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Review

Measures to reduce corporate GHG emissions: A review-based taxonomy and survey-based cluster analysis of their application and perceived effectiveness

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ABSTRACT

Companies contribute to a large extent to greenhouse gas emission. To mitigate this, measures for reducing these emissions can be applied. There is, however, neither a systematized general overview of existing measures nor an estimation of their application and their effectiveness to reduce greenhouse gas emissions. This study strives to close this gap by reviewing research on the reduction of corporate greenhouse gas emissions and synthesizing emission reduction measures in a taxonomy. Furthermore, the application of these measures and their perceived effectiveness is empirically assessed using a survey among companies that are involved in emission reduction activities. On this basis, a cluster analysis is conducted to identify measure types and to unveil application patterns. 27 different measures and 65 respective implementation examples are identified and structured within nine categories: energy, product, process, technology, 6R and waste management, office and mobility, management, reporting and disclosure, and compensation measures. The empirical analysis shows that there exist measures with a high efficiency to reduce emission, which are rarely applied in companies. On the other side, a large share of applied measures is not perceived as highly effective. Companies can use these results to structure their emission reduction activities and identify best practices.

1. Introduction

Climate change is the result of anthropogenic behavior and increasing greenhouse gas (GHG) emissions which lead to increasing natural catastrophes that threaten biodiversity and future generations (IPCC, 2021). For coping with accompanying challenges, nearly 200 countries have discussed how to uphold the Paris Agreement during the UN Climate Change Conference in 2021. They further acknowledged the immediate need for action within this decade and decided on reducing and eliminating the use of coal power among others (UN, 2021a). Subsequently, stronger pledges by participants are required to reduce global warming to 1.5 °C (UN, 2021b). These political decisions impact the economy: Tackling climate risks now is more cost-effective for companies than managing them when the risks hit (Kemp et al., 2022). Consequently, companies should reduce the risks associated with global warming such as changes in precipitation leading to extreme weather events, e.g., strong hurricanes, floods, or droughts, which can damage manufacturing sites as well as warehouses and distribution facilities. Reducing corporate emissions creates further opportunities for companies, e.g., increased competitivity by adapting to consumer preferences (CDP, 2019). Additionally, by reducing the energy demand in companies and, especially, in production, costs can be cut, efficiency increased, and emissions reduced (Arocena et al., 2021; Giama and Papadopoulos, 2018; Liu et al., 2019).

A vast body of literature has examined management actions and the strategies that companies can apply to reduce their emissions and the economic effects of, for example, a carbon tax (e.g., Axelson et al., 2021; Cadez and Czerny, 2016; Potrich et al., 2019). Furthermore, numerous case studies have analyzed how companies can reduce their GHG emissions under a specific setting (e.g., Biswas, 2014; Javadi et al., 2021; Meng et al., 2017). However, few attempts (e.g., Mistage and Bilotta, 2018; Olatunji et al., 2019) have been made to synthesize different measures that companies can implement to reduce their GHG emissions (Cadez and Czerny, 2016; Penz and Polsa, 2018). No study has been identified which focuses on GHG emission reduction measures (ERM) and implementation examples for a wide range of companies. The

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synthesis of ERM measures is important for research to understand the state-of-the-art methods considering ERM and for practitioners to lower their involvement barriers such as the lack of information (Henriques and Catarino, 2016). Hence, this study strives to answer the following research question:

RQ1: Which measures can companies implement to reduce their GHG emissions?

Companies slowly increase the application of ERM. They however, do not have an overview about the respective effectiveness of the ERM in relation to each other. Hertwich et al. (2019) reviewed the literature on material efficiency strategies to reducing greenhouse gas emissions with a focus on buildings, vehicles, and electronics. A holistic comparison of ERM on the basis of their effectiveness to reduce GHG emissions and the application is missing in the scientific literature. This would allow for developing best practices that are demanded by companies (Giama and Papadopoulos, 2018; Yao et al., 2019) Hence, this study strives to answer:

RQ2: What are the applications and perceived effectiveness of the ERM in companies?

This study contributes to the body of knowledge on corporate sustainability by addressing the research questions in the following ways. Corporate carbon emission reduction measures are identified via a systematic literature review and classified in the form of a taxonomy. This comprehensive classification of ERM is valuable for practice and research because it provides an overview of the existing measures that can be applied by companies to reduce their GHG emissions. Furthermore, we conducted a survey in which we identified the degree of application of these measures in companies as well as the perceived effectiveness of these measures, whereby effectiveness is defined within this study as the perceived impact that a measure has when reducing the corporate carbon footprint (CCF). The analysis of the frequency and effectiveness of the identified measures further reduces the barriers for companies to apply EMR, by proving specific measures. This lowers the costs to obtain information on emission reduction actions in companies (Henriques and Catarino, 2016) and contributes to knowledge sharing between research and practice, which, in turn, can enhance the reduction of carbon emissions of companies (Yao et al., 2019). Based on the survey results we identified four types of measures using a cluster analysis: cluster 1 "common high performer", cluster 2 "simple low performer", cluster 3 "economic medium performer", and cluster 4 "rare high performer". These enable enterprises for quick selection of ERM and provide research with investigation foci, e.g, regarding efficiency gains, or development of further ERM. The paper thus closes a research gap by providing a systematized overview, assessment and clustering of measures to reduce corporate GHG emissions, quantifying their application within companies and their perceived effectiveness.

2. Background

The literature on ERM can be divided into the categories: 1) management actions and strategies, 2) case studies and 3) measure overview. Papers of the first category provide tools and decision frameworks on how to reduce emissions and the economic effects. Cadez and Czerny (2016) developed a climate change mitigation strategy framework for decision makers based on the strategic priority focus with the categories of internal or external carbon reduction and carbon compensation. Furthermore, respective strategies and specific carbon practices are provided. Potrich et al. (2019) conducted a systematic literature review and developed a proactive practices implementation model consisting of four stages and three layers (organizational, operational and communicational) with corresponding recommended actions. Nevertheless, the proposed actions focus primarily on tools and frameworks and are therefore not holistic. Case studies analyze how a specific company can reduce its GHG emissions. Javadi et al. (2021) analyzed how automotive companies can reduce their greenhouse gases and provide practices. Axelson et al. (2021) identify nine types of decarbonization strategies for steelmaking and their emission reduction potential. Xu et al. (2015) present methods to reduce the carbon footprint within the food supply chain from the technical, consumption behavior and environmental policies perspective. Mistage and Bilotta (2018) developed a questionnaire with seven different sections assessing the implementation of ERM to conduct a benefit–opportunity–cost–risk analysis to support decision making on ERM in companies.

In contrary to existing literature, this study provides a more detailed synthetization with concrete implementation examples (and their assessment), which remain applicable for a broad variety of companies.

3. Material and methods

3.1. Methodology of the systematic literature review

3.1.1. Planning and preparation of the review

This systematic literature review (SLR) was conducted following the approaches of Tranfield et al. (2003) and Page et al. (2021). The following three steps were included in the planning and preparation of the SLR: (1) research definition, (2) database selection, and (3) identification of keywords. Step one has been described above and focuses on the two research questions.

For step 2, Web of Science (Clarivate) was selected as the database because it includes numerous highly ranked and international outlets in the research field, such as Elsevier, Springer Nature, and IEEE. The search was carried out in August 2021. To gain both broader and deeper insights on the topic and to gain an understanding of the different carbon reduction measures, the literature search was conducted after the first identification of key literature (e.g., Cadez and Czerny, 2016; Ikkatai et al., 2008; Karwacka et al., 2020; Penz and Polsa, 2018; Weinhofer and Hoffmann, 2010; Xu et al., 2015). The search string was repeatedly tested, and the changes in results were analyzed through a screening of the identified key literature (step 3). The final search string was applied for a title and abstract search for studies starting from 2008 till 2021 with studies being written in English. The search had no further limitations. Therefore, no studies were excluded because of their outlet or publication field. To increase the robustness of the SLR, multiple synonyms for the different parts of the search string were included. The search string combined different terminologies frequently used in the field of corporate ERM due to the application of Boolean operators. The first part included synonyms for corporate followed by emission (second part) and reduction terms (third part). We obtained 1962 results by the following search string:

((TI=((compan* OR firm* OR corporate) AND (greenhouse gas emission* OR carbon emission* OR CDP) AND (reduc* OR mitigation strateg* OR incentiv*))) OR (AB=((compan* OR firm* OR corporate) AND (greenhouse gas emission* OR carbon emission* OR CDP) AND (reduc* OR mitigation strateg* OR incentiv*))))

3.1.2. Data collection strategy

For data collection, the titles and abstracts from the dataset were screened for information on ERM. A labeling scheme from A to D was applied to categorize the identified literature. Studies were labeled "A" when they included ERM. Studies were labeled "B" when they included ERM but were highly specific and unlikely to be applied to a broader range of companies. In this study, the focus was not on a specific industry; therefore, highly specialized ERM were excluded. Kim et al. (2011), for example, investigated how GHG emission reduction could be achieved "by vehicle lightweighting using aluminum and high-strength steel". The label "C" was applied to studies that deal with emission reduction but not with measures on how they could be reduced. When papers were directly identified as not fitting for answering RQ1, they were labeled as "D" without considering the abstract. These were studies with an economic or social focus within their titles, like carbon tax or government policies for emission reduction. However, these contents are beyond the direct influence of companies who are the target group of this study. Additionally, yet-to-be-tested scientific methods including prototypes and new optimization models, such as the algorithms developed by Sathiya et al. (2021) for green SCM, were excluded as well.

