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Carbon footprint reporting process and software assessment framework

Abstract

ESG reporting requirements are a response to global environmental and social challenges. Sustainability reporting poses challenge for organizations, mostly due to complex regulations and numerous calculation methods, causing confusion and requiring in-depth research and learning. This research is focused on carbon footprint reporting, indicating the role and importance of purpose-built reporting software in this process. The framework carbon footprint reporting process (F-CF-RP) was proposed based on a literature review, with the aim of providing guidance and indicating the steps required for proper CF reporting. Based on the guidelines, standards, literature and software review, the carbon footprint reporting software assessment framework (CF-RS-AF) was developed to provide researchers and practitioners with a framework to systematize the selection process of carbon footprint reporting software. The framework combines functional and non-functional requirements, support and pricing models, and automated and artificial intelligence functionalities. The framework was positively validated with review of sample tools.

Keywords: carbon footprint reporting, ESG reporting, green IS, sustainability software, automation
JEL Classification: O330 Technological Change: Choices and Consequences; Diffusion Processes; M150 IT Management

Introduction: ESG reporting background

Global environmental and social challenges require organized action and active involvement of a wide range of stakeholders, including governmental institutions, business, and people in the field of academia and science, working toward the same sustainability goals. The growing need for action leads to the emergence of increasingly advanced regulations and reporting requirements. As Corporate Social Responsibility (CSR) initiatives have been voluntary and often involved greenwashing, we are now moving towards formalized and mandatory reporting of environmental, social and governance (ESG) aspects. At the United Nations level, the 17 Sustainable Development Goals (SDGs) were defined in 2015, and guidance on SDG corporate reporting was produced by Global Reporting Initiative (GRI) and UN Global Compact in 2017 [UN; GRI]. For the European Union, the regulatory path leads from the 2014 Non-Financial Reporting Directive (NFRD), through the 2020 EU Taxonomy Regulation and the 2022 Corporate Sustainability Reporting Directive (CSRD), to 2023 European Sustainability Reporting Standards (ESRS) [Stanek-Kowalczyk et al., 2023; Zieliński, 2023]. Each step provides the organizations with more detailed instructions, but also creates higher expectations, while constantly expanding the range of groups subject to reporting requirements.

A thorough literature review on sustainability reporting defined several challenges faced with adopting and implementing it [Paridhi, Arora, 2023]. The first challenge is a lack of common understanding of the concepts related to sustainability. Even though the regulations have a common goal, they differ at a geographical and sectoral level, causing confusion and requiring in-depth research and learning. This issue is then transferred to the measurement phase, with complex frameworks and numerous calculation methods.

The quality of ESG management can be improved using IT technologies, both at the strategy execution and reporting level [Turek, Martinek-Jaguszewska, 2023]. The fundamental climate-related actions are decarbonization strategy establishment, carbon footprint measurement, and decarbonization reporting. This research paper first describes the role of a carbon footprint within ESG strategies, summarizes the key carbon footprint reporting standards and guidelines, and recalls that there is evidence that reporting has an impact on decarbonization effects. Second, based on a literature review, the framework carbon footprint disclosure process (F-CF-RP) was proposed, indicating the role and importance of dedicated reporting software and other IT technologies in this process. Based on the guidelines, standards and literature review, the carbon footprint reporting software assessment framework (CF-RS-AF) was developed to support researchers and practitioners while selecting tools designed to meet specific needs and strategies. The CF-RS-AF enables the selection of a solution based on: functional and non-functional requirements, support and pricing models, and automated and artificial intelligence functionalities. The framework was then positively validated with review of 6 exemplary carbon footprint reporting tools.

Decarbonization as a key element of ESG strategy and reporting

ESRS are currently the most detailed standard for reporting in the European Union and for imposing the reporting obligations as they are part of CSRD regulations. ESRS define specific measures and indicators organized within two cross-cutting standards and ten thematic standards. Further industry-specific standards are expected to be developed. Greenhouse Gas (GHG) emissions disclosure is a baseline for the first thematic standard, namely E1 – Climate change [EFRAG, 2022]. This position demonstrates the critical importance of GHG emissions in addressing global environmental challenges.

There are three scopes for reporting GHG emissions. Scope 1 is related to the company's direct impact on climate change. Scope 2 covers indirect impacts (such as purchased energy). Scope 3 encompasses emissions released in the company's value chain [EFRAG, 2022]. A systematic literature review by Hettler and Graf-Vlachy [2023] identified three key issues in terms of scope 3 reporting capabilities. The first is the mix of reporting standards on carbon emissions that are unclear or/and lead to misunderstandings. The second is the organizational capabilities that are often lacking, as emission reporting requires specific awareness, knowledge, know-how, and skills. The third is a data quality in terms of poor availability, comparability and consistency, causing uncertainty and low accuracy. Scope 3 reporting is considered to be the most complex, and less well defined, and this poses the biggest challenge to organizations, whether they have a reporting obligation or are part of the supply chain.

Carbon footprint reporting standards and guidelines

As recommended by the Task Force on Climate-Related Financial Disclosures (TCFD), climate-related reporting should be based on publicly available frameworks [TCFD, 2021, p. 62]. The Task force specifies numerous possibilities to choose from, such as the GHG Protocol, the Global Reporting Initiative (GRI), ISO Standards, the Sustainability Accounting Standards Board, the Climate Disclosure Standards Board, the World Resources Institute (WRI), the World Business Council for Sustainable Development, the CDP, and various industry-specific guidelines. Such a wide range of frameworks requires a detailed review of the assumptions and a deep understanding of the measurement methodology. This is one of the challenges that can be supported by reporting tools. These tools are usually based on a selected standard or cover a few of them. For the calculation of GHG emissions, EFRAG recommends using the GHG Protocol Corporate Standard (version 2004 or the latest one) and GRI 305 (version 2016) [EFRAG, 2022, p. 31].

