NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF COMPUTER SCIENCE

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Master in Computer Science

DESIGNING FOR SUSTAINABILITY: SUPPORTING THREE ORDER OF EFFECTS

MASTER IN COMPUTER SCIENCE AND ENGINEERING

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Abstract

In the ever-evolving landscape of software development, integrating sustainability aspects has become imperative. The Sustainability Awareness Framework (SusAF) is a valuable tool that helps experts to identify and reason about the short-, medium-, and long-term impacts of its system across the five dimensions of sustainability. However, the absence of tools supporting the utilization of this framework poses a significant challenge. The challenges in SusAF's usability and consequently the time that it takes to effectively be completed, make the work, of experts in this field, (even more) difficult. The shortage of an easy-to-use editor for SusAF intensifies the complexity of the integration of sustainable concerns. To address this problem, we propose a conceptual model and a SusAF editor tool (GreenSusAF) to support the integration of sustainability practices into all software projects. The proposed SusAF editor is designed to help with the identification and analysis of sustainability impacts and to support the integration of sustainability concerns during requirements elicitation and analysis. By offering a user-friendly interface, it empowers software developers to be able to incorporate sustainability considerations into their work in a easy and intuitive manner. To evaluate the SusAF editor and, by extension, the conceptual model, we conducted a detailed study. The evaluation aims to understand participants' perceptions of SusAF, present the developed tool, and collect feedback on its functionalities, ease of use and suggestions for improvement. The results of the study indicate that SusAF is not familiar to the majority of participants, but everyone recognizes the value of the framework in raising awareness of the sustainability impacts of the systems. In addition, participants recognize the beneficial influence that a new supporting tool can bring to SusAF. Results also show that besides helping the utilization of SusAF, the tool also promotes its use to new users.

Keywords: Requirements Engineering, Sustainability, SusAF, Software Development

Resumo

No panorama em constante evolução do desenvolvimento de software, a integração de considerações de sustentabilidade tornou-se imperativa. O SusAF é uma *framework* que ajuda os peritos a identificar e a refletir sobre os impactos a curto, médio e longo prazo do seu sistema de software no ambiente circundante, nas cinco dimensões da sustentabilidade. No entanto, a ausência de ferramentas auxiliares que apoiem a utilização desta framework é um desafio. As dificuldades da usabilidade do SusAF e, consequentemente, o tempo que demora a ser efetivamente aplicado, dificulta o trabalho dos especialistas na área. A falta de um editor fácil de usar para o SusAF intensifica a complexidade da sua utilização. Esta dissertação propõe um modelo conceptual e um editor para o SusAF (GreenSuSAF) com o objetivo de apoiar a integração de práticas de sustentabilidade em todos os projetos de software durante a elicitação e a análise de requisitos. O editor foi concebido para melhorar a identificação e a análise de impactos da sustentabilidade, oferecendo uma interface de fácil utilização. Para avaliar o editor para o SusAF e, por extensão, o modelo conceptual, realizámos um questionário para compreender as percepções dos participantes sobre o SusAF, apresentar a ferramenta desenvolvida e recolher feedback sobre as suas funcionalidades, facilidade de utilização e sugestões de melhoria. Os resultados do estudo indicam que embora o SusAF não seja familiar para a maioria dos participantes, todos reconhecem o valor da *framework* para aumentar a consciência sobre os impactos dos sistemas na sustentabilidade. Além disso, os participantes reconhecem os benefícios que uma ferramenta de apoio ao SusAF pode trazer. Os resultados mostram ainda que para além de auxiliar a utilização do SusAF, a ferramenta também promove o seu uso.

Palavras-chave: Engenharia de Requisitos, Sustentabilidade, SusAF, Desenvolvimento de *Software*

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Acronyms

LCDP Low-Code Development Platform *(p. 33)*

PICOC Population, Intervention, Comparison, Outcome, and Context *(pp. 14, 16)*

RE Requirements Engineering *(pp. 2, 5, 23, 24)*

SusAD Sustainability Awareness Diagram *(pp. 11, 36, 52, 72)*

SusAF Sustainability Awareness Framework *(pp. ii, iii, 1, 5, 11, 16, 23–25, 33, 51, 72)*

1

Introduction

The present work was motivated by the need to develop an editor for the SusAF to help the identification and analysis of sustainability impacts and to support the integration of sustainability concerns into the initial phase of the development of software systems. Recognizing the growing significance of incorporating sustainability considerations into software development, and the lack of tools to assist the application of the SusAF, to study sustainability concerns, raised the clear need for a dedicated tool to help the use of SusAF.

This initial chapter provides an overview of the context and motivation driving this dissertation, defines the problem statement, and presents the objectives, contributions, and structure of this document.

1.1 Context and Motivation

Acknowledging the significance of sustainability in modern software development has become vital [2]. It is becoming crucial to incorporate sustainability into software development as society places a greater emphasis on social and environmental responsibility [3]. In this context, SusAF is known as a valuable instrument [4]. However, despite its importance, the practical application of SusAF faces challenges due to its less-than-intuitive nature and the scarcity of supportive tools [5]. This work is motivated by the need to bridge this usability gap by developing a conceptual model and a dedicated editor for SusAF. The motivation stems from the realization that if we could help every software developer to use SusAF more effectively, this framework could support significantly in integrating sustainability into different application domains.

The objective is to provide developers and requirements engineers with a conceptual model and an intuitive, user-friendly tool, facilitating the seamless integration of sustainability considerations into their projects.

1.2 Problem statement

The problem statement of this dissertation revolves around the shortage of dedicated tools to facilitate the effective application of SusAF, during the initial phases of software development, especially in Requirements Engineering.

The following discussion describes the recognized problem and the subsequent challenges that stem from it.

Problem: There is a shortage of dedicated tools to facilitate the effective application of SusAF during Requirements Engineering

Despite the emerging frameworks and tools over the years to integrate sustainability into software projects, certain Frameworks, particularly SusAF, face some difficulties. There are few or no auxiliary tools to help experts apply SusAF effectively or to accelerate and ensure accurate implementation of the framework. During this study we investigate the existence of such tools, and how the creation of a new tool could impact the integration of sustainability during the initial stage of software development.

The problem was decomposed into 4 main challenges:

Challenge 1: Characterize the background

The first challenge involves providing a clear explanation of the key concepts of this dissertation, presented in Chapter 2. This includes reviewing related articles and papers to fully understand the concepts.

Challenge 2: Characterize the state of the art

Then, we need to investigate the current state of the art on the integration of sustainability into software development, namely using SusAF. Yet a basic *ad-hoc* search is insufficient, we must gather the most complete possible collection of bibliographic references. To ensure that we get a comprehensive overview of the state of the art, we conducted a systematic mapping study, presented in Chapter 3.

Challenge 3: Build a conceptual model

Using the knowledge gathered from the background and the state of the art (Challenges 1 and 2), we started the conceptual modeling of the tool (Chapter 4) to provide an outline for its composition.

Challenge 4: Develop a tool to assist the use of the Sustainability Awareness Framework

Following the conceptual model, we create a specific tool that helps SusAF be successfully applied in software development, especially during Requirements Engineering (RE) (Chapter 5). Finally, to evaluate the tool and the individual's perceptions of SusAF, we conducted a questionnaire and presented its results in Chapter 6.

1.3 Objectives

In this dissertation, we aim to do a conceptual model of the relevant concepts to build a tool to support the application of the SusAF during requirements elicitation and analysis and to be capable of overcoming the problem stated.

1.4 Contributions

This dissertation's contribution is to provide software developers with a tool to facilitate the integration of sustainability into software systems with:

- A systematic mapping study on the integration of sustainability into software development, namely using SusAF (Chapter 3);
- A conceptual model of the tool (Chapter 4);
- A tool editor to facilitate the application of the SusAF, during requirements elicitation and analysis (Chapter 5);
- An assessment of the created tool, considering participants' perceptions about SusAF, and the impact of the tool on the effective integration of sustainability considerations into software development processes (Chapter 6).

1.5 Structure of the document

There are 7 chapters in this thesis, and they are organized as follows:

- **Chapter 1: Introduction,** presents the context and motivation for the dissertation, the problem statement, and the identified related challenges, then this chapter concludes with an explanation of the objectives and expected contributions.
- **Chapter 2: Background,** explains the most important concepts for this dissertation, beginning with requirements engineering, then sustainability, then the SusAF tool, and lastly the systematic mapping studies approach.
- **Chapter 3: Related Work,** gives a summary of the research conducted, including a systematic mapping study. It covers the methodology, findings, and discussion of the research findings.
- **Chapter 4: Conceptual modeling of the tool,** provides a conceptualization of the tool, outlining its composition.
- **Chapter 5: GreenSusAF,** introduces the tool, called GreenSusAF, along with a user manual. Additionally, it presents the application of the tool using a real-case scenario.

- **Chapter 6: Evaluation,** presents the evaluation of the GreenSusAF tool. Displaying the questions alongside the answers and a brief discussion of results.
- **Chapter 7: Conclusions,** outlines the main conclusions of the dissertation and provides suggestions for further work.

2

Background

This research work is driven by the objective of proposing a conceptual model and a Sustainability Awareness Framework (SusAF) editor to facilitate the application of the framework during requirements elicitation and analysis.

The main goal of this chapter is to briefly explain some concepts that are important for this dissertation, including the principal concepts of Requirements Engineering (RE), Sustainability, SusAF, and how we carried out the systematic mapping study that is performed in Chapter 3.

2.1 Requirements Engineering

Software development has a vital phase called requirements engineering, which Pamela Zave defines precisely as follows: "Requirements engineering is the branch of software engineering concerned with the real world goals for functions of and constraints on the software systems. It is also concerned with the relationship of these factors to precise specifications of software behavior, and their evolution over time and across software families" [6]. Requirements Engineering involves the elicitation, analysis, specification, and validation of the software system's needs and constraints, the resulting requirements are then managed throughout the software development life cycle.

Within this segment, we present a summary of the requirements engineering activities.

2.1.1 Requirements Engineering activities

The traditional requirements engineering process is frequently divided into some activities, the five main activities are presented in table 2.1.1 [7].

Table 2.1: Requirements Engineering Activities

Activity	Description
Requirements Elicitation	Is the activity most frequently viewed as the initial stage in the RE process, and is the process of identifying the system requirements and constraints by understanding stakeholders' needs.
Requirements Analysis	Is the activity to review requirements in order to identify and address inconsistencies, and achieve requirements that meet stakeholders' needs.
Requirements Documentation	Involves gathering and documenting the requirements that were created in the preceding phase. The document should include: user requirements, the system requirements for the end-users; system requirements, an outline of the features, qualities, and constraints; and domain requirements, the main domain concepts.
Requirements Validation	Ensures that the specifications are unambiguous, comprehensive, consistent, and clear. Aims to guarantee the quality of what was previously done.
Requirements Management	The last activity of the RE process involves handling changing requirements. This is achieved by ensuring that they are appropriately tracked and analyzed. It also entails managing requirements in accordance with available resources, including time and budget.

These five activities represent a general set of main activities in the RE process. It is important to know that there is no single RE process that works for every organization, so, each one needs to create its own process.

In this dissertation, we will focus on the requirements elicitation and requirements analysis phases.

2.1.2 Requirements Elicitation

Requirements elicitation focuses on discovering and comprehending the requirements and expectations of users and project stakeholders, with the primary goal of successfully communicating this information to the system development team [8]. In the field of requirements elicitation, hundreds of techniques and approaches from different sources have been developed and used [8]. The selection of an elicitation technique is reliant upon the requirements engineer's time and resource constraints, and obviously to the nature of the information that must be obtained. According to Bashar Nuseibeh and Steve Easterbrook [9] we separate elicitation techniques into several classes:

- Traditional techniques
  - Interviews: are used as a means of verbally conversing with stakeholders to gather requirements for the system and understand its goals. Interviews could

be structured or closed (aim towards acquiring quantitative data), semistructured (also aim towards acquiring quantitative data), and unstructured or open (aim to comprehend what the user expects through open discussions with the stakeholders and gather qualitative data) [10].