3.1.3. Data analysis approach

For data analysis, first, all 197 "A"-labeled studies were extracted. These studies were analyzed for ERM, and 74 "A"-labled studies were included in the SLR. Studies were excluded in this step if they did not include measures anticipated from the abstract but remained on a conceptual level, e.g., Al-Tekreeti et al. (2021) and Huang et al. (2016), or centered around calculations of corporate carbon emissions or financial gains, e.g., Giesekam et al. (2021) and Kumari and Patel (2020). For the development of the taxonomy, ERM from individual studies were collected. Second, all abstracts of the "B"-labeled studies were reread with the acquired knowledge and focus gained from analyzing the A-labeled studies. Subsequently, 16 B-; labeled studies were retrieved, and nine were included after ERM could be identified in the text. Through forward/backward searches, 16 additional studies were retrieved, and 10 were included (Fig. 1). If studies already included categories for ERM, these were collected as well (e.g., Centobelli et al., 2020; Mistage and Bilotta, 2018). This process led to a total of 93 studies, which were included in the SLR. The taxonomy development followed a repetitive approach based on the categorization of the identified measures from the literature such as transportation, management, and SCM (Centobelli et al., 2020). Subsequently, existing taxonomies from the literature were applied to the identified measures and thus synthesized. Measures that were not fitting, e.g., process-specific measures or carbon capture, within the identified categories from the literature were analyzed and categorized according to common denominators. The development process of the taxonomy was conducted iteratively by the authors. Each modified the existing order of the categories and category names successively until a consensus was reached.

3.2. Methodology of the survey

3.2.1. Planning and preparation of the survey

For assessing the identified measures, the developed taxonomy was transferred to an online survey tool (Limesurvey). The survey was available in both German and English. Purposeful sampling was performed, and the survey was only sent to companies that were actively involved in reducing their GHG emissions (e.g., committed to Science-Based Targets (SBTi)). First, demographic data concerning the company (region and size) and the job title of the survey participant were collected. Because the survey was anonymous, the job title was requested as a control field to evaluate the participant's qualification for providing detailed information regarding the companies' carbon reduction measures.

The reduction measures were based on the taxonomy (3.1). The participants were asked if the company had implemented the listed measures, and if so, what their perceived effectiveness of the measures was. Consequently, a few measures were excluded, such as *certification* and *offsetting*, because they do not directly influence the CCF. Thus, a total of 20 measures were included in the survey questions. To assess the effectiveness of the measures, a 5-point Likert scale (high to low) was applied for estimation, because it could not be expected that participants would be familiar with exact numbers. A Likert scale assumes that personal opinions can be measured (McLeod, 2019). However, to ensure a realistic reflection of the impact of the measures, primarily sustainability managers were asked to complete the survey. The question section "ERM in production" only applies to manufacturing companies. To view the questionnaire, please see Appendix – Survey Questions.

Pretests were performed with two academics reviewing the survey design. Furthermore, two practitioners with knowledge regarding the company's sustainability activities focused on the comprehensibility of the questions in their pretests. Thus, the questions were divided into smaller question groups and presented on different questionnaire pages to achieve higher usability. Additionally, the wordings of some questions and measures were rephrased.

3.2.2. Data collection

The survey was administered between November and December 2021. The survey link was sent to companies via email along with a short explanation regarding the study. To identify key-informants, companies were selected based on the following criteria: 1) Their efforts to reduce the CCF had to be publicly known, 2) they calculate their CCF, 3) they set reduction targets for their emissions. These criteria indicate that a company is actively engaged in reducing their CCF. This was validated through listings on the initiatives: *SBTi,* and net zero. Furthermore if companies had been commended for their sustainability efforts on the websites of *Baum e.V.*, *Stiftung Deutscher Nachhaltigkeitspreis* and *Utopia („Bestenliste")* the eligibility was further confirmed via the company

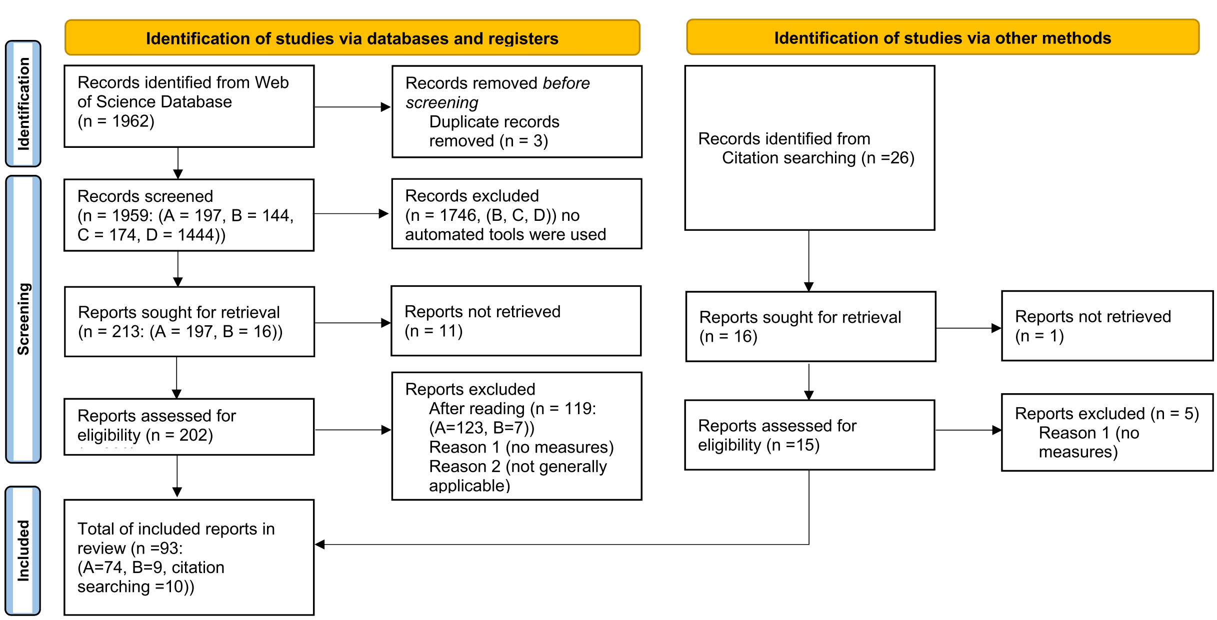

Fig. 1. Hit flow chart following Page et al. (2021).

websites. Contact persons were identified through the company's website. If available, sustainability managers or communication managers were contacted, or if no information was available, the company's email address for general inquiries was used. In this case, recipients were asked to forward the survey to the sustainability department. Additionally, after two weeks, a reminder was sent to the companies to participate in the survey. A total of 400 companies were contacted, with a response rate of approximately 14%. To reach more companies, the environmental organizations *BAUM e.V.* and *WFBB* published the survey link on their website and social media networks.

3.2.3. Data analysis

After closing the survey, all answers were checked for validity and completeness, and the dataset was cleaned. Among the 141 participants, 68 answered the survey completely. Three answers were excluded because they were answered by teachers as public educational institutions are not market-oriented companies and are therefore not the target group of the measures. The remaining 65 answers were used in the analysis. First, the distribution of the demographic data was explored. The survey was answered by a majority of sustainability managers (60%) followed by managers in a technical or communication field of the company (18.5%), CEOs or CCOs (12.3%), and employees (9.2%). The survey included data from companies that conduct their core business within the DACH region or Europe or were internationally active. Out of the 65 companies that answered the questions, 34 were manufacturing companies and 31 were within the services sector.

The data mostly consisted of quantitative responses, were cleaned and preprocessed in Microsoft Excel, and further analyzed using *R*. All quantitative questions were assessed based on their frequency. The effectiveness of the measures was evaluated by a five-point scale. The scale was translated into a weighted average as a calculated effectiveness factor (CEF) to compare the ratings of each measure. A higher CEF indicates a higher effectiveness of a measure, whereas a lower CEF indicates that this measure contributes less to reducing the carbon footprint. An aggregated dataset was created for further analysis which included the measures, the total number of uses, and their CEF. R was used to analyze the distribution of the answers and to cluster the measures. First, we tested if the data followed a normal distribution using the *Shapiro Test*; both the frequency and CEF data had a *p-value* >0.05, indicating that they fulfilled this requirement. Before the clustering