Additionally, the environmental management aspects are mainly (but not solely) covered by the ISO 14000 family of standards, and these aspects consist of several themes: environmental

management (with 28 currently published standards), environmental management systems (7), greenhouse gases (6), stationary source emissions (3), and a standard on climate change management. There is also a group of three standards under development for the validation and verification of sustainability information. The guidelines for carbon footprint accounting are both generic and industry-specific. The examples are as follows:

- ISO 14064 provides guidance on the quantification of greenhouse gas emissions at the organizational level [*ISO 14064–1:2018]*.
- ISO 14067 provides requirements and guidelines for the quantification of the carbon footprint of products (PCF) considering the whole lifecycle [*ISO 14067:2018]*.
- ISO 14068 provides guidance for achieving and demonstrating carbon neutrality [*ISO 14068–1:2023]*.
- ISO 14083 provides an example of guidance specific to reporting GHG emissions in transport chain operations (both freight and passenger) [*ISO 14083:2023]*.

Despite the existence of extensive regulations and frameworks, the guidelines need to be adapted further to address specific sectoral conditions. This makes it possible to define and apply decarbonization strategies in accordance with regulations, taking into account particular activities performed in certain sectors. Such research provides practical recommendations for ESG teams, but above all, it enables the identification of decarbonization pathways leading to a real decrease in absolute emissions. A case study for the automotive industry shows that a holistic impact assessment, considering all industry-specific scope 3 activities and supported by scenario analysis, is required to determine the true emission level in the complete supply chain and to validate the achievement of sectoral reduction targets [Poschmann, Bach, Finkbeiner, 2023].

Similar industry-specific research classifies emission reduction measures in transportation operations of manufacturers [Miklautsch, Woschank, 2022], the personal care industry [Seelig, Schoeneboom, 2023], the building and construction industry [Karlsson et al., 2020], the mining sector [Immink, Louw, Brent, 2018], food supply chains [Deconinck, Jansen, Barisone, 2023] and, for instance, maritime shipping [Grzelakowski, Herdzik, Skiba, 2022]. The TCFD itself released additional guidance for selected sectors, including the financial sector (banks, insurance companies and asset management), as well as energy, transportation, materials and buildings, and agriculture, food and forest product groups [TCFD, 2021]. Additionally, activities related to other ESG themes can impact the carbon footprint results. For example, circular economy (E5) solutions and reusable products can have a huge effect on reduction of carbon emissions across the supply chain [Alshqaqeeq et al., 2020; Castillo-Benancio et al., 2022; Gómez-Prado et al., 2022].

ESG reporting effects

The studies on the relationship between carbon footprint reporting quality and emission reduction itself present mixed results. A study conducted on the selected Global 500 companies revealed that rigorous and comprehensive reporting (measured by disclosure score) does not translate into lower emissions generated by external partners in the supply chain [Mahapatra, Schoenherr, Jayaram, 2021]. However, it was concluded that the effects of carbon reduction initiatives are yet to be demonstrated, hence the results might be due to the short time period for which the impact was measured.

Other research was conducted on a sample of over 19 000 companies listed in the Refinitiv ESG database, to assess the actual impact of ESG reporting on carbon reduction [Luo, Tang, 2023]. The author concluded that the implementation of ESG reporting itself does not enhance carbon reduction indicators, which may be due to the broad scope of ESG reporting, where carbon performance might not be the priority for all entities. However, once the GRI standards are followed to prepare the ESG report, then a carbon emissions reduction is observed from that time. The important fact is that the mentioned study assessed solely the impact of GRI standards, and no other frameworks (such as GHG or ISO) were considered.

There is also evidence from business that incorporating sustainability into operations and strategy is required to accelerate a low-carbon economy, and reporting is crucial to make this process effective [An, 2023]. Reporting on both impact and value in accordance with rigorous regulations is expected to further a company's long-term value creation. Tracking performance and progress also provides investors with information on how the ESG-related actions reduce climate-related risks [DeCotis, 2022]. Purpose-built digital sustainability management solutions are crucial to support those reporting needs.

Research characteristics

There are commercial reviews of sustainability software available for reference. Forrester attempted to identify the most significant providers [Forreseter, 2022, 2024]. Their assessment criteria include materiality assessment, carbon calculation, data management, performance monitoring, reporting, climate action strategy, intelligence dashboards, product vision, execution roadmap, and market approach. Gartner, on the other hand, concluded that the critical uses of sustainability and ESG software are reporting, program management, and data management functionalities [Gartner, 2023]. Such research is focused on leading solutions offered by the key market players. However, the market offers a vast amount of purpose-built carbon footprint applications that can successfully support small and medium-sized organizations. For such applications, there are beta-testing initiatives led by pioneering institutions, that select and promote several solutions. An example in the Polish market is the PKO BP bank

initiative to test six selected solutions [Bełcik, 2024]. However, there is no scientific research providing researchers and practitioners with validated frameworks, supporting the selection of carbon footprint reporting software.

Research goals and impact

The results of the literature review show that carbon footprint reporting is a complex process that requires specific knowledge and skills. Although the literature provides definitions and guidelines for certain steps of this process, no definition of the complex flow was found while conducting the literature review. Hence, a definition for the framework carbon footprint reporting process (F-CF-RP) was proposed and described, with the aim of providing guidance and indicating the steps required for proper CF reporting.

To drive this process, companies face an extensive regulation on the one hand, and a large selection of carbon footprint reporting software on the other. Both require thorough reviews to determine decarbonization and reporting strategies. The main research aim is to provide both researchers and practitioners with an assessment framework to facilitate and systematize the selection process of carbon footprint reporting software, implemented through the carbon footprint reporting software assessment framework (CF-RS-AF).