  - Questionnaires: are simple methods that require less time and cost. They should be clear and well-structured to discover the true needs, goals, and limitations of the user. Still, this method fails in its ability to look for users' clarification on the subject [10].
  - Task Analysis: comprises creating a top-down task hierarchy of the system to determine the knowledge needed or used during system development [10].

- Group elicitation techniques
  - Group Work: is a widely used and frequently default technique for requirements elicitation, it is especially effective since it promotes cooperation and directly involves stakeholders. The wide range of stakeholders who are involved in the project makes these kinds of meetings challenging to plan [8].
  - Brainstorming: is a procedure where members of various stakeholder groups have casual discussions to quickly produce as many ideas as they can without concentrating on any in particular. It's essential to avoid going into extensive detail while doing this kind of technique. Usually, brainstorming does not aim to come up with a solution for big problems or make key decisions, instead, it is mostly used to create the project's initial mission statement and target system while promoting freethinking and expression, allowing the identification of fresh approaches to existing challenges [8].
  - Requirements Workshops: aim to gather stakeholder's requirements for the project. When compared to the brainstorming and group work techniques, the requirements workshops can offer a comprehensive set of requirements but are slower to collect the information. Since the requirements are obtained after multiple sessions, the resulting requirements can not be changed. This technique is only practical for large, complex projects and is thought to be efficient both economically and in terms of time [10].

- Prototyping
  - Prototyping: a prototype is an initial version of a product, and it is used to allow the user to have an early experience of the product and give their needed requirements for the upcoming version. Then, the received feedback is taken into consideration as an additional requirement, helping the investigation of potential solutions. This technique is useful to especially develop novel applications and to build GUI interfaces, however, the user often resists changes if

they have become used to a particular type of system, so prototyping can be costly both in terms of time and money [10].

- Modeling techniques
  - Scenarios: are used to discover and formulate detailed narrative descriptions of both existing and future processes required for the development of a software project. Scenarios are frequently utilized after gathering the initial requirements, and they characterize the actions and interactions between the user and the system. Using scenarios can help with requirement validations and test case development [10].
- Cognitive techniques
  - Repertory Grids: requests stakeholders to construct attributes and assign proper values to the set of certain domain entities on a grid and save requirements in a matrix. This technique is useful for identifying similarities and differences between information domains although its efficacy is insufficient to define particular distinctiveness for the complex requirements [10].
  - Laddering: seeks to obtain precise responses to a variety of questions from the stakeholders, which are then arranged in an understandable hierarchical order to help prioritize the needs of the stakeholders. The stakeholder's domain information is crucial to the effectiveness of this technique. It becomes complex and difficult to make changes, such as adding or removing requirements anywhere on the ladder, if the requirements are too extensive [10].
  - Card Sorting: involves the customer or stakeholders sorting a set of cards according to the names of the domain entities, with an overview of the criteria used to sort the requirements elicitation cards [10].
- Contextual techniques
  - Ethnography: is a method used to determine how users identify their needs, and how those needs are met by software [10]. This technique is helpful for collecting from the people the quality attributes that are necessary for the project's success, such as usability and efficiency [10].
  - Observation/Social Analysis: is one of the types of Ethnography, a requirement engineer visits and observes the customer's environment, where the software services are required to be performed. Additionally, the software engineer actively observes current processes, enhancing the authenticity of this technique while requirement engineers directly visit and observe the entire environment, allowing them to verify and validate requirements more accurately [10].

2.2 Sustainability

Due to the dependence of modern society on software systems, sustainability is becoming a more popular topic of study in requirements engineering and software. In the context of software and engineering requirements, sustainability is defined as the capacity of a socio-technical system to endure [11]. Consensus on what sustainability means continues to emerge despite numerous efforts to establish a concept. However, the Karlskrona Manifesto for Sustainability Design[1] offers a main focus to help create a shared foundation for the software and requirements engineering community to interact with sustainability by promoting a set of fundamental principles and commitments that serve as the foundation for sustainable design. The guiding principles emphasize how crucial it is to acknowledge that sustainability is an explicit consideration, even in cases where it is not the main goal of the system being designed. It further argues that sustainability should be seen as a concept that encompasses five dimensions: environmental, economic, social, individual, and technical. It also takes into account the long-term effects that systems may have [3].

Sustainability use and sustainability development are two relevant concepts that extend the sustainability definition [3].

2.2.1 Sustainable Use

Sustainable use of a system is determined by a function **F** and a time horizon **T**, which essentially means to ”use **S** in a way that does not compromise its ability to fulfill **F** for a period of **T**” [12]. This definition of sustainability seeks to establish a clear relationship between the concept of use and the adjective sustainable, which represents the capacity to persist across time [3].

2.2.2 Sustainable Development

Sustainable development is defined by the Brundtland Commission as development that ”meets the needs of the present without compromising the ability of future generations to meet their own needs” [13]. The term ”need,” which is essential to this definition, includes both the idea of shifting stakeholder requirements as well as a temporal dimension that includes both the present and the future [3].

2.2.3 Dimensions and the Three Order of Effects

Software-intensive systems work in complex socio-technical environments rather than in isolation, manifesting themselves in different dimensions [14]. There are connections between these dimensions. For this reason, if something happens in one system, it may affect one or more system dimensions [15]. Table 2.2 presents these various dimensions.

[1]For more information on the Karlskrona Manifesto for Sustainability Design, visit https://arxiv.org/pdf/1410.6968.pdf

Table 2.2: Five Dimensions

Dimension	**Description**
Individual	Focuses on sustaining the human capital of individuals involved in or affected by the system. ”One example is good trust of the user in the system to support their agency (as they will not work with the system, if they do not trust it).” [16].
Social	Concerns the sustainability of groups and the fostering of a sense of community. ”For example, structures of mutual trust and communication in a social system and the balance between conflicting interests” [17].
Environmental	Addresses the preservation of natural resources, emphasizing the importance of minimizing the environmental impact of the software system. ”It includes questions ranging from immediate waste production and energy consumption to the balance of local ecosystems and climate change concerns” [17].
Economic	Involves maintaining financial assets. ” It includes capital growth and liquidity, investment questions, and financial operations” [17].
Technical	Focuses on the durability of software systems and their infrastructure. ”It refers to maintenance and evolution, resilience, and the ease of system transitions” [17].

Table 2.3: Three order of effects

Effect type	**Description**
Immediate effects	These are the direct consequences of creating, using, and discarding IT products and services. They include the immediate impact of system features and the full life-cycle impacts.
Enabling effects	These are the indirect consequences that unfold over time as a result of the system’s usage. They involve opportunities for altering resource consumption and other modifications caused by the use of the system.
Structural effects	These are the long-term, systemic impacts that evolve from the continuous use of software systems. They lead to enduring changes at the macro level.

It's important to keep in mind that many of the effects[2] of sociotechnical systems take time to manifest. So, it is possible to distinguish between three orders of effects [15], presented in table 2.3. The degree of impact on the five sustainability dimensions is indicated by those three orders of effects [18].

2.3 SusAF Framework

SusAF, proposed by Duboc et al. [19], provides a guideline for conducting workshops or semi-structured interviews with stakeholders. It includes a diagram and five-question sets to facilitate discussions with the stakeholders on the sustainability impacts of software systems [19, 20]. These discussions may then lead to carrying out additional analysis by systems designers along with other stakeholders, possibly leading to modifications in the system requirements to attempt to minimize potential negative impacts while exploiting beneficial ones.

The main purpose of the framework is to raise awareness of the sustainability effects that a software system can have. Recognizing these future effects is crucial for all the stakeholders involved in designing the system, ranging from the customers who order it to the IT product managers and other parties affected by the system's implementation [3].

SusAF will analyze software systems through five dimensions, as shown in Table 2.2 and assess their impact across the first, second, and third orders of effects, introduced in table 2.3, to ensure a thorough evaluation of sustainability effects.

For each dimension, stakeholders are invited to engage in discussions by responding to a set of questions, exploring possible effects, and establishing connections between them.

The outcomes of the analysis are documented, including at least one Sustainability Awareness Diagram (SusAD) that offers a clear representation of the key effect chains [21], see figure 2.1.

Figure 2.2 illustrates the SusAD for the Airbnb booking platform example, as discussed in [19]. The Airbnb booking platform enables landlords to rent their houses or rooms to guests, introducing a range of effects captured in the diagram. Initially, the platform's core functionality allows property owners to rent their accommodations, positioning "rent rooms" as an immediate technical effect due to be the direct consequence of using this service. Subsequently, by renting their places, property owners receive payments for rentals, this is another effect but now on the individual dimension and is an enabling effect since it takes some time to happen. One fundamental economic effect of this platform is a rise in median long-term rent as a result of a decrease in the number of long-term rental properties, so the effect "Increase in rents" is categorized under the

[2]Systems' impacts, results, or changes that are prompted by systems, affecting the five dimensions, and manifest themselves over time.

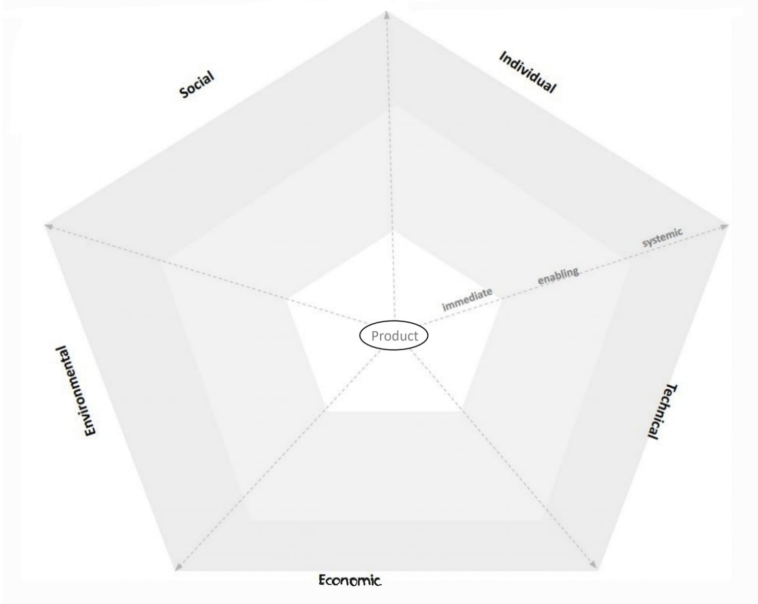


Figure 2.1: Sustainability Awareness Diagram

economic dimension and as a structural effect, reflecting its profound and lasting influence on the housing market. This increase promotes the gentrification of localities, also an effect in the economic dimension and as a structural effect, that ultimately leads to the increase of race separation, represented as the effect of "greater racial disparities", which is a structural effect within the social dimension.

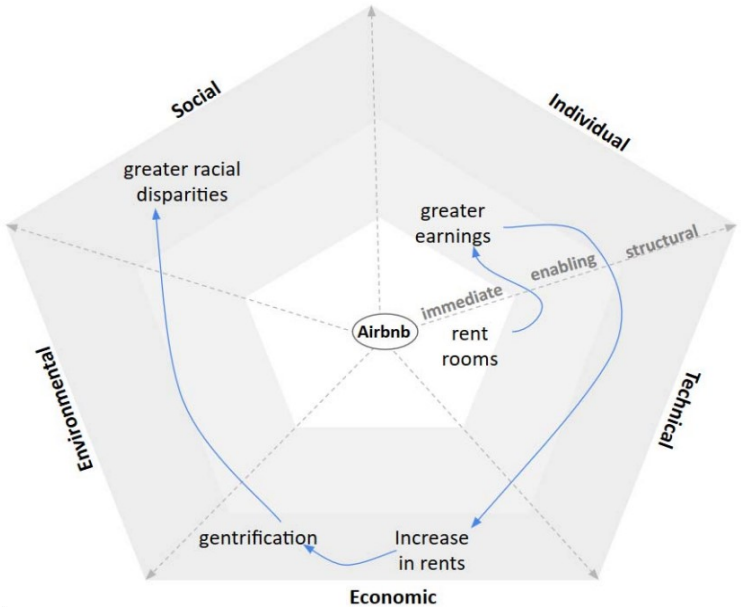


Figure 2.2: Airbnb's Sustainability Awareness Diagram [3]

One important objective of this work is to facilitate the creation of SusAD.