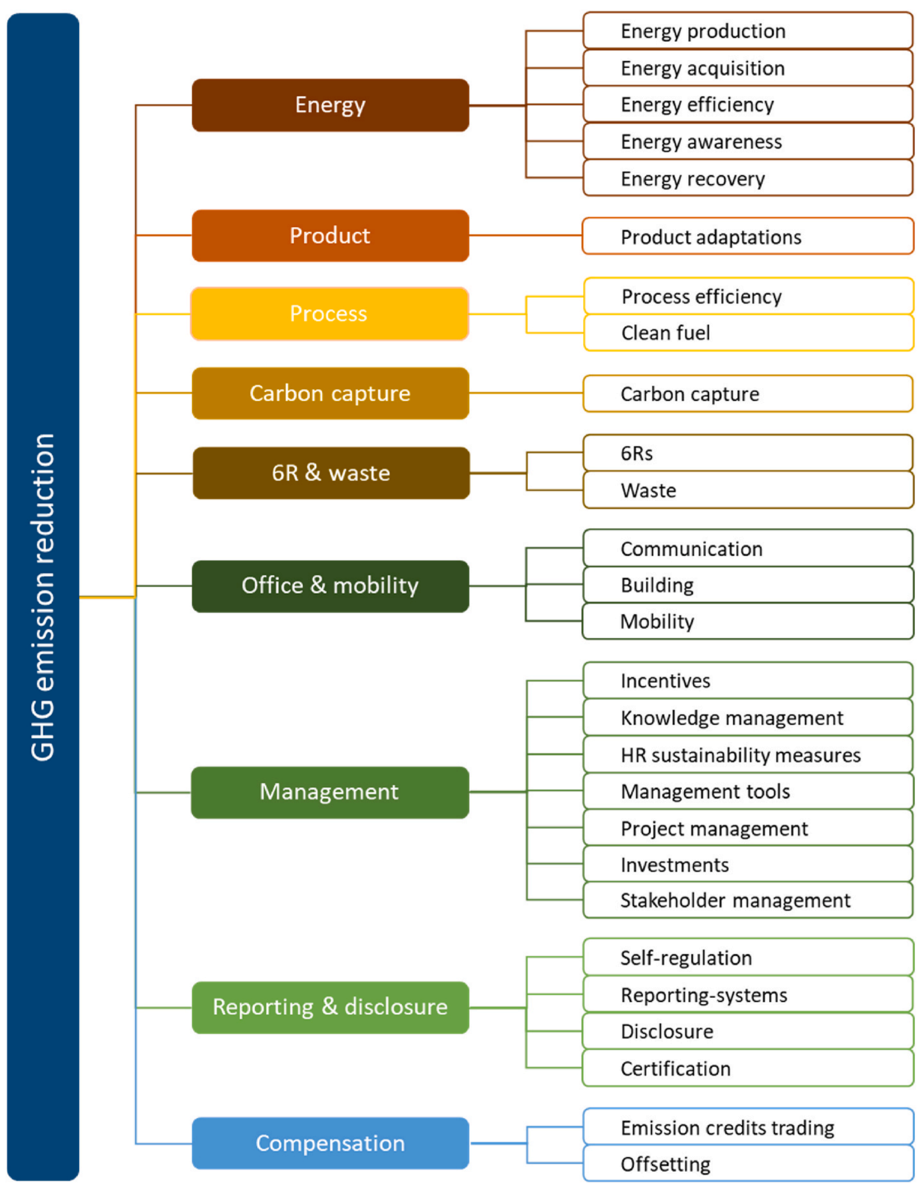

Fig. 2. Categories and measures of the GHG emission reduction taxonomy.

algorithm was applied, the data were standardized using the *scale* function to enable comparison. For clustering, a hierarchical algorithm was applied because the goal was to identify performance clusters based only on the 20 measures and their frequency and effectiveness. A hierarchical approach was more fitting than k-means clustering for this study according to Kaushik and Mathur (2014), because it is more appropriate for small datasets. An agglomerative analysis was performed because the bottom-up approach is more suitable for identifying large clusters and that makes it less sensitive to outliers (supported by the use of Manhattan distance) compared to divisive hierarchical clustering (Boehmke, 2022; Boehmke and Greenwell, 2019). The "cluster" package and algorithm *AGNES* were applied for the analysis. The *ward cluster method* was applied after testing the agglomerative coefficient which revealed that the *ward method* had the highest coefficient with 0.9 and identified the strongest clustering structure. Additionally, the optimal number of clusters was identified using the *elbow method*.

4. Results

4.1. Taxonomy for ERM

Measures that can be used by companies to reduce their GHG emissions were organized within nine different categories: *energy*, *product*, *process*, *carbon capture*, *6R & waste management*, *office & mobility*, *management*, *reporting & disclosure*, and *compensation*. The categories have 27 underlying measures and 65 implementation examples. Fig. 2 provides an overview of the developed taxonomy.

Measures in the *energy* category deal with sustainability along the energy life cycle and how to reduce the overall energy usage (Table 1). The different measures within the energy category were *energy production*, *acquisition*, *efficiency*, *awareness*, and *recovery*. Renewable energy can be produced onsite using a photovoltaic plant, and energy storage can be ensured by installing solar panels on the company building (e.g., Coles et al., 2014; Gonzalez-Garcia et al., 2011). *Energy acquisition* focuses on buying energy from sources that are renewable or have a low carbon footprint, e.g., geothermal energy (e.g., Chen et al., 2011). Installing motion detectors to control lighting or energy-saving light bulbs are two examples of how to implement *energy efficiency* measures. Higher efficiency of existing power plants can be achieved by switching from coal-based to gas-based power plants (e.g., Laing et al., 2019). Teaching employees about energy-saving measures, such as switching computers off overnight, are implementation examples for *energy awareness* measures (e.g., Biro and Csete, 2021). *Energy recovery* measures include recovering waste heat and gases and using them for energy co-production to substitute the main energy sources (Huisingh et al., 2015). Within this category are the most common measures mentioned in the literature, i.e., purchasing renewable energy (energy acquisition) or focusing on energy-efficient equipment and machinery (energy efficiency).

The *product* category focuses on how the footprint of a manufactured good can be reduced. These measures are vital for product development and influence the resources and processes that produce the product (Table 2). One option is to redesign products to reduce the product's carbon footprint. This can be achieved by making modifications to the product or substituting materials with recycled or renewable material (e.g., Cadez and Czerny, 2016; Griessacher and Antrekowitsch, 2012). Cement, for example, can be produced using construction and demolition waste (recycling) or fly ash (renewable resource and waste

Table 1
GHG ERM of the energy category.

Category	Measures	Implementation example	Source
Energy	**Energy production:**Generate renewable energy with PV and use energy storage (onsite)	Installation of solar panels and usage of energy storage on buildings or other onsite renewables (wind, biofuels)	(Coles et al., 2014; Gonzalez-Garcia et al., 2011; Javadi et al., 2021; Kilkis and Kilkis, 2016; Laing et al., 2019; Metta et al., 2020; Steenhof et al., 2012; Tunji-Olayeni et al., 2021)
	Energy acquisition: Use energy from renewable, clean, or low carbon sources	Purchase of renewable energy (e.g., wind, solar, (local) biomass, hydro)	(Amjad et al., 2021; Aroonsrimorakot, 2018; Biro and Csete, 2021; Blanco et al., 2017; Cadez and Czerny, 2016; Chen et al., 2011; Coles et al., 2014; Damert et al., 2017; Das, 2012; Ferreira et al., 2019; Giama and Papadopoulos, 2018; Gonzalez-Garcia et al., 2011; Hoang Duc and Do Ba, 2017; Huisingh et al., 2015; Javadi et al., 2021; Jungbluth et al., 2016; Kilkis and Kilkis, 2016; Kouloukoui et al., 2019; Lee et al., 2018; Lee, 2013; Metta et al., 2020; Misopoulos et al., 2020; Mistage and Bilotta, 2018; Perdue and Stoker, 2013; Steenhof et al., 2012; Weinhofer and Hoffmann, 2010; Wittneben and Kiyar, 2009; Xu et al., 2015)
		Purchase of energy from low carbon or carbon neutral sources (e.g., geothermal, nuclear, fuel cell, power plant-based carbon capture and storage)	(Chen et al., 2011; Ferreira et al., 2019; Hoang Duc and Do Ba, 2017; Huisingh et al., 2015; Kouloukoui et al., 2019; Lee et al., 2018; Metta et al., 2020; Nunes et al., 2015; Weinhofer and Hoffmann, 2010; Wittneben and Kiyar, 2009; Xu et al., 2015)
	Energy efficiency: Increase efficiency of energy production and technology (e.g., equipment)	Increase the efficiency of carbon-based power plants in the fossil fuel sector (e.g., by using gas instead of coal)	(Laing et al., 2019; Weinhofer and Hoffmann, 2010; Xu et al., 2015)
		Co-burning of coal and/or biomass to reduce emissions	Cadez and Czerny (2016)
		Integrated gasification combined cycle (IGCC) using biogas (material for biogas: local agriculture, wood chip, seaweeds and poplars, landfill)	(Broberg Viklund and Lindkvist, 2015; Cadez and Guilding, 2017; Hoang Duc and Do Ba, 2017; Metta et al., 2020; Penz and Polsa, 2018)
		Use of energy-efficient equipment and machinery (e.g., by energy-efficient air conditioning, motion detectors, efficient light adjustments/LEDs/motion sensor, smart metering)	(Aroonsrimorakot, 2018; Biro and Csete, 2021; Britton and Petrovskis, 2021; Chatziaras et al., 2016; Chu and Schroeder, 2010; Coles et al., 2014; Ferreira et al., 2019; Giama and Papadopoulos, 2018; Hoang Duc and Do Ba, 2017; Huisingh et al., 2015; Javadi et al., 2021; Jungbluth et al., 2016; Metta et al., 2020; Navarro et al., 2017; Penz and Polsa, 2018; Perdue and Stoker, 2013; Steenhof et al., 2012; Tantisattayakul et al., 2016; Tunji-Olayeni et al., 2021; Yusuf et al., 2013)
	Energy awareness: Inform employees of energy-saving methods	Create energy awareness, knowledge, and commitment among the employees (e.g., energy-saving tip sheets, lights off, perform regular maintenance on units)	(Aroonsrimorakot, 2018; Biro and Csete, 2021; Chu and Schroeder, 2010; Fernando and Hor, 2017; Giama and Papadopoulos, 2018; Hoang Duc and Do Ba, 2017)
	Energy recovery: Use heat pumps, waste heat recovery, or IGCC	Implementation of energy recovery processes (e.g., waste heat recovery from landfill, recycling of blast furnace gas, IGCC (Integrated gasification combined cycle))	(Ferreira et al., 2019; Gemechu et al., 2013; Huisingh et al., 2015; Lee et al., 2018; Ma et al., 2012; Metta et al., 2020; Penz and Polsa, 2018; Tantisattayakul et al., 2016; Xu et al., 2015)

Table 2
GHG ERM of the product category.