The framework developed combines functional and non-functional requirements, and groups them into categories related to the carbon footprint reporting process. It also covers the assessment of support options and a pricing model. The functionalities with characteristics of automation or artificial intelligence were additionally specified. The purpose of this classification was to identify the solutions that make the reporting process significantly more efficient.

The framework has direct application value. Business users can first choose functionalities of interest from the list, and then use the framework for comparative analysis of preselected solutions. For validation purposes, the framework was tested on sample software applications, however, as this research is not aimed at promoting any of them, the names of the solutions are undisclosed. The result confirmed that the framework can successfully support the selection process based on the individual selection criteria.

Research methodology

The research used a mixed-methodology approach. First, the literature review was used not only to define the research gap and provide the theoretical background, but also to support the definition of the proposed frameworks. To identify the relevant articles, keyword searches were performed in the Science Direct and EBSCO databases in February 2024. The following phrases were used as basic search criteria: *ESG reporting, carbon footprint reporting, GHG reporting, sustainability software*. The following supporting phrases were used to create

various combinations: *digitization, automation, tools, software, technology, process*. Selected articles cited in the found works were also searched.

In addition to the literature review, the functional descriptions on a product website, technical documentation and demo versions of the systems were used to create the carbon footprint reporting software assessment framework (CF-RS-AF). The author selected two solutions listed by Forrester and Gartner, as well as four solutions proposed by Polish start-ups, ensuring diversity of the assessment.

The author participated as a team member in an extensive research on ESG management maturity as part of a scientific project KNOP/S24: 1.4. "The quality of management of ESG aspects vs resilience to crisis. Enterprises – financial institutions – local government units", carried out at the Collegium of Business Administration at the SGH Warsaw School of Economics within the subsidy for maintaining and developing research potential in 2022–2024. First, a novel and comprehensive maturity model was developed according to the best practices based on the systematic literature review and Focus Group Interviews (FGI) [Ocicka, Gemra, 2023]. Second, a quantitative computer-assisted web interviewing (CAWI) study was conducted to measure the current ESG management maturity level. The research was conducted on a random sample of 100 out of 140 companies listed on the Warsaw Stock Exchange, enabling statistical inference. For the purpose of this paper, the CAWI research results were used to determine the importance of carbon footprint reporting software.

Carbon footprint reporting processes, tools, and automation

This section leads to the development of two framework concepts. One is the framework carbon footprint reporting process (F-CF-RP) and the other is the carbon footprint reporting software assessment framework (CF-RS-AF). Both are based on the literature review and aim to support researchers and practitioners in effective carbon footprint reporting.

The framework carbon footprint reporting process (F-CF-RP)

As outlined in the previous section, ESG reporting regulations are extensive, and compliance requires proper planning and implementation at both a strategic and operational level, which can be a challenge for most of the organizations surveyed. Preparing ESG reports including the carbon footprint measurement, is a time-consuming task that requires dedicated specialists with a combination of interdisciplinary skills. There is also a need to involve numerous stakeholders in the process of data collection and analysis, especially when the company approaches ESG reporting for the first time. Moreover, the active involvement of the part of the leadership team is required to ensure effective management of ESG aspects [Turek, Martinek-Jaguszewska, 2023].

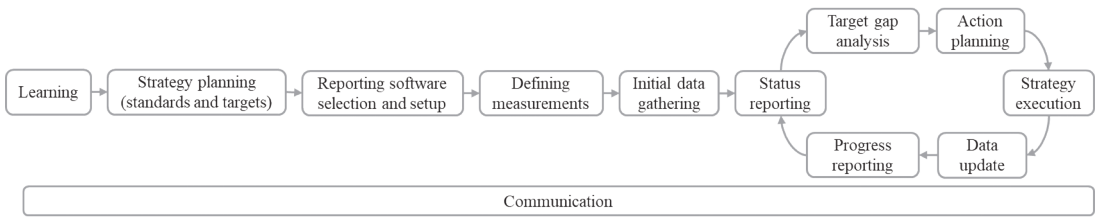
Being just a part of ESG reporting, the carbon footprint measurement and reporting process is complex in itself. The authors describe certain steps of this process, but a holistic flow from the reporting company perspective was not found during the literature review within this research. For this reason, a framework carbon footprint reporting process (F-CF-RP) was proposed and outlined in Figure 1. The flow includes initial preparatory steps and the cyclical steps for reporting improvements and communication.

Initial preparatory steps start with addressing the need for carbon footprint reporting, and learning the context of obligatory disclosure requirements and applicable guidelines. Ensuring mutual understanding of the terminology among all stakeholders is crucial to ensure that an effective decarbonization strategy is followed [Buettner, 2022]. Next, the organization needs to define the material sustainable development goals and set the overall strategy in terms of carbon footprint impact and decarbonization. Defining the roadmap to neutrality requires a thorough review of sectoral conditions, and an organization's ambitions, motivations, needs and priorities [Buettner, 2022]. This is also the time to choose reporting standards (if not specified by law) and set initial decarbonization targets.

This decision is an input for selection of the carbon footprint reporting solution (described in more detail in the following sections) and the initial setup of the tool. The tool setup covers the basic configuration and integration with selected data sources (if direct API integrations are available). The customized configuration leads to selection of applicable actions and metrics. If the required metrics are not available in the selected tool, customized operationalization is required [Bhattacharya, Zaman, 2023]. At this stage, the organization should aim to define the full carbon impact, taking scopes 1, 2 and 3, as well as industry- and company-specific conditions into account. For scope 3, the reporting process covers the definition of industry-specific activities to holistically reflect the areas in which a company has an impact [Poschmann, Bach, Finkbeiner, 2023].

