Design of a recommender system to improve the environmental impact of companies based on their material and energy balances

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Abstract: As worldwide agreements aiming to reduce the carbon footprint keep coming into effect, many companies aim to become more efficient in their production process. However, it is costly to hire environmental experts to help with the efficiency and carbon reduction process. This research aims to analyze the possibility of creating a Recommender System (RS) which suggests Carbon Reduction Measures (CRM) to the users based on their Life Cycle Assessment (LCA) reports. Based on the literature review into the latest RS techniques and the available databases, a study was conducted into creating a RS prototype. Analysis of the results demonstrates, that with the currently available databases, it is not possible to create an effective RS. The results indicate that in order to be able to create a functional and useful RS more detailed data needs to be extractable from the LCA tool. Further research is needed into the exports from other Environmental Management Information Systems (EMIS) and the identification of other factors that could strengthen the effectiveness of the RS.

Keywords: Artificial Intelligence; Resource and Energy Efficiency; Recommender System; Material and Energy Balance; LCA

1 Introduction

Life Cycle Thinking (LCT) and Life Cycle Assessment (LCA) are progressively moving from the academic implementation and in-house uses by large companies to broader applications in society. The same thing can be said about Material Flow Analysis (MFA) [Sa21]. During the process of undergoing a LCA, the practitioner tabulates the data that is created during the whole 'Life Cycle' of a product. This process that starts at raw material extraction and ends at the ultimate disposal of said product includes every step in the life of a newly created product [Re04]. LCA typically involves working with a significant volume of data, and the use of specific software tools can assist in this process. Currently, several LCA software tools are available on the market, the use of which may be more extensive in one software than in others due to many elements. Creating a LCA or a MFA is a long process and would require a specialist that knows how to operate the tools in order to come up with a useful result that can help out the company with their future decision making. That is why many companies choose to outsource this task to sustainability professionals. Nevertheless, it is

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frequently observed that companies, having outsourced the creation of the LCA and gaining insights into the environmental impacts, often struggle with determining the next steps. The results they receive do not provide practical solutions for minimizing the Environmental Footprint (EF), but rather indicate whether the company is performing above average or needs to reduce its EF [He14]. The company management then needs to arrange another external firm that can consult them in the measurements that need to be taken in order for them to reduce their EF. Having to reach out to several companies in order to get the needed carbon reduction help may be easy for big companies, but many Small and Medium Enterprises (SME) can not afford all of this external help despite wanting to become more environmentally conscious [Be12]. This leads to the issue, which is to be studied in this research, about trying to present help, in the form of carbon reduction measures (CRM), to SMEs through their LCA or MFA reports.

The idea of the research is based on three datasets that would need to be synchronized with each other in order to present a viable solution as seen in Figure 1.

The first one entails the general industry data. This data is to be used in comparing the data of a company with other companies of the same or similar branch. The second one contains a dataset of different CRMs that help reduce the EF. The data here needs to be detailed and tailored in a special way to fit in with the other datasets. The final one is about the data which is exported after the completion of the LCA or MFA report. This research was concluded with the tool Umberto, which is a potent environmental management tool. It enables users to carry out sustainability evaluations, material flow analysis, and LCAs. Users of Umberto can model, assess, and improve how efficiently products, processes, and systems use resources and the environment. It offers tools for data management, analysis, and decision assistance, and it aids in assessing environmental impacts including carbon emissions and energy use [MGA04].

During the course of the research it is to be examined whether a connection between those three data sets can be found in order to offer the needed recommendations right after finishing the LCA. Another focus lies on researching what RS technique would be the most suitable for running a RS with theses specifications as well as the software architecture it would be built on.

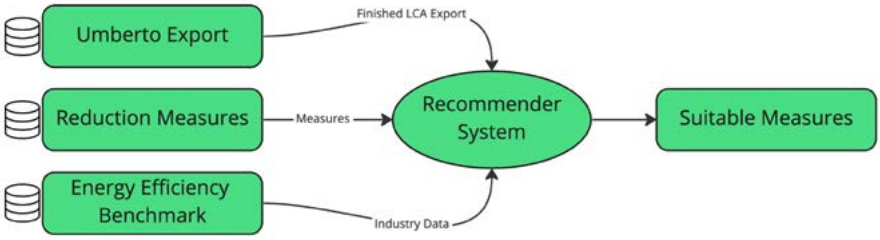

Fig. 1: Concept idea of how the recommender system would function

2 Related Work

Knowing how resource and energy efficiency can be achieved, many companies strive to attain them. Larger companies will be forced to invest money and time by hiring teams and creating a department with the goal of reaching higher levels of sustainability according to the European Parliament [Pa22]. However, SMEs have to rely on external firms that offer efficiency consulting. Consultants step in with a lot of knowledge and experience and usually have a hands-on approach that can help companies progress. The methods used vary from one consulting company to another. Many companies start by conducting a MFA, where they analyze the materials and substances used and try to manage their flows within the production line in a better way [iP22]. Additionally, consultants also inspect waste along with all the costs linked to it as well as the costs associated with all other sorts of losses. Finally, consultants implement flow simulations and energy management by comparing different scenarios. With this, they can create a sturdy knowledge base from which they can improve the company's decision-making [iP22]. Environmental Management Information Systems (EMIS) serve as a tool to support and facilitate these efforts by providing data, analysis, and tracking capabilities to guide organizations towards their carbon reduction goals. However, there are no EMIS which offer precise carbon reduction measures. EMIS can only help by highlighting patterns, trends, and areas of inefficiency, allowing their users to make informed decisions and implement carbon reduction strategies based on the analysis of the environmental data. There are consulting companies which offer assistance through direct questionnaires where a user would receive a recommendation upon answering a question such as the company Global Changer [Ch22].