Category	Measures	Implementation example	Source
Product	**Product adaptations:**Redesign product to use renewable/recycled or less carbon-intensive materials	Redesign products or modify them to reduce their carbon footprint (e.g., by increasing the product longevity, or use of lighter weight material)	(Cheah et al., 2013; Damert et al., 2017; Hoang Duc and Do Ba, 2017; Navarro et al., 2017; Noya et al., 2016; Orsini and Marrone, 2019; Zhang et al., 2021)
		Use recycled and/or renewable materials for products (biodegradable materials, e.g., mushrooms instead of leather)	(Cadez and Czerny, 2016; Cheah et al., 2013; Damert et al., 2017; Griessacher and Antrekowitsch, 2012; Hasanbeigi et al., 2012; Huisingh et al., 2015; Noya et al., 2016; Orsini and Marrone, 2019; Shin and Searcy, 2018; Zhang et al., 2021)

Table 3
GHG ERM of the process category.

Category	Measures	Implementation example	Source
Process	**Process efficiency:**Increase efficiency through process redesign, new equipment, or use of byproducts	Redesign the process to achieve better efficiency (reduction of process time e.g., by implementing automation or IoT devices)	(Amjad et al., 2021; Arocena et al., 2021; Britton and Petrovskis, 2021; Huisingh et al., 2015; Penz and Polsa, 2018; Zhang et al., 2021)
		Regularly update the machinery (e.g., replacing lignite-fired boiler with natural-gas-fired boilers)	(Britton and Petrovskis, 2021; Cadez and Czerny, 2016; Cadez and Guilding, 2017; Coles et al., 2014; Javadi et al., 2021; Ma et al., 2012; Tantisattayakul et al., 2016)
		Use, sell, or reduce the footprint of byproducts (e.g., selling of liquid carbon dioxide and calcium bicarbonate, or having oxygen as an output)	(Axelson et al., 2021; Blanco et al., 2017; Huisingh et al., 2015; Nuβholz et al., 2019; Shin and Searcy, 2018; Zhang et al., 2021)
	Clean fuel: Use or development of cleaner fuels	Improve the efficiency of fuel and fuel consumption (e.g., cars with less consumption) or use low carbon fuels (like fuel-cell, biomass/biofuels, (sewage) sludge as fuel, paint waste, industrial plastic, rubber residues, landfill gas, waste oil)	(Agyemang et al., 2016; Böttcher and Müller, 2016; Broberg Viklund and Lindkvist, 2015; Cadez and Czerny, 2016; Centobelli et al., 2020; Chatziaras et al., 2016; Fernandez et al., 2017; Ferreira et al., 2019; Gemechu et al., 2013; Kilkis and Kilkis, 2016; Kouloukoui et al., 2019; Lee, 2013; Metta et al., 2020; Navarro et al., 2017; Penz and Polsa, 2018; Xu et al., 2015)

recycling) as part of its resources (Hasanbeigi et al., 2012; Orsini and Marrone, 2019).

Process-related reductions focus on increasing process efficiency (Table 3). One method to achieve a higher *process efficiency* involves increasing automation and, therefore, re-designing the production processes (e.g., Penz and Polsa, 2018; Zhang et al., 2021). Internet of Things (IoT) devices can be another tool to optimize the existing processes (e.g., Huisingh et al., 2015). In addition, up-to-date machinery, which, for example, needs less energy, creates less waste, or uses a cleaner technology, such as natural-gas-fired-boilers compared to lignite-fired boilers, can increase process efficiency and reduce emissions (e.g., Britton and Petrovskis, 2021). Another method is to reduce the impact of byproducts by recycling or selling them for further use (e.g., Axelson et al., 2021). The use and/or development of *clean fuel* includes the use of biofuels as an alternative to traditional fuels (e.g., Böttcher and Müller, 2016).

The category *carbon capture* differentiates between technology-based and natural carbon capture methods (Table 4) (e.g., Axelson et al., 2021; Holappa, 2020). *Carbon capture* can be applied, for example, in the cement industry, where technology is engineered to capture carbon dioxide and compress it into its liquid form which can be accumulated underground (Hasanbeigi et al., 2012; Orsini and Marrone, 2019).

6R & waste management-related reductions aim to enforce the 6R principles and appropriate waste discharge (Table 5). The 6Rs are reuse, recycle, reduce, recover, redesign, and remanufacture. A strong focus in the literature is on recycling, which includes, for example, recycling of brickwork from deconstructions (Nuβholz et al., 2019). *Waste* management includes adequate waste discharge, e.g., water filtering on the production site, or proper recycling and discharge at the workplace (e.g., Biro and Csete, 2021).

The category *office & mobility* comprises measures that are primarily applicable in office buildings and service sectors (Table 6). The *communication* measures involve the use of less carbon-intensive communication and information carriers such as the reduction of paper use by applying double-sided printing (Blanco et al., 2017). The second *building* measures involve retrofitting and renovations with the goal of using "green products" and reducing energy consumption by using more energy-efficient ventilation or heating systems (e.g., Coles et al., 2014). Green products can be certified colors for painting the office walls or furniture (Aroonsrimorakot, 2018). Lastly, *mobility* measures aim at reducing emissions arising from business travel or commuting by changing the way of travel. One method to reach optimized GHG emissions with the existing company fleet is to change the fleet to less GHG intensive alternatives. The first implementation example is eco-driving practices that reduce fuel consumption (e.g., Centobelli et al., 2020). The second example involves using electric cars instead of combustion engines or (electric) bicycles (e.g., Kilkis and Kilkis, 2016). Especially, the substitution of cars with bicycles is more applicable in cities (Lee et al., 2019).

The *management* category comprises seven measures and includes

Table 4
GHG ERM of the carbon capture category.

Category	Measures	Implementation example	Source
Carbon capture	**Carbon capture:**Technology-based and natural capture of GHG	Carbon capture and storage or sequestration technologies	(Axelson et al., 2021; Cadez and Czerny, 2016; Daggash et al., 2019; Holappa, 2020; Huisingh et al., 2015; Kouloukoui et al., 2019; Lee et al., 2018; Lee, 2013; Metta et al., 2020; Orsini and Marrone, 2019; Shin and Searcy, 2018)
		Residue management strategies (e.g., remove and collect straw from fields to use it for other purposes)	(Chaiyapa et al., 2016; Eranki et al., 2019; Gan et al., 2011; Metta et al., 2020)

Table 5
GHG ERM of the 6 R & waste management category.

Category	Measures	Implementation example	Source
6 R & waste management	**6Rs:** Application of the 6Rs-principle throughout the organization	Reuse, recycle, reduce, recover, redesign, and remanufacture (with a focus on recycling in lit)	(Alkaya and Demirer, 2014; Biswas, 2014; de Faria et al., 2018; Gonzalez-Garcia et al., 2011; Hasanbeigi et al., 2012; Holappa, 2020; Jawahir and Bradley, 2016; Jungbluth et al., 2016; Kong et al., 2016; Kouloukoui et al., 2019; Lee et al., 2018; MacRae et al., 2013; Meng et al., 2017; Misopoulos et al., 2020; Navarro et al., 2017; Nuβholz et al., 2019; Penz and Polsa, 2018; Shin and Searcy, 2018; Tunji-Olayeni et al., 2021; Vieira et al., 2016; Xu et al., 2015; Yusuf et al., 2013; Zhang et al., 2021)
		Install water recycling processes (e.g., greywater in the lavatory)	(Ma et al., 2012; Meng et al., 2017; Xu et al., 2015)
	Waste: Reduction of waste and appropriate discharge	Implement waste reduction policies (e.g., loss prevention)	(Agyemang et al., 2016; Huisingh et al., 2015; Penz and Polsa, 2018; Vieira et al., 2016; Xu et al., 2015; Zhang et al., 2021)
		Adequate waste discharge (e.g., clean used water before it leaves your production line, look for recycle and reuse opportunities, use recycle bins at work)	(Biro and Csete, 2021; Chu and Schroeder, 2010; Huisingh et al., 2015; Lee et al., 2018; Vieira et al., 2016; Xu et al., 2015; Yusuf et al., 2013)

reduction actions that are initialized on a strategic level (Table 7). The first measure involves internal *incentives* for employees to encourage low carbon behaviors. An example is to monetarily reward fewer business travels (e.g., Chu and Schroeder, 2010). The second measure, *knowledge management*, includes workshops and other information-sharing methods for reducing GHG. Third, *HR sustainability measures* aim at incorporating sustainability within the organizational structure. A higher diversification among board members (e.g., having female board members) has been proven to increase a company's sustainability activities (Al-Qahtani and Elgharbawy, 2020; Ben-Amar et al., 2017). *Management tools* such as SWOT-analysis, portfolio management, vulnerability assessment, scenario analysis, Six Sigma, best practices, and risk management can be used to implement reduction measures (e.g., Chaiyapa et al., 2016). The last three measures, *investments, project-, and stakeholder management* focus on adaptations to new technologies and regulations, investments supporting sustainability, and active engagement with policymakers (e.g., Wittneben and Kiyar, 2009). An essential change to *project management* is to involve suppliers from early project stages to include green technologies such as solar panels in construction projects (Albino and Berardi, 2012). Financially, companies can integrate targets for GHG emissions into investment decisions to limit emissions from new projects and invest in sustainable R&D development such as carbon capture (e.g., Kouloukoui et al., 2019). *Stakeholder management* includes engagement with policymakers on responses concerning carbon regulations (e.g., Hoang Duc and Do Ba, 2017).