Knowing the data requirements, the initial data can be gathered, which is considered to be a great operational effort for both the reporting entity and its suppliers [Patchell, 2018; Villena, Dhanorkar, 2020]. If direct API integrations are available in the selected tool, this is also the time when integrations with other systems, such as ERP, CRM, HRM, are developed. It is crucial to ensure data consistency and reliability. The collected data is aggregated, analyzed, interpreted, and summarized in the form of a status report [Stanek-Kowalczyk et al., 2023].

Figure 1. Framework carbon footprint reporting process (F-CF-RP)



Source: own material.

Next, the organization can enter the progress reporting cycle, which is based on Deming's PDCA concept [Pojasek, 2012]. The scenario-based pathways of corporate emissions and product carbon footprint reduction shall be set and compared to industry targets. The results reveal the target gap and indicate the required carbon offsetting requirements as well as the need to adjust decarbonization strategies [Poschmann, Bach, Finkbeiner, 2023]. In response to the results, a list of improvement initiatives shall be operationalized, and related action plans shall be assigned. While the organization performs all the planned actions, the strategy is executed step by step. Although regulatory requirements provide for annual reporting, continuous or at least cyclical data updates are essential to ensure effective decarbonization. Such updates provide the input for progress reporting, opening the analysis – planning – execution – update and reporting cycle once again.

The communication in this process is a continuous and repetitive task, consisting of various elements. It includes internal and external communication at the stages of strategy communication, data gathering and reporting results. It should be both informative and actionable communication with task assignment [Jayadatta, 2023]. The reporting tool should ideally meet all those requirements. Particularly important is the method of communication adapted to the various recipients of the final report – investors, employees, customers or competitors, as well as the transparency of the disclosed data [Stanek-Kowalczyk et al., 2023].

Technologies supporting carbon footprint reporting

The wide scope of carbon footprint measurement and related data collection, as well as the need to involve numerous stakeholders, implies the need for digitization. The information systems (IS) that support environmental sustainability are referred to as Green IS [Zampou et al., 2022]. This group covers both the IS that enable the achievement of environmental sustainability-related outcomes, and the IS that are used for measurement, monitoring, analysis and reporting. For the latter IS category, the goal is to ensure a coherent and comprehensive decarbonization reporting approach. The steps of this complex process can be supported by a variety of technologies. Companies can choose from a wide range of tools dedicated to carbon footprint reporting, but they can also build their own solutions using internal reporting systems already used in the company [Stanek-Kowalczyk et al., 2023]. This paper focuses on the first group of reporting tools.

In the 2023 CAWI research conducted as part of the SGH Warsaw School of Economics statutory research project entitled "The quality of management of ESG aspects and resistance to crises. Enterprises – financial institutions – local government units." one of the factors measured for correlation with ESG management maturity level was the IT tools used in the ESG management and reporting processes. Respondents stated that core IT systems (68%), generic tools supporting business reporting and data mining (63%), and cloud computing resources (60%) are the technologies that significantly affect the quality of ESG management.

Software dedicated to ESG reporting was considered crucial only among the biggest companies (listed in the WIG-20), and the use of such applications is correlated with increasing ESG management maturity. Thus, it is crucial to better understand how such software can also support small and medium-sized organizations to increase their ESG management maturity.

Carbon footprint reporting software assessment framework (CF-RS-AF)

Based on the reviewed research papers, a repeatable list of functionalities can be observed that are required in the carbon footprint reporting tools to ensure a holistic reporting approach. Those requirements can be grouped into nine categories, summarized in Table 1, which form the carbon footprint reporting software assessment framework (CF-RS-AF). Certain CF-RS might have capabilities that are limited to selected groups, for example they would only enable status reporting without progress tracking or strategy planning. The framework allows the user to choose which capabilities are required for the organization and select the most appropriate solution. It is expected that the pricing model would be adjusted to the scope of capabilities, and thus using the model could lead to cost savings.

As the key value of using CF-RS is the ease of the reporting process, the availability of automation capabilities needs to be determined while choosing the solution, as this can affect the time and reliability of this process. By definition, the capabilities that reduce or eliminate the hands-on role of a human to carry out certain tasks, enabling them to be performed faster, more efficiently and more accurately, can be considered automation [Dao, Langella and Carbo, 2011]. Moreover, artificial intelligence models are increasingly being used in the ESG reporting tools. There is strong evidence that AI is being used for data anomaly detection, valuation and risk assessment, or for assessing the impact of a firm's performance on ESG rating anticipation [Saxena et al., 2023]. While assessing the CF-RS, it needs to be remembered that some of the basic statistical models are often marketed as AI functionalities, just to increase the interest in a certain product. Both automation prospects and possible AI functionalities were marked within the CF-RS-AF to ensure that evaluators will pay special attention to these evaluation criteria.

The key functionality group defines the available carbon footprint measurements to enable compliance with regulations (e.g. ISO, GHG Protocol, GRI) and industry standards [TCFD, 2021], but also enables the comprehensive industry-specific reporting scope and all material activities to be included [Castillo-Benancio et al., 2022; Gómez-Prado et al., 2022; Miklautsch, Woschank, 2022; Poschmann, Bach, Finkbeiner, 2023]. Ideally, a large set of built-in activities and measurements should be available, with the additional possibility to define customized measurements. Built-in measurements can be considered as an automation functionality, assuming that they reduce the operationalization workload.