2.4 Systematic Mapping Studies

There are two methodologically distinct approaches to synthesizing research findings, each suited to different research objectives, the systematic mapping study [22] and the systematic literature review [22]. A systematic mapping study is a valuable tool to better understand the overview of a particular research area, identifying all the evidence related to a specific topic of interest and mapping it in a structured manner. The primary focus of a systematic mapping study is the classification and categorization of relevant information, conducting thematic analysis, and identifying publication venues. The articles are not assessed for their quality since the aim is not to establish the state of evidence [22]. The primary objective of this study is to give an overview of a research area and discover the amount and kind of existing studies and results [22]. A systematic literature review is a method for "identifying, evaluating and interpreting all available research relevant to a particular research question, or topic area, or phenomenon of interest" [23]. A systematic literature review might not be as appropriate as the systematic mapping study if it is detected, during the initial assessment, that probably it will exist insufficient evidence available on the topic [23].

We decided to choose to do a systematic mapping study, the essential stages include [22] (see figure 2.3):

1. **Definition of Research Questions**: Defining precise and comprehensive research questions to guide the mapping study's scope.

2. **Conduct Search**: Search for papers in several databases to make sure all possibly relevant research is found.

3. **Screening of Papers**: Evaluating the identified papers against predefined inclusion and exclusion criteria to retain only the relevant ones for further analysis.

4. **Data Extraction and Mapping Process**: Extracting pertinent data from the selected papers and categorizing this information according to predefined classification schemes to facilitate thematic analysis and mapping.

5. **Systematic Map**: Outlining the findings in a structured report, and discussing the implications of the observed patterns and gaps in the literature.

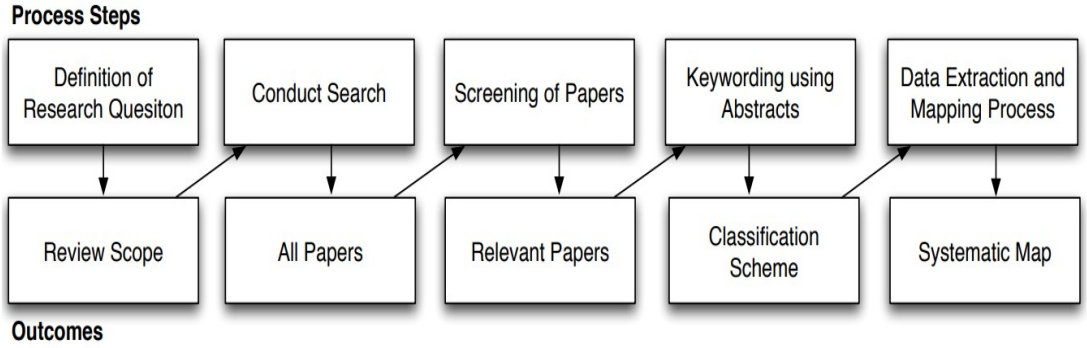


Figure 2.3: The Systematic Mapping Process [22]

2.4.1 Definition of Research Questions

In the planning stage, we develop a plan that will serve as the basis for performing the systematic mapping study, it will model and influence the outcomes and credibility of the entire process.

The first step is defining the research questions, it is the most important part because they drive the whole research [23].

They can be structured according to the Population, Intervention, Comparison, Outcome, and Context (PICOC) criteria, as presented in Table 2.4.1. This method recommends considering the question from the five points of view.

Table 2.4: PICOC analysis

P (Population)	Group of interest for the research
I (Intervention)	Methodology/tool/technology/procedure that addresses a specific issue
C (Comparison)	Methodology/tool/technology/procedure with which the intervention is being compared
O (Outcome)	Significant results from the study
C (Context)	Context in which the comparison takes place

Once the research questions are formulated, we can proceed with the creation of the search strings that will run on the databases.

2.4.2 Search strategy

This is the conducting stage, where we execute the search, formulating and using the search strings gathered in the previous stage while following the research plan. We can find the primary studies using search strings on scientific databases, i.e automatic search, or searching manually through studies from conferences or journal publications, i.e manual search. Using both allows having a more complete set of relevant studies [22]. The elaboration of the search strings should be based on the research questions, and they consist of a set of related keywords connected with ANDs and ORs logic operators. The

objective of this search is to collect a wide range of studies that may be relevant to our study.

2.4.3 Inclusion and Exclusion Criteria

After gathering the studies from the previous step, they are all assessed through some inclusion and exclusion criteria. The inclusion and exclusion criteria have been carefully designed to filter through papers, removing those that are not pertinent to the present research. [22]. By applying these criteria, any study that fails to meet all of the inclusion criteria, or meets any of the exclusion criteria, is excluded from consideration. This approach ensures that only the most pertinent studies are selected for analysis and extraction of pertinent data for the research questions.

2.4.4 Data Extraction and Mapping

At this stage, a pre-designed form (such as Excel sheets) is used, which contains specific fields to record the basic information of each paper(Title, URL, Date of publication, and Authors). Furthermore, additional fields are included to record relevant information to answer the research questions.

The frequency of publications for each category is the main focus of the findings analysis. This enables the identification of gaps and opportunities for further research by highlighting the areas that have received the most attention in previous studies [22].

2.4.5 Analysis and Reporting

Analysis and Reporting is the final phase of the systematic mapping study, is where the extracted data is analyzed to respond to the established research questions. Results are then documented and presented in a structured way. This facilitates a clear understanding of the findings.

2.5 Summary

In this chapter, we have presented a brief overview of the key concepts relevant to our work. Beginning with the definition of Requirement Engineering and its activities, to Sustainability and its dimensions and order of effects, to an introduction of the Sustainability Awareness Framework, and finally to the explanation of what is Systematic Mapping Study. In the next chapter, we will actually perform a systematic mapping study.

3

Related Work

To address the scope of our research, we initiated our investigation with a systematic mapping study to conduct a thorough and encompassing analysis of the current state of the art regarding the integration of sustainability considerations in software development using SusAF. Through this study, we aim to comprehensively explore and categorize existing literature, methodologies, and frameworks related to the integration of sustainability principles using SusAF.

3.1 Research methodology

A mapping study consists of the following stages: definition of research questions, search strategy, inclusion and exclusion criteria, data extraction and mapping, and analysis and reporting [22].

3.1.1 Definition of Research Questions

We begin the mapping study's initial phase by developing the research questions and corresponding search strings to use in the digital library (Google Scholar). An effective approach for constructing the research questions is to structure them in terms of Population, Intervention, Comparison, Outcome, and Context (PICOC) [22]. Using the PICOC method we can build the researched questions presented in table 3.1.1. The main research terms are highlighted in bold.

Table 3.1: PICOC analysis

P (Population)	Articles/papers about engineering requirements, **sustainability on software systems**, and **SusAF**, considering all types of **software developement**.
I (Intervention)	Searching on online libraries using search strings containing important keywords.
C (Comparison)	No comparison will be made
O (Outcome)	Overview and analysis of the state of the art.
C (Context)	Elaboration of a Master Thesis

Researched Questions

Following the PICOC analysis, the following research question was determined:

How can a sustainability awareness framework tool support the integration of sustainability concerns in the software development process?

To allow us to conduct a more in-depth search we divided the main question into four sub-questions, see table 3.1.1.

Table 3.2: Research Sub-Questions

Sub-Questions	Research Questions
RQ1.	What is the importance of **sustainability** in software projects?
RQ2.	What are the main challenges to integrating **sustainability** in software projects?
RQ3.	What is the importance of **RE** to integrate **sustainability** in software projects?
RQ4.	What is the impact of the **sustainability awareness framework** on the development of software projects?

3.1.2 Search strategy

The objective of the search strings is to gather all the results that relate to the formulated researched questions. After collecting all the keywords from each researched question (RQ) the search strings can be established.

"Sustainability" AND "Requirements Engineering" AND "Sustainability Awareness Framework"

We gathered 57 papers through the search using the established search strings.

3.1.3 Inclusion and exclusion criteria

The establishment of inclusion and exclusion criteria is a crucial step in the research process of selecting the relevant study material. When utilizing a digital library, like Google Scholar, to search for studies, many may not align with our research questions, lack credibility, i.e., if the article comes from slides or blogs and not from workshops, conferences, or journals, not be in English, or the full paper may be inaccessible. Analyzing these aspects is essential when evaluating the relevance of the identified papers [23]. In table 3.3 are presented the inclusion and exclusion criteria for the first iteration, where only the title and abstract were analyzed.

Table 3.3: Inclusion and Exclusion Criteria

Inclusion Criteria	
IC1.1	The article is from a conference, workshop, or journal.
IC1.2	The article is available in full text.
IC1.3	The title and/or abstract of the article is related to one of the research questions.
Exclusion Criteria	
EC1.1	The article is a duplicate.
EC1.2	The article is not in English.
EC1.3	The article is informal (slides, extended abstracts, blogs).
EC1.4	The article is an introduction to special issues, books, workshops, or posters.
EC1.5	The title and/or abstract do not relate to any of the research questions.
EC1.6	PDF not available.

In the first iteration, we excluded 34 papers. Through the exclusion criteria EC1.1 which handles duplicates, we excluded 5, with the exclusion criteria EC1.2 which deals with papers not written in English, we removed 9 papers, with the exclusion criteria EC1.3, which handles papers that are informal, we excluded 7, with the exclusion criteria EC1.4, which cares for papers that are introductions, we excluded 2, with the exclusion criteria EC1.5, which addresses papers that have a title or abstract not related to any researched questions, we excluded 9, and finally with the exclusion criteria EC1.6, which deals with PDFs that are not available, we removed 2.

The remaining studies were then entirely read and analyzed during the second iteration. Table 3.4 presents the inclusion and exclusion criteria used in the second iteration.

Table 3.4: Inclusion and Exclusion Criteria

Inclusion Criteria	
IC2.1	The article content has pertinent information regarding one or more research questions.
Exclusion Criteria	
EC2.1	The article content does not answer any of the research questions.
EC2.2	The article mainly discusses challenges and problems in this domain but does not provide any beneficial solution or suggestion to solve such problem

In the second iteration, we started with 23 papers. Using the exclusion criteria EC2.2, which handles papers whose content does not provide any beneficial solution or suggestion to solve the problems that it discusses, we excluded 2 articles.

We ended up with 21 papers after both iterations.

The table 3.5 provides a summary of the number of all identified articles and also the number of the excluded ones during the study.

Table 3.5: Summary of the automatic search

	Query
1st Iteration	57
EC1.1	-5
EC1.2	-9
EC1.3	-7
EC1.4	-2
EC1.5	-9
EC1.6	-2
2nd Iteration	23
EC2.1	0
EC2.2	-2
Total	**21**

3.1.4 Data Extraction and mapping

To facilitate the process of data extraction, we created an Excel worksheet with the basic information of each paper, namely the title, the URL, the date they were published, and the authors, with the inclusion and exclusion criteria and the fields to record relevant information to answer the research questions. The template can be found in the table 3.6.

In total, this research has 21 articles selected, all selected automatically. All articles are in the table 3.7.

Table 3.6: Extraction Sheet

Paper Information	
Title	
URL	
Date Published	
Authors	
Inclusion Criteria	
Inclusion Criteria for the iteration	
Exclusion Criteria	
Exclusion Criteria for the iteration	
Relevant Information	
Goal of the Study	
Requirements Engineering Definition/Importance to Sustainability	
Sustainability Definition	
Importance of Sustainability	
Challenges to Integrate Sustainability	
Mentioned Tools, Frameworks or Approaches	
SusAF Definition	
Dimensions, Dependencies, and Effects of 1st, 2nd, and 3rd Order	
Techniques Used to Represent Dimensions	
Conclusion	
Accepted?	
Requires Discussion/Further Thinking?	