Reporting- & disclosure-related ERM focus on self-regulation to create an organizational system that can regulate its emissions, achieve reduction goals, and report the process (Table 8). One step toward a self-regulated system is to commit to environmental or specific emission reduction targets. After the targets have been set, a detailed plan on how to reach these goals must be implemented. Initiatives such as SBTi can help companies communicate their ambitions and consolidate the commitment (e.g., Chaiyapa et al., 2016). *Reporting-systems* such as ECO2MAN can help companies track their progress on GHG emission reduction (Amjad et al., 2021; Chatziaras et al., 2016). The *disclosure* measures set requirements on how environmental information should be made available for the public. This can be performed through a company report or via initiatives such as CDP (e.g., Ferreira et al., 2019). *Certification* involves certifying the companies' actions to reduce emissions (e.g., PAS, 2050; GHG protocol) (e.g., Biro and Csete, 2021).

The final category, *compensation*, realizes indirect emission reductions by having companies pay a monetary price for GHG emissions (Table 9). The first measure is *emission credits trading*. In the European Union, companies require EUA (EU-Allowances), which limit the amount of GHG emissions of a company. These allowances can be traded according to a company's needs (buy more or sell allowances) (e.g., Damert et al., 2017). Furthermore, a company can offset its emissions by supporting projects that reduce emission outputs. *Offsetting* projects are for example reforestation projects or building less carbon-intensive power plants and are not limited to regional borders (Xu et al., 2015).

Table 6
GHG ERM of the office & mobility category.

Category	Measures	Implementation example	Source
Office & mobility	**Communication:** Usage of less carbon-intensive communication	Reduce paper usage (e.g., double-sided and reduced printing)	Blanco et al. (2017)
		Send emails instead of fax	(Fernandez et al., 2017; Giama and Papadopoulos, 2018)
		Conduct online meetings and conferences to reduce business travel	(Blanco et al., 2017; Chu and Schroeder, 2010; Penz and Polsa, 2018; Roby, 2014; Tunji-Olayeni et al., 2021)
	Building: Improve Buildings through modernization and more efficient heating	Create more effective building insulation (walls, windows, roofs)	(Coles et al., 2014; Metta et al., 2020; Penz and Polsa, 2018; Perdue and Stoker, 2013)
		Retrofit and renovate with "green products" (e.g., efficient, and low energy consumption heating and ventilation system)	(Aroonsrimorakot, 2018; Coles et al., 2014; Metta et al., 2020; Penz and Polsa, 2018; Perdue and Stoker, 2013; Vogl et al., 2021)
		Installation and usage of heat pumps	Ferreira et al. (2019)
	Mobility: Change to less carbon-intensive travel modes	Reduce business travel (overall and distances, especially flights)	(Blanco et al., 2017; Centobelli et al., 2020; Davis and Sonesson, 2008; MacRae et al., 2013; Penz and Polsa, 2018; Roby, 2014)
		Change the mode of transportation (e.g., taking the train instead of a plane or car)	(Blanco et al., 2017; Roby, 2014)
		Use hybrid or electric cars and/or bicycles if applicable	(Kilkis and Kilkis, 2016; Lee et al., 2019; Metta et al., 2020; Saenz et al., 2016)
		Foster eco-driving and car-sharing to reduce fuel consumption	(Centobelli et al., 2020; Davis and Sonesson, 2008; Tunji-Olayeni et al., 2021)

Table 7
GHG ERM of the management category.

Category	Measures	Implementation example	Source
Management	**Incentives:** Incentives to foster low carbon behavior	Create incentives (e.g., monetary rewards) for low carbon behavior	(Chu and Schroeder, 2010; Damert et al., 2017; Fernandez et al., 2017; Perdue and Stoker, 2013)
	Knowledge management: Conduct workshops and information sharing	Information sharing of mitigation activities, raise awareness for internal and external stakeholders	(Casarejos et al., 2016; Damert et al., 2017; Fernandez et al., 2017; Hoang Duc and Do Ba, 2017; Jungbluth et al., 2016; Kouloukoui et al., 2019; Lee, 2013; Olatunji et al., 2019; Penz and Polsa, 2018; Perdue and Stoker, 2013; Wittneben and Kiyar, 2009)
		Involve employees in sustainability by conducting workshops and training for low carbon behaviors and actions	(Centobelli et al., 2020; Hoang Duc and Do Ba, 2017; Javadi et al., 2021; Perdue and Stoker, 2013)
	HR sustainability measures: Incorporation of sustainability within the organizational structure	Generation of green jobs (by hiring an environmental/sustainability manager)	(Coles et al., 2014; Damert et al., 2017; Fernandez et al., 2017)
		Create a corporate social responsibility (CSR) committee to lead your environmental changes	(Casarejos et al., 2016; Damert et al., 2017)
		Have diversification among your board members	(Al-Qahtani and Elgharbawy, 2020; Ben-Amar et al., 2017)
	Management tools: Use quality control tools, best practices, and scenario analysis and risk management to apply the reduction measures	Conduct a SWOT-analysis (risk management, recognize new markets through climate change effects)	(Biro and Csete, 2021; Casarejos et al., 2016; Wittneben and Kiyar, 2009)
		Create green portfolio management (decrease the share of products with a relatively high environmental impact in a company's product portfolio)	(Casarejos et al., 2016; Damert et al., 2017)
		Vulnerability assessment (systematic review of security weaknesses)	Biro and Csete (2021)
		Use scenario developments to identify carbon hotspots and the highest reduction impacts	Bessou et al. (2014)
		Identify industrial symbiosis options (e.g., can your waste be used for a biogas plant nearby?)	Axelson et al. (2021)
		Implement Six Sigma	Blanco et al. (2017)
		Collect and apply best-practice examples and benchmark yourself against competitors	(Casarejos et al., 2016; Chaiyapa et al., 2016; Laing et al., 2019; Wittneben and Kiyar, 2009)
	Project management: Adaption of project management to new regulations and technologies	Adapt project organization to new technologies and regulations (e.g., guarantees from suppliers for functionality for innovative technologies, including suppliers earlier in the planning phase for, e.g., solar panels or new water filtration systems)	Albino and Berardi (2012)
	Investments: Place investment decisions that support sustainability	Integrate targets for emissions into investment decisions for new projects	(Ferreira et al., 2019; Hoang Duc and Do Ba, 2017; Kouloukoui et al., 2019)
		Invest in R&D for sustainability (develop sustainable technologies and products)	(Kouloukoui et al., 2019; Wittneben and Kiyar, 2009)
	Stakeholder management: Engage with policymakers	Engage with policymakers on possible responses to climate change including taxation, regulation, and carbon trading	(Casarejos et al., 2016; Hoang Duc and Do Ba, 2017; Wittneben and Kiyar, 2009)
		Public-private partnerships (PPPs) for energy-efficient investments	(Casarejos et al., 2016; Liu et al., 2019)

4.2. Application and effectiveness of ERM in companies

All measures addressed in the survey are implemented in companies, with an application frequency range between 17.7% and 91.2% and a CEF between 2.3 and 3.9 (Table 12). The five most applied measures by companies are shown in Table 10. Regularly increasing *process efficiency* through process redesign or new equipment has been applied by 91.2% of the manufacturing companies. Second, *energy efficiency* measures such as energy-efficient equipment and machinery are used by 86.2% of the participants. Energy-efficient machinery involves machines with low energy consumption compared to up-to-date standards. Policies to support less carbon-intensive *communication* measures like less printing and online conferences instead of personal meetings are applied by 86.2% companies. Furthermore, 84.6% of the companies apply *HR sustainability measures* such as a sustainability manager (e.g., Fernandez et al., 2017). Additionally, 79.7% of the companies have *self-regulation* measures; for example, they set emission reduction targets and/or measure their results, and/or communicate climate actions. Specifically, this includes joining an initiative such as SBTi, calculation of GHG emissions (e.g., GHG Protocol), and having a corporate social responsibility committee. Hardly applied measures include *carbon capture*, *energy recovery*, *incentives,* and *clean fuel* with an application rate of below 40%.

