting are not performant and user-friendly. Our taxonomy helps practitioners that aim to develop new IS solutions for CCRM. It provides a structured overview of important characteristics they need to consider if they want to develop an IS for a comprehensive CCRM. Fourth, we provide a comprehensive approach that addresses and fosters not only CCRM as our taxonomy also illustrates important characteristics of carbon emission data collection, which may improve carbon emission management, emission reporting, or sustainability reporting accordingly.

Our results also provide a necessary starting point for researchers, who aim to design solutions or concepts in the field of CCRM. Our research supplements the already existing research in carbon emission management and digitalization in risk management. Moreover, it holds various insights for the research stream on data sharing and data spaces, especially when considering the processing of company-external emission data in CCRM. Acknowledging the complexity of CCRM, our work is the first that comprehensively illustrates that there are various dimensions to account for, i.e., different types of targeted scopes, regulations, standards, frequencies of data update, data formats of input data, data collection transmission, origins of processed data, data collection automation, data aggregation automation, data sources, responsible parties for data verification, data verification automation, contents of reports, types of reports, frequencies of report generation, reporting process automation, document classifications, and customizability options. The taxonomy provides an overview of relevant characteristics and forms the basis for researchers that aim to evaluate their developed IS-based CCRM approach. In addition, the interviewed experts confirm that there is a need for research, as companies lack data verification mechanisms, performant data formats, and general approaches for CCRM. As aforementioned, the verification of carbon emission data might become increasingly important in the future. For this, IS scholars need to consider the contribution of IS in CCRM and need to investigate the applicability and potential of different verification mechanisms and data formats.

6 Conclusion

Companies are under severe pressure to become more sustainable as regulatory requirements and stakeholder pressure increase. The reduction of carbon emissions is one major task for mitigating global warming and climate change. However, the active management of carbon-related risks within companies, which is closely linked to decarbonization, is still in its infancy in academic literature. Companies are aware of the importance of carbon emission reduction and resulting risks but they lack approaches to actively manage these risks as we outline in our paper. According to practitioners, carbon risks are a complex issue due to large amounts of data, different data sources, and various application areas within industry. The experts that we interview for this paper emphasize the need for digital solutions for processing the large amounts of data associated with CCRM efficiently to monitor and actively manage carbon-related risks. For this, research must combine existing approaches and concepts from the corporate carbon accounting and the corporate risk management field to guide practitioners and bridge the gap of lacking IS solutions for CCRM. We present a structured overview of the characteristics of IS that foster CCRM. Therefore, we develop a taxonomy with 18 dimensions, and 53 characteristics and evaluate it by conducting eleven semi-structured expert interviews. Our taxonomy illustrates the data input and processing requirements, the output used for CCRM, and the application of CCRM in practice. It furthermore underlines the complexity and manifoldness of IS for CCRM. By providing our results, we are the first to structure the research field of IS-enabled CCRM in a comprehensive manner – laying the foundation for IS designers and scholars in this relevant field. Moreover, we discuss the potential roles of Blockchains as well as AI applications for CCRM.

Nevertheless, there are, of course, limitations to our paper. First, our literature review bases on our developed search string, the selected databases, and the exclusion criteria. Since the selection, despite a scientific approach, always contains subjective decisions, errors cannot be excluded. Second, the research field of carbon emission (risk) management and digitalization is currently undergoing a lot of change. New requirements evolve rapidly and for this, our taxonomy should be updated regularly. And third, our taxonomy is mainly based on academic literature and opinions of experts while a test of real-world applicability is lacking.

Against this background, our results also provide several starting points for future research. First and referring to our limitations, scholars may evaluate our results against their real-world applicability. Moreover, researchers adopt our taxonomy as a basis and develop a taxonomy for IS solutions in carbon management for citizens in combination with personal carbon allowances, which might support the decarbonization of private households. Third, future research should analyze the obstacles to CCRM implementation in practice. At the moment, companies are aware of carbon risks but mostly have not implemented an IS for CCRM. To reduce carbon emissions and the related risks, companies need to implement a CCRM, which should, as aforementioned, be based on IS solutions. Our taxonomy provides a starting point for the development of the CCRM-IS. Analyzing implementation obstacles might help to overcome them, foster the implementation of an IS for CCRM, and support the creation of a more sustainable future.

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