Table 3.7: List of all Papers

Paper Titles	**Reference**
Requirements engineering for sustainability: an awareness framework for designing software systems for a better tomorrow	[3]
Application of the Sustainability Awareness Framework in Agile Software Development	[20]
Do we Really Know What we are Building? Raising Awareness of Potential Sustainability Effects of Software Systems in Requirements Engineering	[19]
SusAF Welcomes SusApp: Tool Support for the Sustainability Awareness Framework	[21]
Requirements Engineering Knowledge as a Foundation for a Sustainability-Aware Scrum Framework	[24]
From Sustainability in Requirements Engineering to a Sustainability-Aware Scrum Framework	[25]
Transforming our World through Software - Mapping the Sustainability Awareness Framework to the UN Sustainable Development Goals	[26]
Vision Paper: The Sustainability Awareness Framework (SusAF) as a De-Facto Standard?	[4]
Raising awareness for potential sustainability effects in Uganda: A survey-based empirical study	[11]
Application of Sustainability Awareness Framework in Software Engineering Courses: Perspectives from ICT Students	[5]
On the Importance of a Requirements Elicitation Framework to Ensure Sustainability in the Digital Education Ecosystems	[27]
Requirements engineering for sustainable software systems: a systematic mapping study	[7]
How Could We Have Known? Anticipating Sustainability Effects of a Software Product	[28]
Sustainability for Artificial Intelligence Products and Services - Initial How-to for IT Practitioners	[29]
Software Sustainability: A Design Case for Achieving Sustainable Pension Services in Developing Country	[30]
The Connection between the Sustainability Impacts of Software Products and the Role of Software Engineers	[31]
Towards Automatically Identifying Potential Sustainability Effects of Requirements	[14]
The ”Vattn” Case: Analyzing Sustainability Impacts in a Software Startup	[18]
Iterative Sustainability Impact Assessment: When to propose?	[32]
Sustainability Design in Mobile Augmented Reality	[33]
Transformation^2: Making software engineering accountable for sustainability	[15]

3.1.5 Analysis and reporting

The analysis and reporting stage, as suggested by the name, has the objective of analyzing all the found articles (either from automatic search or manually) with the aim of being able to answer the researched questions. For better comprehension, we have structured this section according to each research question presented in 3.1.1.

RQ1. What is the importance of sustainability in software projects?
The majority of the papers we reviewed recognize the importance of sustainability in the days we live. In our search, we found papers that discuss the increasing importance of sustainability due to modern society's reliance on software systems, especially in the field of requirements engineering [3, 19, 24], some also suggest adding sustainability as a qualitative attribute of software systems and addressing it in the same way as other non-functional requirements, such as safety or security [25], others highlight the positive impact of incorporating sustainability in both new and existing projects, particularly concerning the effects of software systems development [7, 11, 15, 30], and finally one talks about the importance of bridge sustainability and today's students with education [5].

The above reflects a growing understanding within the software engineering community of the critical role that sustainability plays in the longevity and effectiveness of software systems, aligning with the urgent global call for sustainable practices across all projects.

RQ2. What are the main challenges to integrating sustainability in software projects?
Unfortunately, there are plenty of significant challenges that still need to be overcome in integrating sustainability into software projects. The found articles mention some challenges, like the lack of knowledge and experience in requirements engineering in facilitating discussions on sustainability effects and integrating sustainability considerations into software projects [3, 7, 15, 20], the insufficient sustainability education on education institutions, this problem could be a cause for the previous challenge, sustainability education is neglected in many higher education institutions, leading to a lack of sustainability awareness among software engineering students and professionals [5, 11, 27], the neglection of sustainability in software design, often software systems are built without sustainability in mind [26, 32], the lack of suitable tools and methodologies to assess and integrate sustainability [15, 28] and finally the addition of complexity and cost concerns, the field of software engineering already faces issues like high costs and late deliveries and integrating sustainability analysis can be seen as adding to this complexity and cost, which may discourage its adoption [19].

Thus, overcoming these challenges requires an effort to improve knowledge and tools, improve educational approaches, and address practical concerns in the field.

RQ3. What is the importance of RE in integrating sustainability into software projects?

The articles that talk about the importance of RE describe it as the "key to sustainability". RE is considered one of the most important parts of the software development process, and the success or failure of a product can often hinge on the effectiveness of RE [3]. It is essential to understand the nature of software systems and how they affect the dimensions of sustainability, and the RE offers the first opportunity to think about sustainability effects [7, 24, 25]. The significance placed on RE highlights its essential role in guiding the overall trajectory of software development as well as making sure that sustainability considerations are integrated from the very beginning, helping to shape future software solutions that are more responsible and sustainable.

RQ4. What is the impact of the sustainability awareness framework on the development of software projects?

SusAF is recognized as one of the most mature approaches for identifying potential sustainability effects in the realm of software development [20]. It is specifically designed to raise awareness about the various sustainability effects that a software system might have within its intended context. This framework helps researchers and practitioners predict the immediate, enabling, and structural effects of social-technical systems. Moreover, the impacts take into account various aspects of sustainability, including social, environmental, technological, economic, and individual [4]. It also involves a participatory methodology, often implemented in workshops, encouraging stakeholder engagement for a deeper understanding of the sustainability impacts. These discussions may prompt further study by system designers and other interested parties, who may modify the requirements of the system to minimize any potential negative effects and exploit positive ones [3]. Companies frequently recognize the immediate effects of their technological products and services, however, SusAF pushes designers and companies to consider the wider picture and the systemic chain of effects of their IT systems [29]. Many practitioners in this field often express concerns about their lack of knowledge regarding incorporating sustainability into their projects [4]. This gap can lead to challenges in creating software that is mindful of its long-term effects. However, the SusAF presents appropriate assistance for this problem [11]. By involving software development workers with the guidelines and question sheets provided by SusAF, it is possible to facilitate their shift towards a sustainable software design process. SusAF's incorporation into their development processes can greatly improve their capacity to take sustainability issues into account and deal with them [30].

However, some limitations of the SusAF framework have been identified, including the considerable time required to apply the process, the excessive use of paper, difficulties in initiating the SusAF process without a clear starting point, and a lack of detailed guidance on addressing threats and opportunities [5], overcoming these issues could significantly enhance the framework's impact on projects. There are already some existing tools to support SusAF, one called SusApp, which is a software tool to support stakeholders when applying SusAF by simplifying documentation and the visualization of effects

[21], and the other one named SuSoftPro, that is useful in RE for tracking changes at the product vision level, documenting sustainability impacts, and visualizing the results [24], both of these tools are supposed to assist SusAF to positively impact the development of software systems.

3.2 Threats to validity

The use of an automatic search process to gather relevant literature poses some threats to validity. Even though we tried to optimize our search strings they can be incomplete or inaccurate, the effectiveness of an automatic search is heavily dependent on the choice of the search strings. Also, there is a risk that important articles might have been excluded because their PDF is unavailable or because it is in another language. A set of inclusion and exclusion criteria was created to make the selection process for the study easier.

3.3 Summary

In summary, we have successfully established a comprehensive understanding of the related work by performing a systematic mapping study. By analyzing the set of relevant studies that we gathered, we were able to extract all the information that we thought relevant to our work and use it to answer our research questions. Here, the importance of integrating sustainability into software projects was recognized as an important concern and the challenges that this integration faces are also explored. The role of RE in this integration was investigated as well. Finally, we focused on the principal impacts that SusAF brings during the development of a project, talked about some framework problems, and mentioned two existing tools with their purpose briefly explained.

To conclude, it is clear that there is still a long way to go before software engineering fully integrates sustainability. There are a lot of opportunities for research, innovation, and education to help create software systems that will be more sustainable in the future.

4

Conceptual modeling of the tool

In this chapter, we elaborate on the conceptualization of sustainability, including the SusAF, which will serve as the backbone of the tool. To ensure that its goals and main users are well understood, we start by defining the target audience and stating its primary goals. Then a conceptual model is created, it provides an outline for the composition and functionalities of the tool.

4.1 Conceptualization of the SusAF's auxiliary Tool

4.1.1 Goals

The main purpose of the tool is to support the application of SusAF by offering a user-friendly and digital manner to engage with the framework.

The tool aims to:

- Help with the application of SusAF for a wide range of users, whether they have a high level of expertise in the area or low;
- Offer guidelines to apply SusAF;
- Potentially increase the use of SusAF on user's projects.

4.1.2 Target Audience

The main users of the tool are of course experts in the Sustainability field, particularly requirements engineers, business analysts, and decision makers, along with all associated stakeholders. However, the tool's functionality and design are made to be useful and accessible to a wider range of users. This inclusion guarantees that the tool may be used effectively by anyone interested in incorporating sustainable issues into their projects, regardless of their level of expertise. Therefore, the tool serves a broad audience that encompasses not just sustainability specialists and stakeholders but also professionals and students from other fields who are enthusiastic about adopting sustainability into their projects.

4.1.3 Conceptual model

We build our conceptual model using StarUML. In our conceptual model, it was possible to distinguish three main components: Application core, Sustainability considerations, and Requirements management. The ”Application core” represents the structure of GreenSusAF, which is responsible for the system’s core functionalities. The ”Sustainability considerations” encapsulate the effect hierarchy, the five dimensions of sustainability, and also their related key aspects. The systematic mapping study elaborated in Chapter 3, highlighted the increasing importance of sustainability in software projects and the challenges to its integration, such as the lack of supporting tools and awareness among software engineering students and professionals. The model seeks to address these challenges and promote the awareness of sustainability in software systems. The ”Requirements management” includes all project and requirements management, necessary for identifying project objectives and requirements, with functional requirements leading to the system’s initial effects. The systematic mapping study also showed the importance of Requirements Engineering in integrating sustainability into software projects, and described it as the ”Key to sustainability”. This is reflected in our model, where the system’s initial effects are defined by functional requirements, ensuring that sustainability considerations are considered in the project from the beginning.

Figure 4.1 illustrates the conceptual model separated into its three main components.

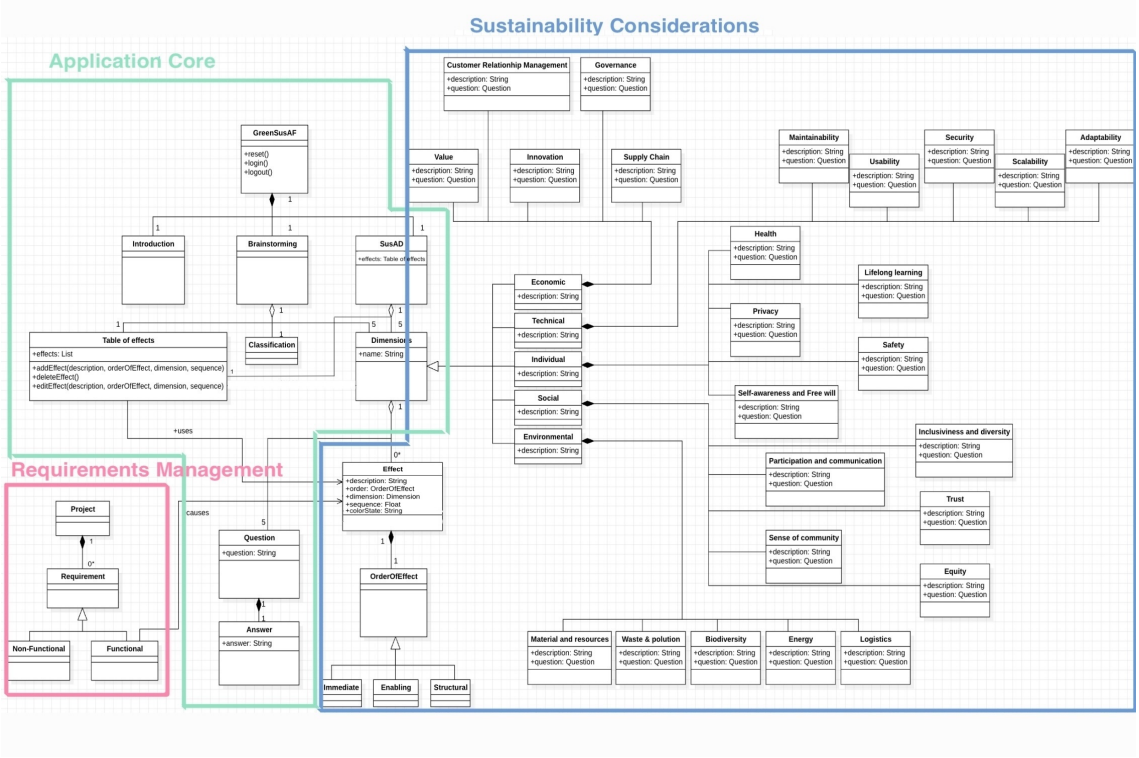


Figure 4.1: Conceptual model with main components

The application core component, as illustrated in figure 4.2, includes 9 classes:

- **GreenSusAF**: Represents the application itself, which includes the methods "reset()", "login()" and "logout()". **Relationships**: The class "GreenSusAF" is a composition of the classes "Introduction", "Brainstorming", and "SusAD", which implies that these classes can only exist if "GreenSusAF" exists;
- **Introduction**: Represents the GreenSusAF's introduction page, where the main concepts are introduced;
- **Brainstorming**: Represents the GreenSusAF's brainstorming page, designed to explore potential impacts that a system may have. **Relationships**: The class "Brainstorming" is an aggregation of the classes "Table of effects", "Classification" and "Dimension", meaning that these classes can exist independently of "Brainstorming", but "Brainstorming" uses and depends on them to function properly;
- **SusAD**: Represents the GreenSusAF's SusAD page, where we can find SusAD with all created effects positioned. **Relationships**: The class "SusAD" is an aggregation of the classes "Dimension" and "Table of effects", meaning that those classes can exist independently of "SusAD", but "SusAD" uses and depends on them to properly work;
- **Table of effects**: Represents the table that lists the system's effects, it includes the methods "addEffect(...)", "deleteEffect(...)" and "editEffect(...)". **Relationships**: The class "Table of effects" has an association "uses" with the class "Effect" (not presented in this component), it uses objects from the class "Effect";
- **Classification**: Represents an informative section aimed at raising some awareness about the importance of prioritizing effects;
- **Dimension**: Represents one of the five dimensions of sustainability. **Relationships**: The class "Dimension" is an aggregation from the classes "Question" and "Effect" (not present in this component), meaning that the classes "Question" and "Effect" can exist independently from the class "Dimension", however, the class "Dimension" needs them to work properly. Furthermore, the class "Dimension" is also a generalization of the classes "Economic", "Technical", "Individual", "Social", and "Environmental" (From the sustainability concerns component), implying that the properties and behavior of the "Dimension" class are passed down to these subclasses;
- **Question:** Represents a question to a specific dimension. **Relationships**: The class "Question" is a composition of the class "Answer", meaning that the class "Answer" only exists if the class "Question" exists.
- **Answer:** Represents a response to a correspondent answer.

The requirements management component, figure 4.3, includes 4 classes:

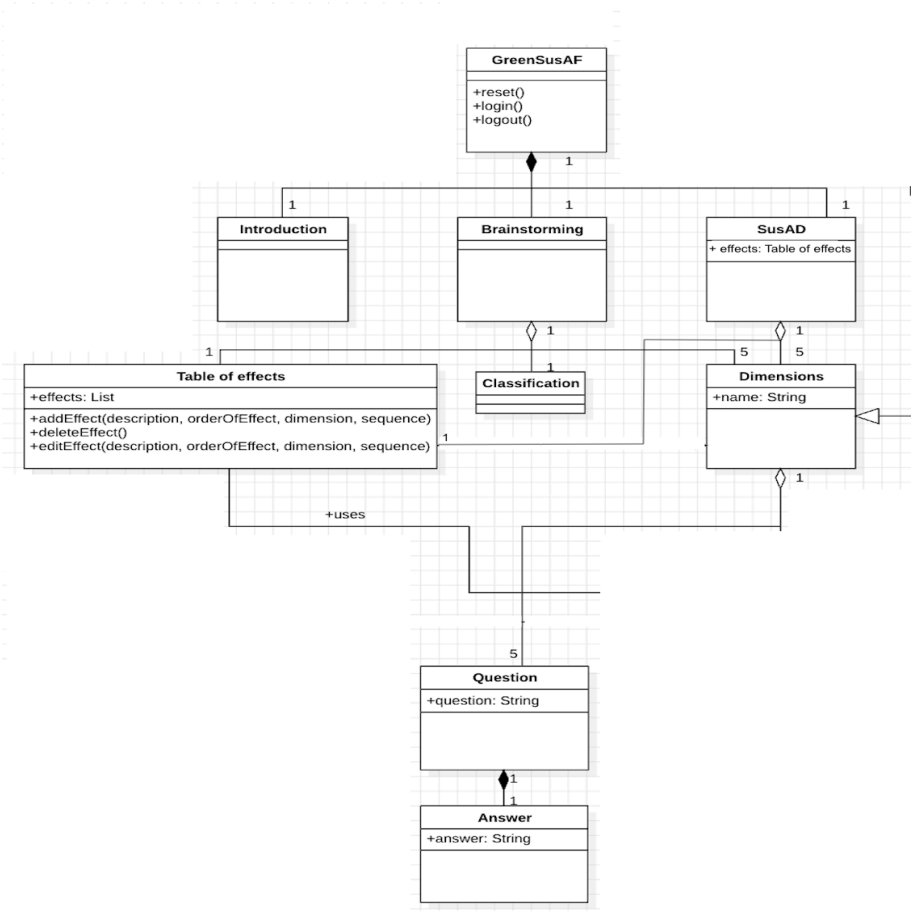


Figure 4.2: Application core component

- **Project**: Represent a project. **Relationships**: The class ”Project” is a composition of the class ”Requirement”, which implies that the class ”Requirement” can only exist if the class ”Project” exists;

- **Requirement**: Represent all requirements that a project has. **Relationships**: The class ”Requirement” is a generalization of the classes ”Non-functional” and ”Functional”, meaning that both ”Non-functional” and ”Functional” classes inherit the characteristics of the ”Requirement” class;

- **Non-Functional**: Represent the project's non-functional requirements (e.g. security);

- **Functional**: Represent the project's functional requirements (functionalities that the system should have). **Relationships**: The class ”Functional” has an association ”causes” with the class ”Effect” (not present in this component). This relationship indicates that each functional requirement triggers or produces certain effects in the system.

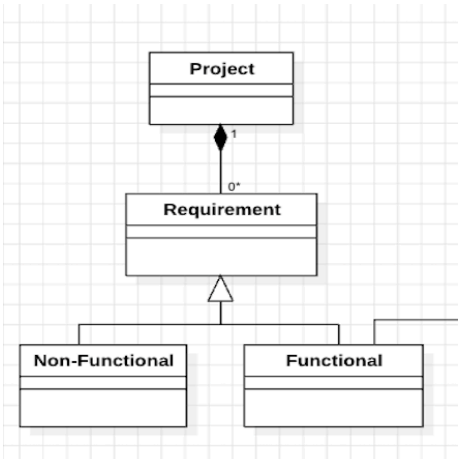


Figure 4.3: Requirements management component

The "Sustainability concerns" component, figure 4.4, comprise 35 classes:

- **Effect**: Represent an effect of the system. This effect has a description, an order of effect, a dimension, and a sequence number. **Relationships**: The class "Effect" is a composition of the class "Order of Effect", which implies that the class "Order of effect" only exists if the class "Effect" exists;

- **Order of effect**: Represent the order of effect that an effect has. **Relationships**: The class "Order of effect" is a generalization of the classes "Immediate", "Enabling", and "Structural" meaning that these subclasses inherit the properties and behavior of the 'Order of Effect' class;

- **Immediate**, **Enabling**, and **Structural**: Represent the immediate, enabling, and structural order of effect, respectively;

- **Economic**, **Technical**, **Individual**, **Social**, and **Environmental**: Represent the dimensions of sustainability. Each dimension has a description. **Relationships**: The class "Economic" has a composition relationship with the classes "Value", "Customer Relationship Management", "Innovation", "Supply Chain", and "Governance". This means that each of these classes only exists in the context of the class "Economic" and contributes to defining the economic dimension;

  The class "Technical" has a composition relationship with the classes "Maintainability", "Usability", "Security", "Scalability", and "Adaptability". Each of these classes is an essential part of the class "Technical" and defines critical aspects of the technical dimension;

  The class "Individual" has a composition relationship with the classes "Health", "Lifelong Learning", "Privacy", "Safety", and "Self-awareness and Free Will". These classes represent different aspects of the individual dimension and are necessary for defining this dimension;

The class ”Social” has a composition relationship with the classes ”Inclusiveness and Diversity”, ”Participation and Communication”, ”Trust”, ”Sense of Community”, and ”Equity”. Each of these classes contributes to understanding and defining the social dimension;

The class ”Environmental” has a composition relationship with the classes ”Material and Resources”, ”Waste and Pollution”, ”Biodiversity”, ”Energy”, and ”Logistics”. These classes are essential elements of the environmental dimension and are necessary for its definition.

- **Value**, **Customer relationship management**, **Innovation**, **Supply chain**, and **Governance**: Represent the key aspects of the economic dimension. Each key aspect has a question of the type ”Question” associated, the questions are about how the system creates or destroys value, how it influences the relationship between customers and businesses, and if it modifies the supply chain, governance, processes, or innovation activities [26];

- **Maintainability**, **Usability**, **Security**, **Scalability**, and **Adaptability**: Represent the key aspects of the technical dimension. the key aspects of the economic dimension. Each key aspect has a question of the type ”Question” associated, the questions seek to identify how the system is maintained and used over time, to show the system’s ability to adjust its functions to a changing environment, and whether the security and privacy are taken into account [26];

- **Health**, **Lifelong learning**, **Privacy**, **Safety**, and **Self-awareness and free will**: Represent the key aspects of the individual dimension. Each key aspect has a question of the type ”Question” associated, the questions are related to how the use of the system may affect the individuals themselves, including a person’s physical and mental health, their level of knowledge, privacy, safety, and capacity to in their surroundings [26];

- **Inclusiveness and diversity**, **Participation and communication**, **Trust**, **Sense of community**, **Equity**: Represent the key aspects of the social dimension. Each key aspect has a question of the type ”Question” associated, the questions are related to how the system may affect people’s sense of belonging, their trust in its surroundings, how they view other people, and how they participate in social groups, or whether they are being treated equally with others [26];

- **Material and resources**, **Waste and pollution**, **Biodiversity**, **Energy**, and **Logistics**: Represent the key aspects of the environmental dimension. Each key aspect has a question of the type ”Question” associated, the questions are related to how the system may affect the consumption of resources, the production of waste and pollution, and biodiversity [26].