Considering the effectiveness of the applied measures, the order differs from the applied frequency of the measures. The highest-ranking measure is *energy acquisition*, which includes primary energy consumption from renewable, clean, or low carbon sources with a CEF of 3.9 (see Table 11). This measure is followed by implementing *carbon capture* measures, with a CEF of 3.8. *Self-regulation* is the only measure that ranks within the top five measures in both frequency and effectiveness. Consequently, it is considered a core activity to measure, track, and communicate the GHG emission reduction targets. Ranked fourth is the use and/or development of *clean fuel*. Finally, *energy recovery* measures such as the implementation of heat pumps, IGCC, and waste heat recovery were ranked among the five most effective measures. In contrast to the described high-ranking energy measures, the lowest-ranked measure with a CEF close to 2 is *energy awareness* (2.3).

The measures are clustered according to their frequency and effectiveness in Fig. 3. The axis numbers are based on a dimensional calculation used to reduce the number of variables in cluster analysis. The ERM are grouped into four different clusters. Cluster 1 contains frequently used and effective measures (3.5<factor>3.9; 73.6% <frequency>80%); cluster 2 includes less used measures with a low-to-moderate effect (2.3 factor>2.8; 49.2%<frequency>66.2%); cluster 3 includes frequently used measures with a moderate effect (2.8<factor>3.3; 60% <frequency>91.2%); and cluster 4 includes effective, but rarely used measures (3.2<factor>3.8; 17.7% <frequency>46.2%).

Table 8
Reporting & disclosure category.

Category	Measures	Implementation example	Source
Reporting & disclosure	**Self-regulation:** Join sustainable organizations, set targets, measure results, and communicate them	Join international climate change institutions to manifest your commitment	Hoang Duc and Do Ba (2017)
		Participate in climate change business groups for information exchange	(Hoang Duc and Do Ba, 2017; Orsato et al., 2015)
		Commit to environmental management & emission reduction targets and make a detailed plan	(Casarejos et al., 2016; Chaiyapa et al., 2016; Coles et al., 2014; Cordova et al., 2018; Ferreira et al., 2019; Hoang Duc and Do Ba, 2017; Javadi et al., 2021; Olatunji et al., 2019)
		Integrate climate change considerations into core decision-making, investment decisions, and corporate strategy	(Casarejos et al., 2016; Chu and Schroeder, 2010)
		Measure your emissions precisely (e.g., according to GHG protocol scope 1–3) and communicate the results	(Casarejos et al., 2016; Centobelli et al., 2020; Giama and Papadopoulos, 2018; Hoang Duc and Do Ba, 2017; Lee et al., 2018)
	Reporting-systems: Use software to improve overall efficiency	Apply smart energy monitoring or use an energy management system	(Amjad et al., 2021; Lee et al., 2018)
		Use a process control system (e.g., total productive maintenance (TPM))	(Amjad et al., 2021; Chatziaras et al., 2016)
		Use an environmental management system (EMS) such as a GHG management system (e.g., ECO2MAN) or Water–Energy–Food Nexus (WEFN)	(Casarejos et al., 2016; Centobelli et al., 2020; Chaiyapa et al., 2016; Giama and Papadopoulos, 2018; Laing et al., 2019; Lee et al., 2018; Mistage and Bilotta, 2018; Olatunji et al., 2019; Xu et al., 2015)
		Computational fluid dynamics (CFD) for simulation purposes to optimize processes and production	Xu et al. (2015)
	Disclosure: CDP, CSR, sustainability report, GRI, etc.	Disclose your sustainability activities officially in a sustainability report, CDP, greenhouse gas emissions protocol, Global Reporting Initiative (GRI), Carbon Reduction Commitment, CSR - report, energy audit	(Casarejos et al., 2016; Cordova et al., 2018; Ferreira et al., 2019; Nuβholz et al., 2019; Quintás et al., 2018; Roby, 2014)
	Certification: Implementation and improvement of certificates and standards (e.g., ISO, EMAS)	Follow standards that help reduce emissions such as ISO 14001, 15001, 14040–14044, 14064–65, LEED, BREEAM, EMAS, PAS 2050, NATURA 2000, and other Ecolabels	(Biro and Csete, 2021; Britton and Petrovskis, 2021; Centobelli et al., 2020; Ferreira et al., 2019; Giama and Papadopoulos, 2018; Liu et al., 2019)
		Coordinate your sustainability activities, programs, and certificates to achieve a high impact	(Casarejos et al., 2016; Centobelli et al., 2020)

Cluster 1 includes the measures *energy acquisition*, *self-regulation,* and *HR sustainability measures* identified in the taxonomy. Therefore, buying energy from renewable or low carbon sources is considered to have the highest emission reduction contribution in companies. Furthermore, *self-regulation*, which includes setting emission reduction targets, has also been rated to be highly effective. Lastly, *HR sustainability measures* such as having a sustainability manager are also within this cluster even though the CEF is slightly lower (3.5) than those of the other two. These three measures have a broad distance to *carbon capture* and *clean fuels*, which are other measures with a high CEF. Further, even though they are widely applied like other measures, e.g., *process efficiency*, their higher CEF sets them apart.

Cluster 2 has nearly reverse characteristics to those of cluster 1. This indicates that the high frequency and effectiveness of the measures in cluster 1 is now changed to the medium application rate and the lowest CEF scores in cluster 2 among the analyzed measures. The measures include *energy production, energy awareness*, and *knowledge management*. These are applied by half and up to two-thirds of the participants. The CEF values of these measures are the lowest-ranked and below "moderate" (CEF of 2.8) with a tendency toward a "low effect" (CEF of 2.3).

The third cluster includes measures that are widely applied and moderately effective, considering the CEF score range of between 2.8 and 3.3. Thus, *product adaptations* and *process efficiency* are the most effective measures in this cluster. *Product adaptation* measures are applied less often (64.7%) than *process efficiency* measures, which have overall the highest application rate (91.2%). Further measures within this cluster are *management tools*, *communication*, *energy efficiency*, 6Rs, and *waste*. The lowest-ranking measures of cluster 3 are the 6Rs in terms of the frequency (60%) and waste due to the low CEF (2.8). The measure *energy production* from cluster 2 has the same CEF as *waste*; however, due to their high application differences, they are in separate clusters.

The last cluster (4) contains all measures with an application frequency of below 48%. The CEF values of these measures are all above three, indicating overall high effectiveness. *Carbon capture* is an outlier that is included in cluster 4 with the lowest application rate (17.7%) and second-highest effectiveness rating (3.8). The cluster borders without *carbon capture* would be *energy recovery* with a frequency of 33.6% and

Table 9
GHG ERM of the compensation category.

Category	Measures	Implementation example	Source
Compensation	**Emission credits trading:** EUAs or other allowances & Kyoto mechanisms	Involvement in EUA trading or other allowances	(Cadez and Czerny, 2016; Damert et al., 2017; Hoang Duc and Do Ba, 2017; Tunji-Olayeni et al., 2021; Yousuf et al., 2014)
		Use Kyoto mechanisms: (Clean Development Mechanism (CDM); Joint Implementation (JI))	(Damert et al., 2017; Hoang Duc and Do Ba, 2017; Weinhofer and Hoffmann, 2010)
	Offsetting: Improve existing standards, reduce your emissions first	Improve offsetting standards (offsetting should only be used if the emissions cannot be reduced) (CDM, GS, VCS, 2007, VERC, VOS, CCX, CCBS, Plan Vivo System, ISO 14064–2, and GHG Protocol for Project Accounting)	(Richards and Huebner, 2012; Xu et al., 2015)
		Establish partnerships with sustainable NGOs to support sustainable projects	Laing et al. (2019)

Table 10
Top five frequently applied measures.

Rank	Category	Measures	Frequency
1	Process	**Process efficiency:** Increase efficiency through process redesign, new equipment, or use of byproducts	91.2%
2	Energy	**Energy efficiency**: Increase energy efficiency of energy production and technology (e.g., equipment)	86.2%
3	Office & Mobility	**Communication:** Usage of less carbon-intensive communication	86.2%
4	Management	**HR sustainability measures:** Incorporation of sustainability within the organizational structure	80.0%
5	Reporting & disclosure	**Self-regulation:** Join sustainable organizations, set targets, measure your results, and communicate them	78.5%

Table 11
Top five ranked effective measures.

Rank	Category	Measures:	CEF
1	Energy	**Energy acquisition:** Use energy from renewable, clean, or low carbon sources	3.9
2	Carbon capture	**Carbon capture:** Technology-based and natural capturing of GHG gases	3.8
3	Reporting & disclosure	**Self-regulation:** Join sustainable organizations, set targets, measure your results, and communicate them	3.8
4	Process	**Clean fuel:** Use or development of cleaner fuels	3.7
5	Energy	**Energy recovery:** Use of heat pumps, waste heat recovery, or IGCC	3.5

Table 12
Overview of the evaluation of the measures from the survey.