3 Recommender Systems

RS are programs that aim to suggest the most appropriate objects (products or services) to specific users (individuals or businesses) by anticipating a user's interest in an item based on related information about the items, the users, and the interactions between the items and users [Bo13]. The most crucial feature of a RS is its ability to guess a user's interests by examining this user's activity and/or the behavior of other users to produce individualized recommendations [RV97]. In this research, however, the recommendations do not depend on the examination of user activities, since the user does not spend much time on the platform. What happens is that the system is fed information through the upload of the LCA export created using an EMIS tool, along with some directly entered information, and recommends based on that.

There are many RS techniques, however the most suitable one for this model comes from the hybrid filtering and is called the Knowledge Based (KB) recommendation technique. It works by presenting users with objects depending on information about the users, items, and/or relationships between them. Assuming there is a connection between a user's need and a potential recommendation, KB recommendations often preserve a functional

knowledge base that explains how a specific item satisfies a particular user's requirement [Bu02]. This method comes closest to fitting the needs of the RS since it could take the information from the used EMIS and connect it to the needs of the user. The RS would deploy and inference mechanism involving several steps. First of the Knowledge Representation where the relevant knowledge about the users is represented through the analysis of their LCA. Secondly the Knowledge Acquisition where the RS acquires explicit knowledge from the external databases and the targeted questions to the user. After that comes the Reasoning and Inference step which uses rule-based inference to draw conclusions. Lastly comes the Recommendation Generation using the inferred knowledge, the RS generates recommendations for users, suggesting CRMs that match their needs.

4 Purpose and Scope

The user group for a RS of this scale is extensive, as it is intended to be used by all industries in Germany and potentially globally. It must be easy to use and understandable for people working in small and large companies across all industries. Therefore, gathering user groups and understanding all their needs through surveys, focus groups, or interviews can be challenging given the diverse capabilities of the workers. In this case, a goal-based requirements analysis may be more appropriate than a user-based one [An96].

The tool should be able to recommend fitting measures to the users based on their export from the used LCA tool. As the user is looking for an easy and cheap way to find out what to do without having much knowledge or wanting to spend money on sustainability consultants the user would need an easily usable system which gives out CRMs based on the current Data Export from the LCA tool. The measures should be described in detail and have steps to follow so that an inexperienced user may understand and follow them easily. The user should also get to compare their company with the competitors in order to know where the industry average lies.

The system will be strictly for business use, so the main use will be on desktop computers and the prototype will not need to be developed in a responsive way for all screen sizes. The data input process will take place in offices, and the completion of subtasks for the measures will also be done in an office environment.

The desired user group could be the management of any given company. Many companies are starting to look into sustainable practices these days, so many managers are seeking ways to do that. Those companies may not be able to get a lot of information from other companies in the same branch because of the nature of the competitor relationship. Therefore, there is no interaction that takes place there. The only way for them to find out the measures is by contacting sustainability consultants. These interactions are then formal and happen after the signing of contracts.

The context here pertains to the management of a company. They would use the system after purchasing it, knowing that the product they have on their hands would be able to

provide them with carbon reduction solutions that fit their requirements very well. The system should be able to provide recommendations based on the EMIS export, which has a clear data-filled model of the company's process. The system could be used in a variety of circumstances, such as the need to reduce material to save money, reduce emissions to reach a sustainability goal, or become more attractive to customers.

This software tool should enable users to upload finalized exports from an LCA tool and display recommended measures based on factors such as highest benefit and lowest expenses. It should provide detailed information for each measure, including subtasks and overall benefits in terms of carbon emission reduction, cost savings, and more. The tool should offer visualizations for comparing performance to other companies in the same industry and include various filtering and sorting functions to enhance user experience and data analysis.

At the time of this research, the competitors are sustainability consultants and online search engines. Market revenues and annual growth from environmental consulting companies is growing rapidly [En21]. The advantage of them is that they offer well-thought-out and professional advice in these fields. The problem is the high expenses that many SMEs cannot afford. The other option is to have people at the company dedicate their time to finding solutions through research. However, this method, although much cheaper, may only come up with simple advice, and the individuals might lack the knowledge to complete the newly found measures. Both of the current solutions have their pros and cons. That is why this solution might turn out to be an affordable way to deliver well-thought-out measures to the end-users of the system.