Table 1. Carbon footprint reporting software assessment framework (CF-RS-AF)

Requirement group	Functionalities
Measurements and compliance	• Built-in definition of aspects material to carbon footprint disclosure • Built-in definition of carbon footprint measurements [automation] • Standard-compliant measurements (e.g. ISO, GHG Protocol, GRI) • Sector-specific measurements (e.g. automotive, manufacturing, telecommunications, etc.) • Scope 1/2/3 reporting measurements • Possibility to define customized activities and measurements
Data collection	• Manual data collection • Upload and bulk upload functionalities • Automated data integration through GUI/RPA [automation] • Automated data integration through API [automation] • ML/NLP models to collect scope 3 data [AI]
Status reporting	• Standard reporting capabilities with data visualization • Customized reporting capabilities • Data analysis tools [including AI models] • Benchmark analysis • Generative descriptions of the results [AI]
Progress and target reporting	• Change and progress tracking over time • Target setting • Target baselining and variance analysis • Reporting on the target gap
Strategy and action planning	• Defining decarbonization strategy • Breakdown of the strategy into projects • Breakdown of the projects into actions • Budget forecasting • Impact forecasting • Scenario analysis [might be AI-based, rather statistical models] • Carbon offset planning [manual, automated or AI based]
Communication	• Informative communication with internal stakeholders [manual or automated] • Actionable communication with internal stakeholders (assigning tasks) • Informative communication with external stakeholders [manual or automated] • Actionable communication with external stakeholders (assigning tasks) • Notifications when certain thresholds are reached [automation]
Non-functional requirements (NFR)	• Data processing performance • System reliability • Data validation • Data security • Cloud or on-premise installation • Access control • Change history and user change log • User experience
Reporting and application support	• Support with determining the carbon footprint reduction strategy (training, workshops) • Support with integrations and data collection processes • Support with reporting configuration • SLA support for the solution • Platform to suggest solution roadmap changes
Pricing model	• Single payment (lifetime license) • Monthly subscription model • Yearly licensing model • User-based pricing model • Free demo or testing period available • Pricing level

Source: own material.

Data collection is one of the most time-consuming steps in the overall reporting process [Patchell, 2018; Villena, Dhanorkar, 2020]. It requires data collection from numerous and heterogeneous internal sources such as ERP, WMS, BMS, LCI and other corporate systems [Zampou et al., 2022], as well as external sources from the supply chain [Patchell, 2018]. Manual data collection and upload functionalities require periodic manual data updates throughout the reporting process. Automated data collection, on the other hand, requires more work in the first attempt of the reporting process, but benefits when the cyclical updates are required, enabling continuous updates. This functionality can be realized by developing application programming interfaces (API) or using robotic process automation (RPA). Moreover, the use of blockchain technology was proposed for automated ESG data collection [Saxena et al., 2023].

Enabling the understanding of the carbon footprint level is the basic capability of any CF-RS. The basic systems provide users with standardized data visualization, usually ensuring at least basic filtering options. More advanced CF-RS provide users with the possibility to customize reports according to individual needs. Data analysis tools can provide users with additional insight into the results. Some of the tools in this family can be based on AI models (e.g. predictive algorithms). Another useful functionality might be the benchmark analysis – it would require the solution provider to anonymize and aggregate the data from all users or external sources and provide it as a benchmark reference. However, generative AI, not recognized in any of the tools analyzed by the author, could potentially be useful in providing a descriptive analysis of the reporting results.

Progress and target reporting is the extension of the previous step, and allows not only for tracking progress over time, but also for setting targets and reporting the results regarding the target gap. Similarly to project management best practices, the target assumption could be baselined (fixed), allowing for the variance analysis.

The results visualized in the previous two steps are the baseline for strategy and action planning. The CF-RS can make it possible to outline the decarbonization strategy in relation to certain results and targets. The systems can also enable the breakdown of strategy into projects, and projects into tasks. This breakdown can be a good basis for budgeting the required actions and understanding the costs of improvement initiatives. As such initiatives are planned, the next step is a visualization of the expected impact on each of them, providing the impact forecast and enabling the verification if the planned actions are good enough to meet the target. Some of the tools would enable scenario analysis (not necessarily AI-based). If the analysis reveals that the decarbonization plan is not sufficient, then carbon offset planning could be another useful functionality that can be performed manually, but the CF-RS can also automatically propose some sectoral solution, even (but not necessarily) using the AI recommendation models for this purpose.

Communication requirements were discussed in the previous section. The CF-RS can cover both internal and external communication capabilities to serve the purpose of informing stakeholders (possibly with an option to define different recipient groups and scope

of information shared at the stages of strategy communication, data gathering and results reporting) or to assign specific tasks (data collection or improvement initiatives). This includes both informative and actionable communication with task assignment [Jayadatta, 2023]. The reporting tool should ideally meet all those requirements. Particularly important is the method of communication adapted to the various recipients of the final report – investors, employees, customers or competitors, as well as the transparency of the disclosed data [Stanek-Kowalczyk et al., 2023]. Information sharing can be manual or automated. Notifications when certain thresholds are reached can be considered as an automated functionality.

Non-functional requirements determine the quality of IS. They mainly include the features of data processing performance, reliability, security and user experience [Sacha, 2010, pp. 51–53]. Data processing performance might be crucial if large amounts of data are expected to be analyzed. System reliability is determined by factors such as availability and downtime, but can also include data validation mechanisms. As sensitive business data might be processed, it is crucial to ensure high security standards. It needs to be determined whether installation in the cloud or on-premises is preferred, access control must be verified, and change history logs should be provided. Last but not least, the user experience for key stakeholders is assessed. An unintuitive graphical user interface can make the reporting process difficult and irritating, negating all efforts to facilitate the reporting process.