Cluster	Category	Measures	Frequency	CEF
1	Energy	**Energy acquisition:** Use energy from renewable, clean, or low carbon sources	73.9%	3.9
1	Reporting & disclosure	**Self-regulation:** Join sustainable organizations, set targets, measure your results, and communicate them	78.5%	3.8
1	Management	**HR sustainability measures:** Incorporation of sustainability within the organizational structure	80.0%	3.5
4	Carbon Capture	**Carbon capture:** Technology-based and natural capturing of GHG gases	17.7%	3.8
4	Process	**Clean fuel:** Use or development of cleaner fuels	38.2%	3.7
4	Energy	**Energy recovery:** Use of heat pumps, waste heat recovery, or IGCC	33.9%	3.5
4	Reporting & disclosure	**Reporting-systems:** Use software to improve overall efficiency	44.6%	3.3
4	Office & Mobility	**Building:** Improve Buildings through modernization and more efficient heating	46.2%	3.3
4	Management	**Incentives:** Incentives to foster low carbon behavior	35.4%	3.2
3	Product	**Product adaptations:** Redesign product to use renewable/recycled or less carbon-intensive materials	64.7%	3.3
3	Process	**Process efficiency:** Increase efficiency through process redesign, new equipment, or use of byproducts	91.2%	3.3
3	Energy	**Energy efficiency**: Increase energy efficiency of energy production and technology (e.g., equipment)	86.2%	3.1
3	Management	**Management tools:** Use quality control tools, best practices, and scenario analysis and risk management to apply the reduction measures	72.3%	3.1
3	Office & Mobility	**Communication:** Usage of less carbon-intensive communication	86.2%	3.0
3	Office & Mobility	**Mobility:** Change to less carbon-intensive travel modes	76.9%	2.9
3	6Rs & waste management	**6R:** Application of 6Rs-principle throughout the whole organization	60.0%	3.0
3	6Rs & waste management	**Waste:** Reduction of waste and appropriate discharge	73.9%	2.8
2	Energy	**Energy production:** Generate renewable energy with PV and use energy storage (onsite)	49.2%	2.8
2	Management	**Knowledge management:** Conduct workshops and information sharing	64.6%	2.6
2	Energy	**Energy awareness:** Inform employees of energy-saving methods	66.2%	2.3

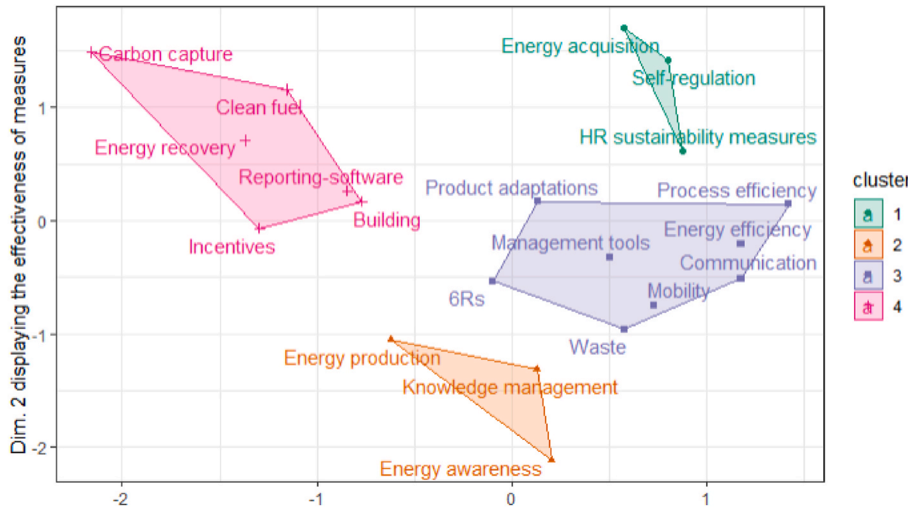

Fig. 3. Cluster-plot of GHG ERM

clean fuel with a CEF of 3.7. The other measures are *reporting-software, building,* and *incentives*. Here, *incentives* are the lowest-ranking measure because if their CEF ranking of 3.2. *Reporting-software* and *building* are the most applied ERM in cluster 4. Similar to cluster 1, this cluster has easily detectable differentiation characteristics compared to the other clusters, namely the frequency (cluster 4 $<$ 48%) and effectiveness (cluster 1 $\geq$ 3.5).

The results described above from the survey regarding the frequency, CEF, and clusters are shown in Table 12.

5. Discussion

This study aimed to identify measures that can be implemented by companies to reduce their GHG emissions and further assess the application frequency among companies and the perceived effectiveness of the measures. The results enable a deeper understanding of the possibilities companies have to reduce their GHG emissions and apply to all industries and enterprise sizes. RQ1 was answered by developing a taxonomy to adequately represent the identified measures and make them accessible through categorization for companies and the scientific community. RQ2 was answered by conducting a survey and cluster analysis to provide recommendations for companies and by stating which measures should be implemented preferentially by companies to achieve emission reductions.

When the findings from the literature are compared with the results of the survey, commonalities can be observed in terms of the frequency with which certain measures are mentioned. The *energy efficiency* measures were ranked second in the survey in terms of frequency and are frequently mentioned in the literature as well. This can be explained by the versatile potential offered by *energy efficiency*. Findings in the literature show that with the implementation of *energy efficiency* measures, companies can improve their process efficiency, reduce costs, and cut emissions (Arocena et al., 2021; Liu et al., 2019; Olatunji et al., 2019). The *self-regulation* and *HR sustainability* measures are more popular in practice as the survey results show than compared to the mentions in the literature. Even though, e.g., Ben-Amar et al. (2017) proved the effectiveness of a higher board-diversity on the emission reduction efforts of the company, the board-diversity in companies is still low. The measures *office & mobility* with a focus on mobility measures are unlikely to be the highest emission reduction contributors in manufacturing companies (Misopoulos et al., 2020). However, for companies in the service sector, such as consultancies, *office & mobility* measures have a high influence on their carbon footprint (Roby, 2014). This explains their high rating in the survey because the number of companies in the manufacturing and service sector was nearly equal. Furthermore, the low implementation rate of *carbon capture* in the survey is consistent with previous literature stating that high investment costs and process changes are required for the application (Cadez and Czerny, 2016) along with a high mitigation potential (Yao et al., 2018). Additionally, *energy acquisition* has been ranked as the most effective measure. This is reflected by the literature where *energy acquisition* was mentioned frequently, and the effect has been proven multiple times (e.g., Arocena et al., 2021).

The clusters can be ordered after the corresponding types: cluster 1 “common high performer”; cluster 2 “simple low performer”; cluster 3 “economic medium performer”; and cluster 4 “rare high performer”. Accordingly, companies should focus on measures from clusters 1, 4, and 3. Here, measures from cluster 1 have a higher demand in companies corresponding to a high application rate, as Fernandez et al. (2017) concluded for the HR sustainability measure that there is a “significant green job generation”. Additionally, the high effectiveness from, e.g., *energy acquisition*, has been described above.

Measures from cluster 2 will not make significant contributions to lowering the CCF. Nevertheless, the measures are commonly applied (above 49%) despite their low effectiveness. Especially, *energy awareness* and *information sharing* are easy to implement and have low implementation costs. This supports the findings of Cadez and Czerny (2016) that practices applied by companies are the ones with low barriers in terms of investment and change.

By analyzing the measures in cluster 3—*process efficiency, energy efficiency, waste, communication,* and *mobility*—a shared underlying implementation motivation of a high cost-saving potential can be identified. The implementation of *process* and *energy efficiency* and *waste* measures is often motivated by cost-saving potentials in companies (e.g., Amjad et al., 2021; Fernando and Hor, 2017; Olatunji et al., 2019), whereas Roby (2014) show that conducting an online meeting instead of traveling to meet in person saves traveling costs and time. This reduces the risk of having to work over hours for employees. Furthermore, online meetings are considered to be more productive than visits by, for example, converting a two-day travel visit into a couple of hours of online meeting time. Consequently, a lower footprint is not always the main goal when implementing these measures, but it can be a side effect and further explains why numerous frequently used measures are not the most effective ones. Nevertheless Blanco et al. (2017) argue that the potential of waste prevention is often overlooked by managers and consequently the measure is less applied. Even though the study findings do not directly support this claim, the effectiveness of the measures are dependent on the individual execution of the company and may leave room for improvement and higher reduction potentials then previously depleted by the company.

Companies implementing the measures from cluster 4 are likely to accomplish higher GHG emission reductions than those implementing measured from clusters 2 and 3. As stated earlier, *carbon capture* is expensive and complicated to implement. C*lean fuel* requires careful implementation that the preservation of energy efficiency and product quality is assured, when for example, the use of waste derived fuels from sewage sludge is considered. Consequently, as described by Chatziaras et al. (2016), the implementation barrier of *clean fuel* is higher than that for *energy efficiency* for example. These findings are further represented in the study of Perdue and Stoker (2013) who focused on the *building* measures and, by implementing retrofitting, realized high cost-saving potentials. Nevertheless, retrofitting may require fundamental changes and high capital investments. These findings explain the high CEF rankings of cluster 4 and lower application rate due to higher implementation barriers compared to other clusters.

A large share of effective measures (cluster 4) are not very frequently applied. In turn, low (cluster 2) and medium (cluster 3) effective measures to reduce emissions are much more applied than they should be, according to their effectiveness. This suggests (partly) inefficient financial investments in emission reduction activities, when we assume rational decision making and points out the necessity for an effectiveness driven perspective of ERM implementation in companies.