With the questions answered, an overall view has been established about the system and where it should be headed.

5 Systems Architecture

The concept of this research is relatively simple which makes the system small. There are few inputs and outputs which makes it easy to define a sharp boundary. Figure 2 shows the internal system which is defined as what can be controlled by the audited system, while everything outside that internal system is utilised by the system but controlled by third parties. The borders of the internal system depicted in the figure represent the system boundary. The users of the system connect to the web server which needs to be protected by a firewall on both ends. Through that they gain access to the internal system. All user interactions happen through that point which is why it needs to be very secure since the company using it might be sharing sensitive information there. The web server would also be connected to a backend SQL Server which would be responsible for storing and accessing the users information and data. This server can be connected to a storage provider which lies outside of the internal system. The storage provider is a third party that provides the server space needed for that system to store the information. The second group of people interacting with the system are the employees who manage it. They lie inside the boundary

and can access the organizations endpoints and authenticate through the active directory of the endpoint. The employees should also be able to store and access information on an external sharepoint. The whole information system can be monitored by a Hosted Security Service (HSS) along with its different components such as the firewalls and the web server.

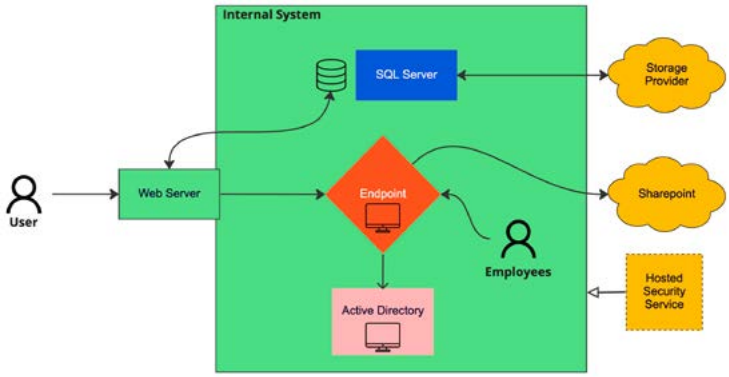

Fig. 2: The internal system architecture for the recommender system

6 Discussion

The results indicate that the RS, using a combination of a database provided by Global Changer [2], a company which delivers CRMs to their users, and an export from Umberto, would not be suitable for delivering useful results to users. The research went through the CRMs and examined each one to see if the Umberto export has enough information to suggest that measure. However, the majority of the measures cannot be recommended based on the information due to a lack of data. Both databases do not have much in common to be combined in a useful way. The Reduction Measures Database used in the research provides only 113 CRMs. Each measure holds 36 columns of data to it but 11 of them hold almost no data.

The research conducted faced several limitations, which have impacted the scope and validity of the findings.

1. Time constraints: The research was completed within a timeframe, which did not allow for a comprehensive examination the measures taken by different industries. This may have resulted in a narrower focus of the study.
2. Sample size: The sample size used for the CRMs was limited, which has impacted the generalizability of the findings. A larger sample size could have provided a more representative view of the measures taken by different industries and a more robust analysis of the results.

[2] https://www.globalchanger.com/de/

3. Data availability: Limited access to CRM and EMIS data from consultant companies and the unavailability of data from other sources constrained the study's scope and validation potential.

4. Methodological limitations: Researcher's training and experience influenced the choice of methods, potentially impacting validity. Alternative methods and deeper RS technique analysis could have yielded different or more reliable results.

5. Financial constraints: Insufficient resources curtailed the study's breadth and depth, including limitations in fieldwork and access to specialized equipment, compromising data quality and result validity.

6. Ethical considerations: Collaboration with consulting companies imposed restrictions on reaching out to experts for validation or insight, hindering result validation and the opportunity to strengthen conclusions with expert input. Limited access to official LCA exports further restricted data availability.

It is important to acknowledge these limitations and to consider them when interpreting the results of the research. While these limitations may have impacted the scope and validity of the findings, they do not diminish the importance of the research or the potential for future research to build upon the findings of this study.

7 Outlook and Prospects

The study has sought to explore the feasibility of a RS as a means to suggest CRMs to SMEs.

Future Implications: The research conducted holds significant implications for the future of CRMs, specifically in terms of their implementation and potential benefits. The RS offers a cost-effective approach for SMEs with limited budgets to achieve quick emissions reductions. The study provides insights into the existing databases, outlining their current information and potential usage within a RS.

Further Research: Opportunities for future research exist to expand upon the findings of this study. Due to limitations in sample size and data availability, additional investigations could explore alternative CRMs, enhance data collection, and examine industry-specific strategies. Exploring reduction measures employed at various production sites, analyzing associated machinery, and assessing their impact on carbon emissions would be valuable. Sorting measures by industry and gathering more data on their effects would contribute to a more comprehensive understanding of the RS's potential.

The research has demonstrated the need for a RS that can easily provide companies with information about the most effective CRMs based on their specific production process and

machinery. The research provides a foundation for future work, including the development of a prototype RS that can incorporate more data or improved data gathering methods, if they become available.

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