While choosing the CF-RT, one can consider not only the functional and non-functional requirements, but also the reporting and application support provided by the supplier. Some of the suppliers provide services to help with the reporting process. They would assist with establishing the carbon footprint reduction strategy through training and workshops, develop integrations or provide support with manual data collection processes, as well as configure the system according to the company's needs. The service level agreement (SLA) provided by the supplier needs to be determined, and it needs to be stated whether it is possible to suggest the developments for the product roadmap (i.e. the impact on the future functionalities).

The final consideration that reflects the scope of certain CF-RS capabilities, is the pricing model. The basic pricing models for such applications are lifetime licenses, monthly subscriptions, or annual licenses. Additionally, the price can be based on the number of users. Free demonstrations or the option of registering for a free trial can be an important decision factor. Last but not least, the price level itself needs to be examined.

Framework assessment

For validation purposes, the proposed CF-RS-AF was tested on sample software applications. As this research is not aimed at promoting any specific solutions, the names of the providers are undisclosed. However, the result confirmed that the framework can successfully support the selection process based on the individual selection criteria. The sample assessment is visualized in Figure 2. The evaluator can choose the functionalities required for the

organization before or after the assessment. The functionalities can be assessed using a binary yes/no scale, but can also be described with more detailed characteristics.

Figure 2. Assessment of sample CF-RS using the CF-RS-AF

Requirements' group	Functionalities	Tool A	Tool B	Tool C	Tool D	Tool E	Tool F
Basic info	Reference webpage						
	Is part of the ESG software?	yes	yes	no	no	no	no
Measurements and compliance	- Built-in definition of aspects material to carbon footprint disclosure	yes	yes	yes	yes	yes	yes
	- Built-in definition of carbon footprint measurements [automation]	yes	yes	yes	yes	yes	yes
	- Standards' compliant measurements (ex. ISO, GHG Protocol, GRI)	GHG, GRI	GHG, GRI	ISO	GHG	GHG	GHG
	- Sector specific measurements (ex. automotive, manufacturing, telecommunications, etc.)	yes	no	yes	yes	no	no
	- Scope 1/2/3 reporting measurements	1,2,3	1,2,3	1,2	1,2	1,2,3	1,2,3
	- Possibility to define customised activities and measurements	yes	yes	yes	yes	yes	no
Data collection	- Manual data collection	yes	yes	yes	yes	yes	yes
	- Upload and bulk upload functionalities	yes	yes	yes	yes	yes	no
	- Automated data integration through GUI/RPA [automation]	yes	no	no	yes	no	no
	- Automated data integration through API [automation]	yes	yes	yes	no	no	no
	- ML/NLP models to collect scope 3 data [AI]	no	no	no	no	no	no
Status reporting	- Standard reporting capabilities with data visualization	yes	yes	yes	yes	yes	yes
	- Customized reporting capabilities	yes	yes	yes	yes	yes	no
	- Data analysis tools [including AI models]	yes	yes	yes	no	no	no
	- Benchmark analysis	yes	yes	yes	yes	no	no
	- Generative descriptions of the results [AI]	no	no	no	no	no	no
Progress and target reporting	- Change and progress tracking over time	yes	yes	yes	yes	yes	no
	- Target setting	yes	yes	yes	yes	yes	no
	- Target baselining and variance analysis	yes	no	yes	no	no	no
	- Reporting on the target gap	yes	yes	yes	yes	no	no
Strategy and action planning	- Defining decarbonization strategy	yes	yes	yes	yes	no	no
	- Decomposition of the strategy into projects	yes	yes	yes	yes	no	no
	- Decomposition of the projects into actions	yes	yes	yes	yes	no	no
	- Budget forecasting	no	no	yes	no	no	no
	- Impact forecasting	yes	no	yes	no	no	no
	- Scenario analysis [might be AI based, rather statistical models]	yes	no	yes	no	no	no
	- Carbon offset planning [manual, automated or AI based]	manual	automated	manual	AI based	no	no
Communication	- Informative communication with internal stakeholders [manual or automated]	yes	yes	yes	yes	yes	yes
	- Actionable communication with internal stakeholders (assigning tasks)	yes	yes	yes	yes	no	no
	- Informative communication with external stakeholders [manual or automated]	yes	yes	yes	yes	yes	no
	- Actionable communication with external stakeholders (assigning tasks)	yes	yes	yes	no	no	no
	- Notifications in case certain thresholds are reached [automation]	yes	no	no	no	no	no
Non-functional requirements (NFR)	- Data processing performance	ok	ok	ok	ok	nok	ok
	- System reliability	ok	ok	ok	ok	ok	ok
	- Data validation	ok	ok	N/A	ok	N/A	N/A
	- Data security	ok	ok	ok	nok	ok	nok
	- Cloud or on-premise installation	both	cloud	cloud	cloud	cloud	cloud
	- Access control	ok	ok	ok	N/A	N/A	N/A
	- Change history and user change log	ok	ok	ok	N/A	N/A	N/A
	- User experience	ok	nok	ok	ok	nok	ok
Reporting and application support	- Support with setting carbon footprint reduction strategy (training, workshops)	N/A	N/A	N/A	N/A	yes	yes
	- Support with integrations and data collection processes	N/A	N/A	N/A	N/A	yes	N/A
	- Support with reporting configuration	yes	yes	yes	yes	yes	yes
	- SLA support for the solution	ok	ok	ok	nok	ok	N/A
	- Platform to suggest solution roadmap changes	ok	N/A	N/A	N/A	ok	N/A
Pricing model	- One time payment (lifetime licence)						
	- Monthly subscription model			x	x	x	x
	- Yearly licencing model	x	x				
	- User based pricing model		x		x		
	- Free demo or testing period available	no	yes	yes	no	yes	yes
	- Pricing level	high	medium	medium	medium	low	low

Source: own material.