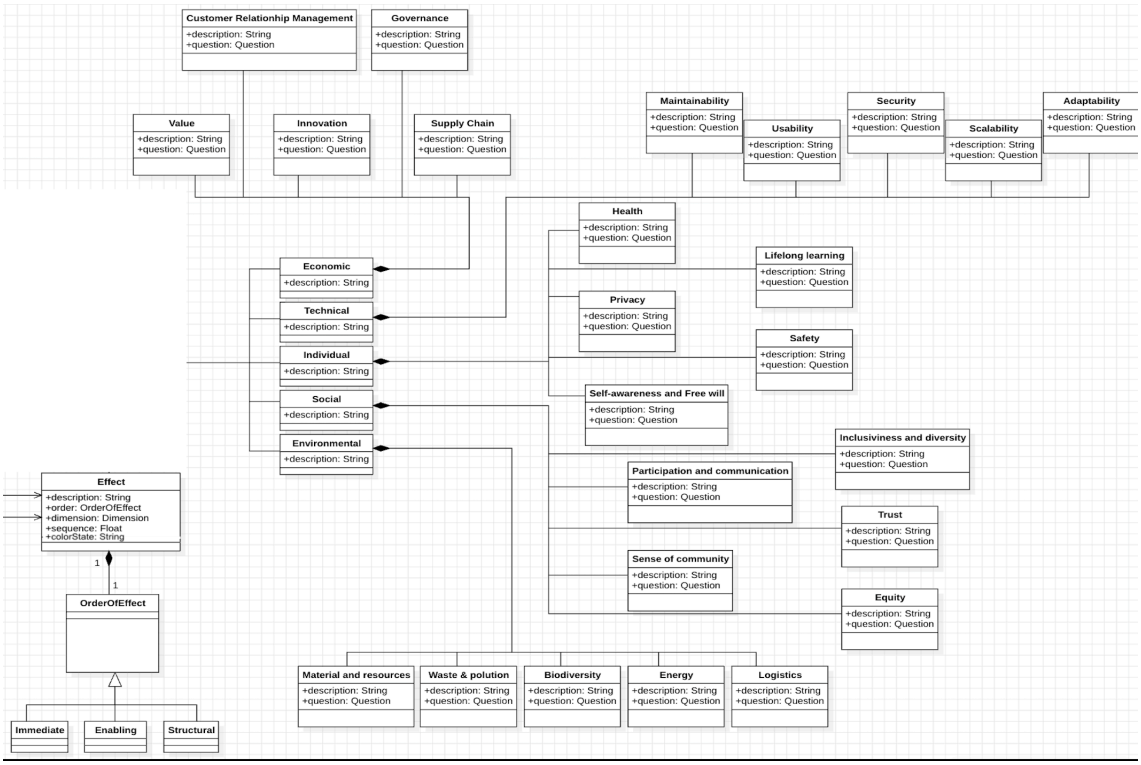


Figure 4.4: Sustainability concerns component

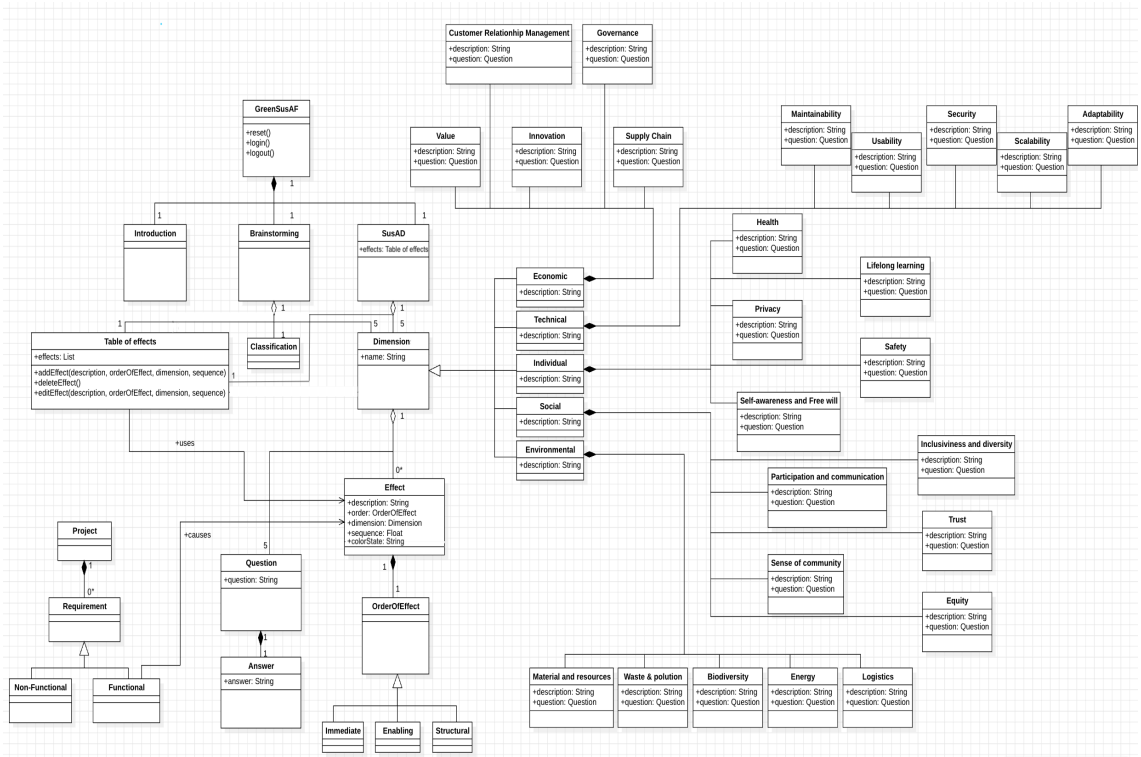


Figure 4.5: Conceptual model

4.2 Summary

In this section, we elaborated on the conceptualization of the tool, beginning with an analysis of its main goals and target audience. Following that, we presented the conceptual model of the tool, developed using StarUML. To provide a clear understanding of the conceptual model, we highlighted the main components of the model and provided a detailed explanation of each.

5

GreenSusAF

In this section we will present the GreenSusAF tool, showing its functionalities and exploring the various interfaces that it offers. Following this, we will go through a practical application of GreenSusAF by discussing its use in a case study, offering insights into how the tool performs in a real-world scenario.

This chapter concludes with a summary, highlighting how GreenSusAF effectively supported the application of the framework.

5.1 A supporting tool to SusAF- GreenSusAF

The auxiliary tool developed, called GreenSusAF, was created based on the SusAF Workbook[1]. The tool aims to assist SusAF in a way that facilitates its application, making it more user-friendly for anyone wishing to apply it. To achieve this, it includes an introductory page to present some of the basics.

Figure 5.1: GreenSusAF logo

5.1.1 Implementation

The Bubble.io[2] platform was used to develop our tool.

The Bubble.io platform has been gaining a larger user base due to its active community forum where developers, regardless of their level of knowledge, can ask for help and share solutions [34]. Bubble.io stands out as one of the top Low-Code Development Platform (LCDP), due to its easy-to-use interface that enhances the creation of web applications [34]. One of the features that stands out most on this platform is its powerful plugin editor, which allows the extension of the platform's capabilities [34]. Bubble allows the creation

[1]https://www.suso.academy/en/sustainability-awareness-framework-susaf/
[2]https://bubble.io

of workflows to define how elements react to each other or to actions such as a click. The platform also has an integrated database, which facilitates the storage and manipulation of information. Bubble.io manages all technical aspects of hosting applications, including security, and backups.

Figure 5.2, illustrates the design page of Bubble.io, it offers an intuitive interface for the construction of web applications.

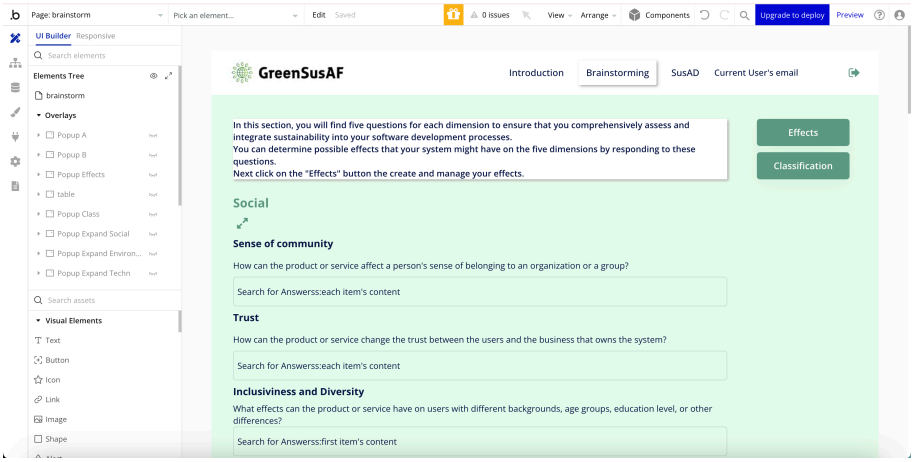


Figure 5.2: Bubble.io design page

Figure 5.3, shows the workflow page of Bubble.io, here users can define the actions and events that will happen in the application.

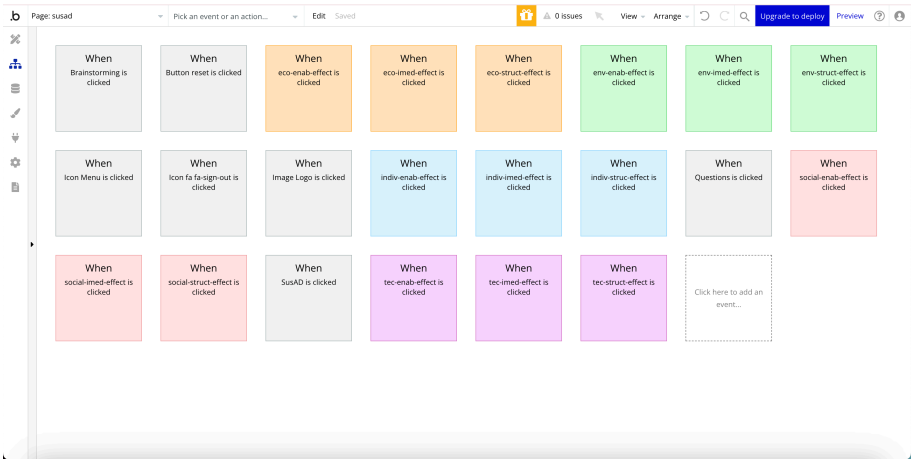


Figure 5.3: Bubble.io workflow page

Figure 5.4, presents the database page of Bubble.io, where users can choose and control the application's data structure. Users can specify fields and attributes, create custom data types, and view, update, and arrange the data that has been stored.

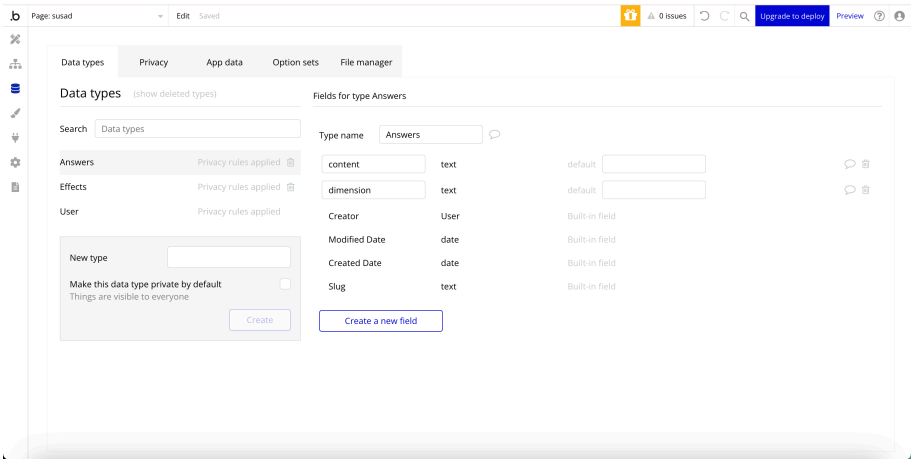


Figure 5.4: Bubble.io database page

5.1.2 User manual

The GreenSusAF is divided into six pages: Home, Login, Register, Introduction, Brainstorming, and SusAD.

The figure 5.5 represents the home page. The home page only has the GreenSusAF's logo and the header common to all pages, we can only proceed to another page after logging in.

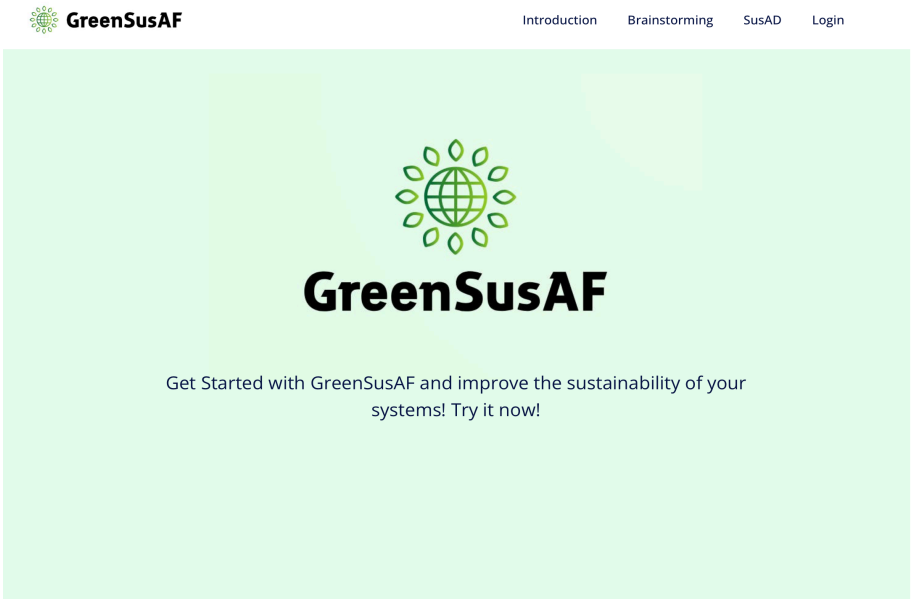


Figure 5.5: GreenSusAF's home page

Figure 5.6, depicts the login page, with its respective fields. If we still need to create an account, we should click on the phrase "Don't have an account? Register here" to go to the registration page.