6. Conclusions

This study offers a comprehensive overview of the existing literature on ERM and implementation examples. To achieve a transparent overview, a review-based taxonomy was developed, which enables companies to gain knowledge of the possible actions they can take. The elaborate body of knowledge overcomes the lack of information companies experience when getting involved with ERM and proposes a basis for further research in this area. Using the nine categories (energy, product, process, carbon capture, 6 R & waste management, office & mobility, management, reporting & disclosure, and compensation), 27 measures, and their respective implementation examples (65), the developed taxonomy shows what types of different ERM can be undertaken independently from the corporate mitigation strategy.

In addition, the results of the survey reveal that the measures companies implement to reduce GHG emissions individually often do not have a high impact. The measures were clustered according to their frequency of use and the perceived effectiveness by the companies. These four different performing clusters were identified as cluster 1 “common high performer”, cluster 2 “simple low performer”, cluster 3 “economic medium performer”, and cluster 4 “rare high performer”. Cluster 1 includes *energy acquisition* measures, e.g., switching to renewable energy sources, and self-regulation measures, such as the setting of emission reduction targets. As the “common high performer” cluster, these measures should be considered first by companies that are about to be involved with corporate emission reduction. Cluster 2 will most likely not have a visible effect on a company’s emissions. Consequently, measures such as creating *energy awareness* should not be focused on in the beginning. The measures from clusters 3 and 4 should both be considered for their application possibilities in companies. In particular, manufacturing firms should evaluate the implementation of *carbon capture* and the use of *clean fuel*. Cluster 3 has further measures such as increasing *energy efficiency* that can cut costs. A company implementing ERM should be concentrating on the reduction output and not solely on implementing different measures without considering their GHG emission saving potential.

Contrary to other studies, this research considers some practices for GHG emission reduction as unfitting for mitigating climate change and reaching net-zero emissions (IPCC, 2021). Hoang Duc and Do Ba (2017) included within their reduction measures that companies could outsource their emissions. However, this does little to solve the overall problem of GHG emissions. Of course, this may reduce the footprint of one company, but only at the cost of another. Both options of outsourcing highly emitting parts of the company or transferring emitting parts of the company to other countries with fewer environmental restrictions will effectively do more harm like wasting time to act than limiting global warming. Therefore, these measures were not included. Additionally, offsetting is carefully viewed considering its drawbacks. For companies, offsetting offers an easy way to pay for their emissions. Based on the country, the price can be highly attractive and a monetary incentive to pay for the emissions rather than to reduce them (Spiekermann, 2014; Wittman and Caron, 2009). However, the offsetting standards are contradictory and often not rigorous, leaving significant room for interpretations and, consequently, improvements (Richards and Huebner, 2012). Furthermore, the offsetting projects do not have solely positive effects on the environment. In contrast, they can damage the local biodiversity and have negative socioeconomic impacts, e.g., project developers are not required to involve local communities (Wilson, 2011; Wittman and Caron, 2009).

This study forms a basis for actions that companies can take to reduce their GHG emissions. The organized measures further lower the bar of being engaged with the topic and can mitigate the barrier of lacking information on ERM (Henriques and Catarino, 2016; Böttcher and Müller, 2016). Cluster analysis offers a structured approach with underlying comprehensive information from the taxonomy, showing which measures companies should start implementing and are likely to have a high impact on reducing their emissions. By mainly focusing on the results of emission reductions and not as much on the strategy, companies can avoid a long planning phase without results. Cluster analysis offers further guidance on which measures to start with and which ones should be attempted later or are not worth implementing at all. Best practices have been identified previously (e.g., by Kilkis and Kilkis (2016)) as an important tool for companies to lower their emissions. Cluster analysis offers guidance based on other companies’ experiences and can therefore be seen as a best-practice guide. Because the application is not industry-specific, companies can look for their best-fit among the performance of measures and apply them accordingly. Companies should be focusing on implementing measures that have a higher effect (clusters 1,4).

Even though the reasons for a company disclosing GHG emissions may differ and are most likely not purely of environmental concern as an analysis of the CDP survey showed, they yield economical potential to save emissions and costs (Blanco et al., 2017; Cadez and Guilding, 2017). Secinaro et al. (2020) confirmed in their study that “the firm-wide adoption of environmental practices reduces environmental risks, and thereby lowers production costs and increases profits”. This is further underlined by the main impact factor which influence the successful implementation of measures being management support and a strong business case (Blanco et al., 2017). Therefore the main reason a company invests in a climate project is the projects profitability (Kouloukoui et al., 2019). However, since environmental risk-reduction reduces costs and lower emissions reduce environmental risks, it is argued that additional to the project’s profitability the potential of emission savings should be considered. Therefore, CO_2 emissions per dollar of estimated return on investment should be a KPI for the management to focus on measures with a strong business case and emission reduction.

The results should be viewed in light of their limitations. First, no specific industry was focused on. Even though the generic perspective might be an advantage, there is also a flip side. The taxonomy would probably differ if developed for specific industries. Each industry has different pain points and emerging technologies, which can in this respective setting, reduce emissions. The peculiarities are not considered here and offer room for further research. Second, the SLR has been limited to studies available in English on the Web of Science database. Content from further outlets may enrich the taxonomy. Finally, effective emission reduction highly relies on the company’s structure. Subsequently, a measure guide is a good starting point, but it cannot replace the individual calculation and analysis of a company’s emissions. The results of the survey are reflected by other literature findings, which highlights their reliability. Furthermore, the survey had a limited number of participants. This was mitigated by the application of selective sampling, where only companies engaged in ERM were targeted. Future work may include generating a higher sampling size that allows the results to be merged with the taxonomy, providing companies with a complete list of measures and their respective effectiveness.

Carbon capture must be made available for companies along with more efficient fuel and energy recovery methods. Hence, future research needs to focus on these topics to achieve better commercialization for highly effective GHG ERM. Furthermore, ERM measures that are applied by companies but were not identified in the literature are missing. These measures, e.g., sustainability constitution, need to be further researched to assess their impact and effect on the organization. The respective contribution of these measures must be determined to reduce the CCF. If they have a low implementation barrier and great potential to reduce emissions, they will be useful to other companies as well. Additionally, better offsetting regulations need to be developed to create more environmentally and socially beneficial offsetting projects.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Survey Questions

Demographic questions					
1.1 In which region is your company mainly active?					
Drop down (Australia, Asia, Africa, America, Europe, Germany Worldwide, DACH)					
1.2 How many employees does your company have?					
Less than 50 employees	51 to 100 employees	101 to 250 employees	251 to 500 employees	501 to 1000 employees	More than 1000 employees
1.3 Please name your job title.					
Open question					

Please indicate in the first column whether your company uses the proposed measures. In the second column, please estimate the effectiveness of each measure within your company. The effectiveness of a measures is its contribution to the total amount of emissions which have been reduced. (A company can reduce its carbon footprint by 30%. The highest contribution to these savings has been through changing to a solar energy provider - which contributed to 25% of the realized 30% in reduction. Therefore, this measure had a "very high" contribution).

If you do not use a measure please indicate "no" in the first column and "no specification" in the second column.

If you do not use a measure, please indicate "no" in the first column and "no specification" in the second column.

Which measures or actions has your company in place to reduce its emissions (carbon footprint)?									
	Application of measures			Contribution to emission reduction					
	yes	un-cer-tain	no	very high	high	mo-de-rate	low	very low	no speci-fica-tion
Primary energy consumption from renewable, clean, or low carbon sources									
Installments of solar panels or energy storage									
Use of energy-efficiency equipment (e.g., efficient lights, machinery)									
Measures to raise energy awareness, knowledge & commitment (e.g., energy-saving tip sheets)									
Use of heat pumps, waste heat recovery, or IGCC (Integrated gasification combined cycle)									
Fulfillment of latest requirements for properties in terms of insulation, energy, and heating (Your buildings do not require modernization)									
Application of 6Rs-principle throughout the whole organization (reuse, recycle, reduce, redesign, recover, remanufacture)									
A waste management and reduction system that is regularly adapted and optimized to new findings									
Policies to support less carbon-intensive travel behavior (less traveling, electric cars, bicycles)									
Policies to support less carbon-intensive communication like online conferences instead of a personal meeting that involves traveling or reduction of paper use									
Incorporation of sustainability within the organizational structure (e.g,. CSR committee, sustainability manager)									
Use of quality control tools, best practices, and scenario analysis or risk management									
Incentives to support a low-carbon behavior within the organization (e.g., monetary)									
Workshops and information-sharing policies to educate employees about reduction measures									

(*continued on next page*)

(*continued*)

Which measures or actions has your company in place to reduce its emissions (carbon footprint)?		
	Application of measures	Contribution to emission reduction
Having set emission reduction targets, measurement of results, and/or communication of the undertaken climate actions		
Use of software to improve overall efficiency (energy-management-, process-management-, environmental management-software)		
Are there additional measures that your company uses, or examples that you would like to give for emission reduction measures? (open question)		
Emission reduction measures in production		
Does your company manufacture products and has production or manufacturing facilities?	yes or no question	
Mechanisms to regularly increase process efficiency through process redesign or new equipment		
Product modifications to include renewable/recycled or less carbon-intensive materials		
Use of carbon capture & storage technologies		
Use or development of cleaner fuels		
Are there additional measures that your company uses, or examples that you would like to give for reducing production related emissions? (open question)		

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