Summary

ESG reporting requirements are a response to global environmental and social challenges. However, the numerous regulations cause adoption and implementation challenges. The quality of ESG management can be improved using IT technologies, that are part of the Green IS solutions. This research paper describes the role of a carbon footprint within the ESG strategies and summarizes the key carbon footprint reporting standards and guidelines.

Based on the literature review, the framework carbon footprint disclosure process (F-CF-RP) was proposed. It was found that there is no holistic reporting process flow. The proposed process model consists of five preparatory steps realized when the CF reporting is initiated in the company, six cyclical steps for reporting and executing the strategy, as well as recurrent communication activities. The model can help researchers and practitioners to understand the key actions that are required to execute the carbon footprint and decarbonization strategy reporting process.

Based on the guidelines, standards, literature review and market research, the carbon footprint reporting software assessment framework (CF-RS-AF) was developed. The proposed CF-RS-AF stands as an alternative to commercial reviews of sustainability software provided by agencies such as Forrester or Gartner. The CF-RA-AF can be used for the independent assessment of self-selected solutions, enabling the comparison of both leading solutions and medium-sized purpose-built applications. The developed framework covered functional requirements grouped into six categories: measurement and compliance, data collection, status reporting, progress and target reporting, strategy and action planning, and communication. It also covered non-functional requirements, as well as the assessment of support options and the pricing model. To enable the selection of solutions that can significantly increase the efficiency of the reporting process, automation and AI functionalities were explicitly marked. The framework was validated using sample software applications. The result confirmed that the framework can successfully support the CF-RS selection process based on the individual selection criteria.

The key limitation of the study is the constantly developing technology, which requires the periodical review of new functionalities and their adaption and development to the framework proposed. Moreover, evolving regulations might impose additional requirements that affect the selection process and limit the choice of available solutions. The research shall continue to maintain the topicality of the framework. A similar research method can also be replicated and used to create other IT solutions' assessment frameworks. The CF-RS-AF could be used for a broad scale carbon footprint software review study.

References

1. Alshqaqeeq, F. et al. (2020). Comparing reusable to disposable products: Life cycle analysis metrics. *Journal of Advanced Manufacturing and Processing*, *2*(4), pp. 1–9, doi: 10.1002/amp2.10065.
2. An, E. (2023). Accelerating sustainability through better reporting. *Sustainability Accounting, Management and Policy Journal*, *14*(4), pp. 904–914, doi: 10.1108/SAMPJ-08-2022-0453.
3. Bełcik, A. (2024). PKO BP testuje technologie wspierające ESG. Są pierwsze pilotaże *Puls Biznesu*, https://www.pb.pl/pko-bp-testuje-technologie-wspierajace-esg-sa-pierwsze-pilotaze-1206113 [accessed: 11.02.2024].

4. Bhattacharya, C., Zaman, M. (2023). The What, Why and How of ESG Dashboards. *NIM Marketing Intelligence Review*, *15*(1), pp. 32–39, doi: 10.2478/nimmir-2023-0005.
5. Buettner, S.M. (2022). Roadmap to Neutrality – What Foundational Questions Need Answering to Determine One's Ideal Decarbonisation Strategy. *Energies*, *15*(3126), pp. 1–24, doi: 10.3390/en15093126.
6. Castillo-Benancio, S. et al. (2022). Circular Economy for Packaging and Carbon Footprint. *Environmental Footprints and Eco-Design of Products and Processes*, pp. 115–138, doi: 10.1007/978-981-19-0549-0_6/COVER.
7. Dao, V., Langella, I., Carbo, J. (2011). Information Technology and an integrated sustainability framework. *Journal of Strategic Information Systems*, *20*(1), pp. 63–79, doi: 10.1016/j.jsis.2011.01.002.
8. Deconinck, K., Jansen, M., Barisone, C. (2023). Fast and furious: the rise of environmental impact reporting in food systems. *European Review of Agricultural Economics*, *50*(4), pp. 1310–1337, doi: 10.1093/erae/jbad018.
9. DeCotis, P.A. (2022). Digitizing Climate Reporting Compliance. *Climate and Energy*, *38*(11), pp. 21–27, doi: 10.1002/gas.22292.
10. EFRAG (2022). *Draft European Sustainability Reporting Standards. ESRS E1. Climat Change*.
11. Forreseter (2022) *The Forrester New Wave™: Sustainability Management Software, Q1 2022*, https://reprints2.forrester.com/#/assets/2/2273/RES176324/report?utm_source=Persefoni [accessed: 11.02.2024].
12. Forreseter (2024). *The Forrester New Wave™: The Sustainability Management Software Landscape, Q1 2024*, https://www.forrester.com/report/the-sustainability-management-software-landscape-q1-2024/RES180343 [accessed: 11.02.2024].
13. Gartner (2023). *Emerging Tech: Sustainability and ESG Software Providers Focus on Simplifying ESG Reporting*, https://www.gartner.com/en/documents/4341799 [accessed: 11.02.2024].
14. Gómez-Prado, R. et al. (2022). Circular Economy for Waste Reduction and Carbon Footprint. *Environmental Footprints and Eco-Design of Products and Processes*, pp. 139–159, doi: 10.1007/978-981-19-0549-0_7/COVER.
15. GRI (n.d.). *GRI–Mission & history*, https://www.globalreporting.org/about-gri/mission-history/ [accessed: 11.02.2024].
16. Grzelakowski, A.S., Herdzik, J., Skiba, S. (2022). Maritime Shipping Decarbonization: Roadmap to Meet Zero-Emission Target in Shipping as a Link in the Global Supply Chains. *Energies*, *15*(6150), pp. 1–16, doi: 10.3390/en15176150.
17. Hettler, M., Graf-Vlachy, L. (2023). Corporate scope 3 carbon emission reporting as an enabler of supply chain decarbonization: A systematic review and comprehensive research agenda. *Business Strategy and the Environment*, (Nov. 2022), pp. 1–20, doi: 10.1002/bse.3486.
18. Immink, H., Louw, R.T., Brent, A.C. (2018). Tracking decarbonisation in the mining sector. *Journal of Energy in Southern Africa*, *29*(1), pp. 14–23, doi: 10.17159/2413-3051/2018/v29i1a3437.
19. *ISO 14064–1:2018 – Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals* (n.d.), https://www.iso.org/standard/66453.html [accessed: 10.02.2024].