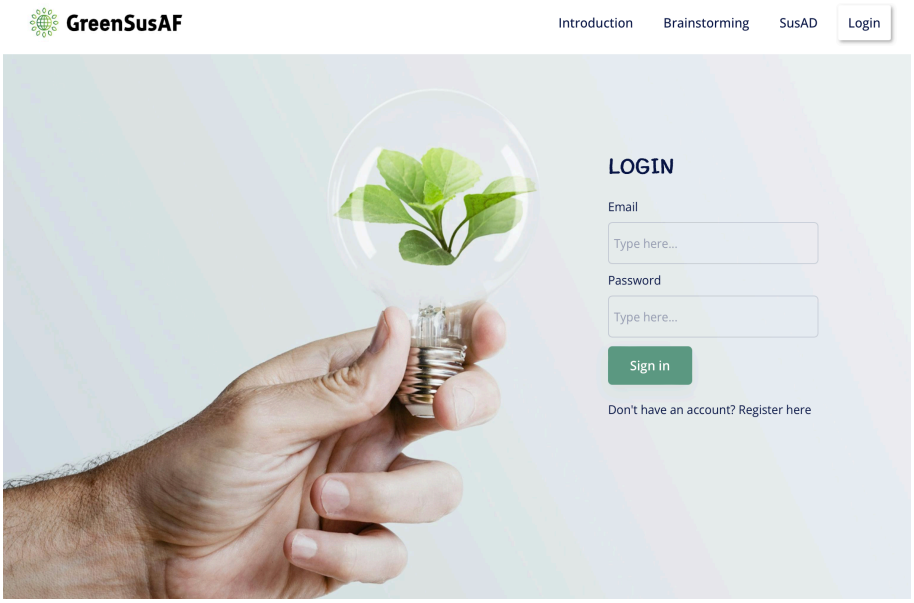


Figure 5.6: GreenSusAF's login page

On the register page, figure 5.7, after filling in all the fields, we can create our account. Then, we are automatically directed back to the login page to log in.

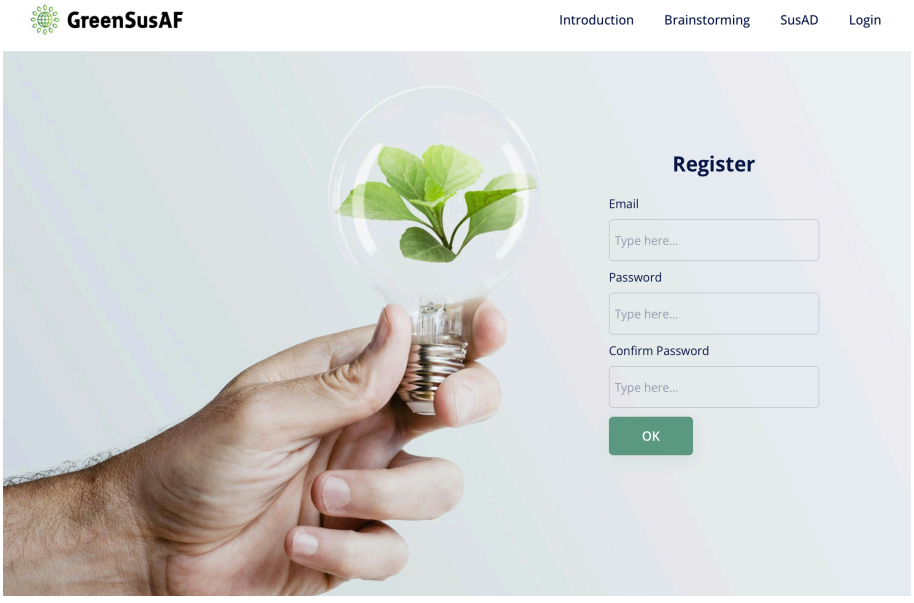


Figure 5.7: GreenSusAF's register page

After logging into the account, we are directed to the introduction page, figure 5.8. Here we can learn or consolidate important bases for better use of SusAF, such as the five dimensions of sustainability, the three order of effects, and the SusAD.

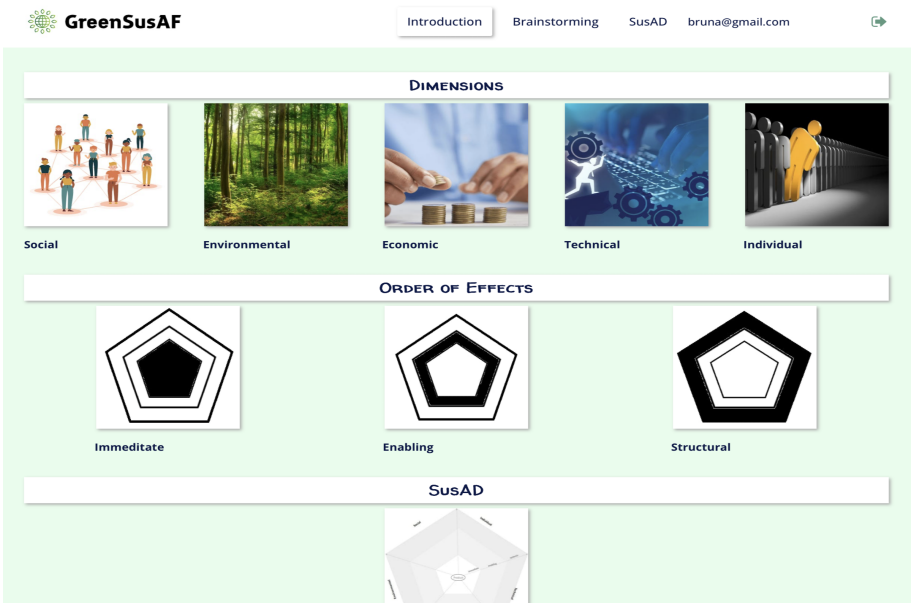


Figure 5.8: GreenSusAF's introduction page

Figure 5.9 shows an example of the social dimension on the introduction page. By simply clicking the social icon, a short explanation appears. The same happens in the figures 5.10, 5.11, but instead of the social dimension icon, we click on the immediate effect icon and the SusAD icon, respectively.

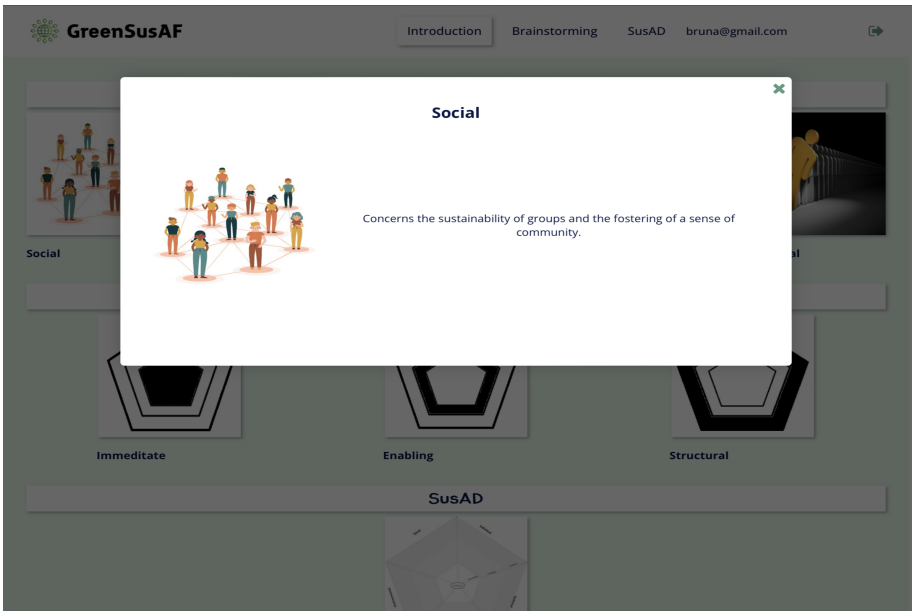


Figure 5.9: Introduction of the social dimension

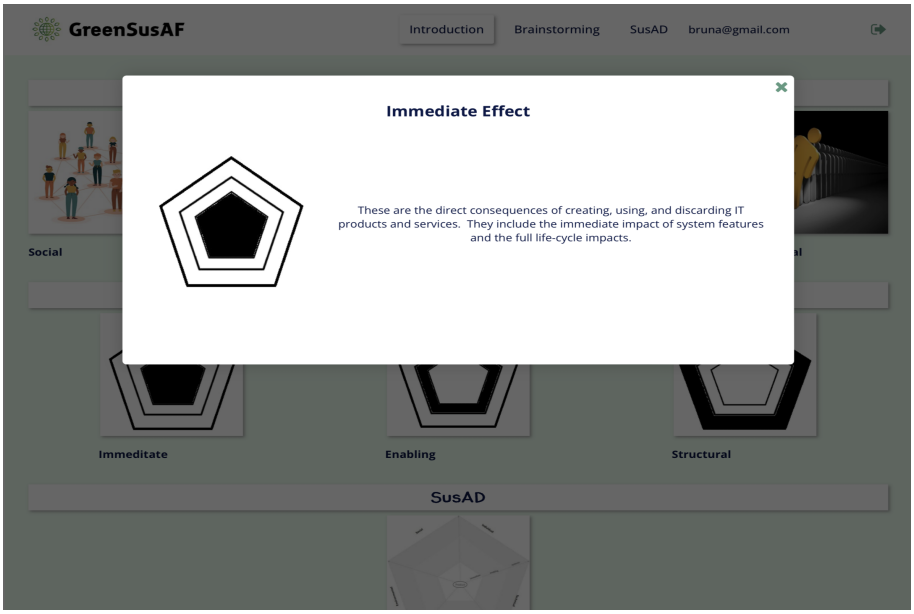


Figure 5.10: Introduction of the immediate order of effect

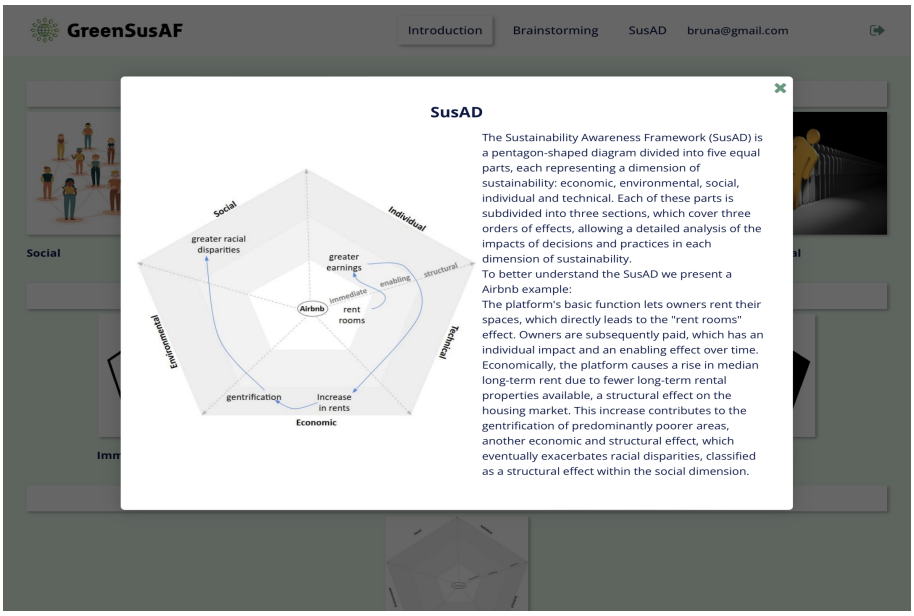


Figure 5.11: Introduction of SusAD

Figures 5.12, represent the brainstorming page. Here we are presented with 25 questions (from the SusAF workbook), 5 for each dimension of sustainability. The objective is to answer all questions to help determine the possible effects that a system can have.