20. *ISO 14067:2018 – Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification* (n.d.), https://www.iso.org/standard/71206.html [accessed: 10.02.2024].
21. *ISO 14068–1:2023 – Climate change management – Transition to net zero – Part 1: Carbon neutrality* (n.d.), https://www.iso.org/standard/43279.html [accessed: 10.02.2024].
22. *ISO 14083:2023 – Greenhouse gases – Quantification and reporting of greenhouse gas emissions arising from transport chain operations* (n.d.), https://www.iso.org/standard/78864.html [accessed: 10.02.2024].
23. Jayadatta, S. (2023). The Role of Social Media in Promoting ESG – A Theoretical Assimilation. *International Journal of Marketing and Business Communication*, *12*(2), pp. 25–36, doi: 10.32441/kjhs.4.6.13.
24. Karlsson, I. et al. (2020). Roadmap for climate transition of the building and construction industry – a supply chain analysis including primary production of steel and cement. *Energies*, *13*(4136), pp. 1–40.
25. Luo, L., Tang, Q. (2023). The real effects of ESG reporting and GRI standards on carbon mitigation: International evidence. *Business Strategy and the Environment*, *32*(6), pp. 2985–3000, doi: 10.1002/bse.3281.
26. Mahapatra, S.K., Schoenherr, T., Jayaram, J. (2021, Feb). An assessment of factors contributing to firms' carbon footprint reduction efforts. *International Journal of Production Economics*, 235, p. 108073, doi: 10.1016/j.ijpe.2021.108073.
27. Miklautsch, P., Woschank, M. (2022, June). A framework of measures to mitigate greenhouse gas emissions in freight transport: Systematic literature review from a Manufacturer's perspective. *Journal of Cleaner Production*, 366, p. 132883, doi: 10.1016/j.jclepro.2022.132883.
28. Ocicka, B., Gemra, K. (Red.). (2023). Zrównoważona transformacja. Stan i uwarunkowania w kontekście ESG. Oficyna Wydawnicza SGH.
29. Paridhi, Arora, A. (2023). Sustainability reporting: Current state and challenges. *Business Strategy and Development*, 6(3), pp. 362–381, doi: 10.1002/bsd2.244.
30. Patchell, J. (2018). Can the implications of the GHG Protocol's scope 3 standard be realized?', *Journal of Cleaner Production*, 185, pp. 941–958, doi: 10.1016/J.JCLEPRO.2018.03.003.
31. Pojasek, R. (2012). Checking and Reviewing Sustainability Progress. *Environmental Quality Management*, pp. 83–91, doi: 10.1002/tqem.
32. Poschmann, J., Bach, V., Finkbeiner, M. (2023, Apr). Deriving decarbonization targets and pathways – A case study for the automotive industry. *Journal of Cleaner Production*, 409, p. 137256, doi: 10.1016/j.jclepro.2023.137256.
33. Saxena, A. et al. (2023). Technologies Empowered Environmental, Social, and Governance (ESG): An Industry 4.0 Landscape. *Sustainability*, *15*(309), pp. 1–17.
34. Seelig, B., Schoeneboom, J. (2023). Product Carbon Footprint: A Key to Effective Sustainability Strategies. *SOFW Journal*, 149, pp. 12–17.
35. Stanek-Kowalczyk, A., Martinek-Jaguszewska, K., Turek J. (2023). Raportowanie niefinansowe. Pomiar aspektów środowiskowych, społecznych i ładu korporacyjnego. In: Ocicka, B. and Gemra, K. (Eds.), *Zrównoważona transformacja. Stan i uwarunkowania w kontekście ESG* (p. 47–60). Oficyna Wydawnicza SGH.

36. TCFD (2021, Oct). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures. *Task Force on Climate-related Fiancial Disclosures*, pp. 1–87, https://assets.bbhub.io/company/sites/60/2020/10/FINAL-TCFD-Annex-Amended-121517.pdf
37. Turek, J., Martinek-Jaguszewska, K. (2023). Transformacja ESG przedsiębiorstw i łańcuchów dostaw – wyniki badań wśród przedsiębiorstw produkcyjnych i handlowych. In: Ocicka, B. and Gemra, K. (Eds.), *Zrównoważona transformacja. Stan i uwarunkowania w kontekście ESG* (p. 149–166). Oficyna Wydawnicza SGH.
38. UN (n.d.). *THE 17 GOALS | Sustainable Development*, https://sdgs.un.org/goals#history [accessed: 11.02.2024].
39. Villena, V.H., Dhanorkar, S. (2020). How institutional pressures and managerial incentives elicit carbon transparency in global supply chains. *Journal of Operations Management*, *66*(6), pp. 697–734, doi: 10.1002/joom.1088.
40. Zampou, E. et al. (2022). A Design Theory for Energy and Carbon Management Systems in the Supply Chain. *Journal of the Association for Information Systems*, *23*(1), pp. 329–371, doi: 10.17705/1jais.00725.
41. Zieliński, D. (2023). ESG a wyzwania dekarbonizacyjne przedsiębiorstw działających w Polsce. *Studia BAS*, *74*(2), pp. 127–144, doi: 10.31268/studiabas.2023.15.