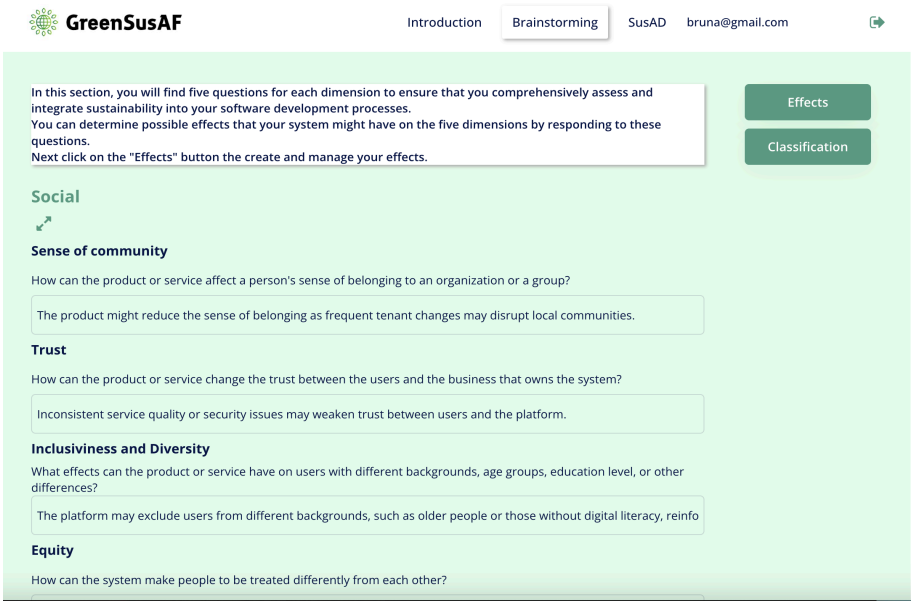


Figure 5.12: GreenSusAF's brainstorming page

Still on the brainstorming page, we can click on the button effects and a table of effects will be presented, figure 5.13. Here we can manage the system's effects by clicking the "Add" button to create new effects 5.14, clicking the pencil icon to edit existing effects 5.15, or just deleting an effect by clicking the bin icon.

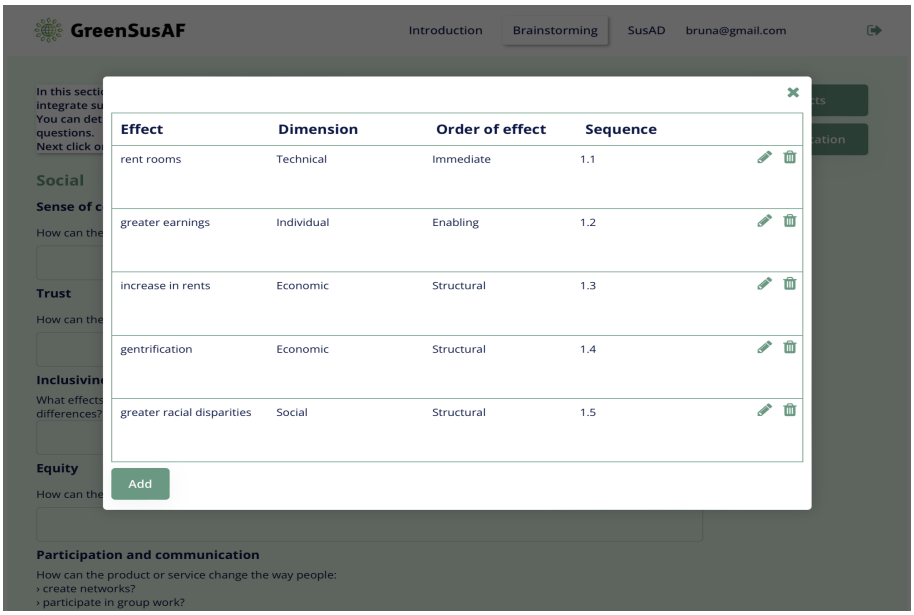


Figure 5.13: GreenSusAF's table of effects

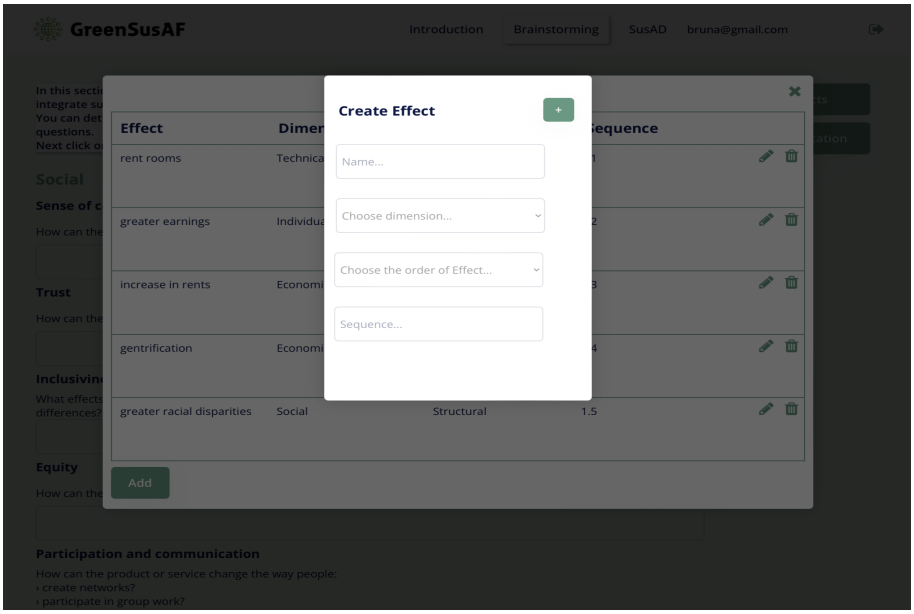


Figure 5.14: Create effect

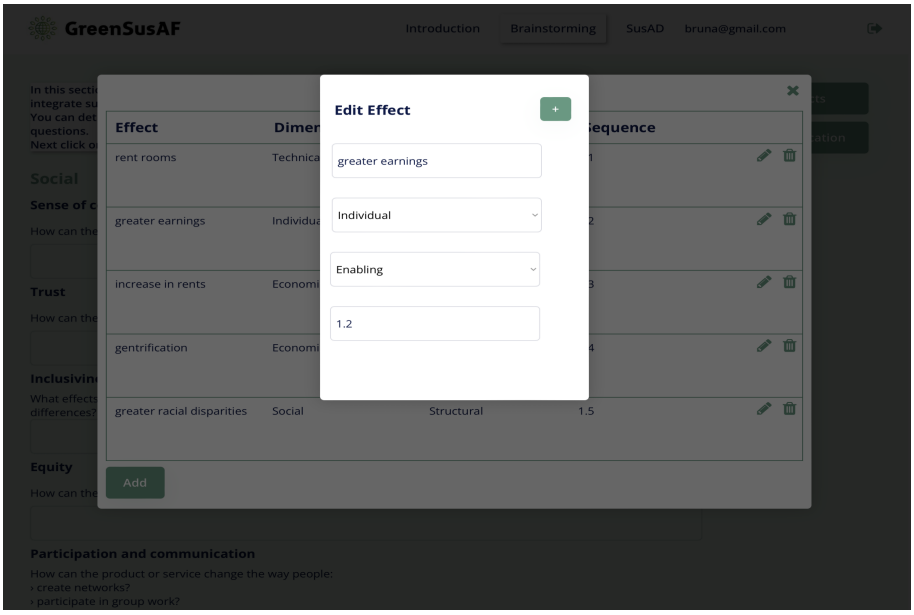


Figure 5.15: Edit effect

Finally, also on the brainstorming page, when clicking on the ”classification” button, a small paragraph along with a graph is presented, in order to show that it is important to prioritize effects, figure 5.16. The effects crucial to be analyzed are the ones that are very likely to happen and also have a high impact.

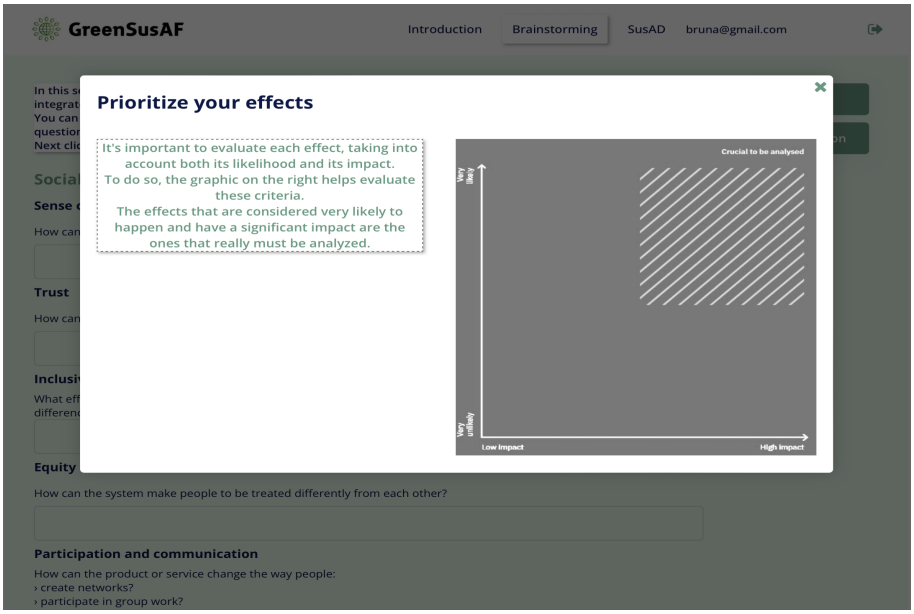


Figure 5.16: Classification of effects

The SusAD page, figure 5.17, is where the diagram itself is displayed with all the previously created effects arranged in the correct dimension and order. On the left side of the page, a list of the current effects is shown for reference. Additionally, this page features a ”Reset” button that allows you to erase all effects if needed.

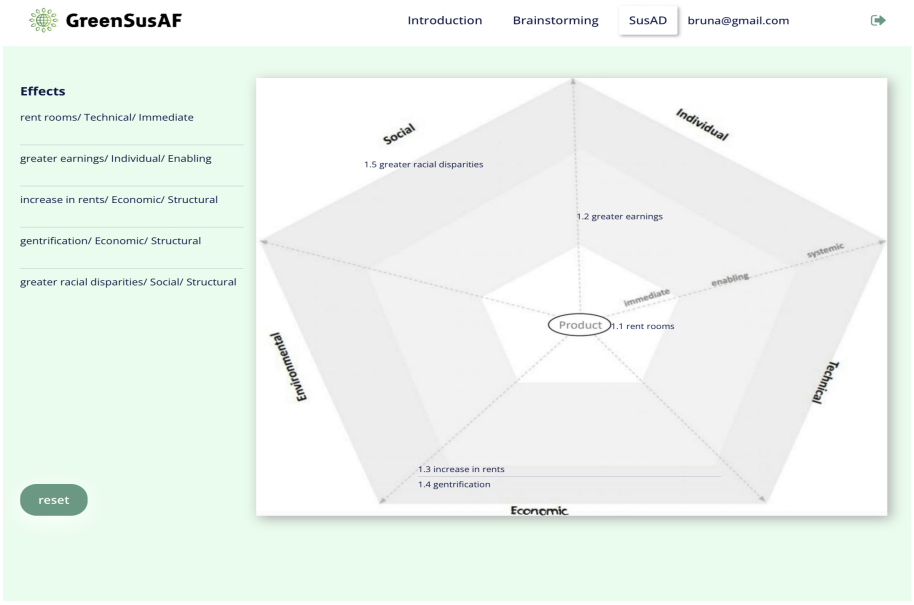


Figure 5.17: GreenSusAF’s SusAD page

In order to distinguish positive and negative effects, there is a functionality to change the color of the effect. Simply click on the effect to turn it green, and click again to turn it red. Figure 5.18, shows which effects are positive (color green) and which are negative (color red), enabling the translation of effects into opportunities and threats.

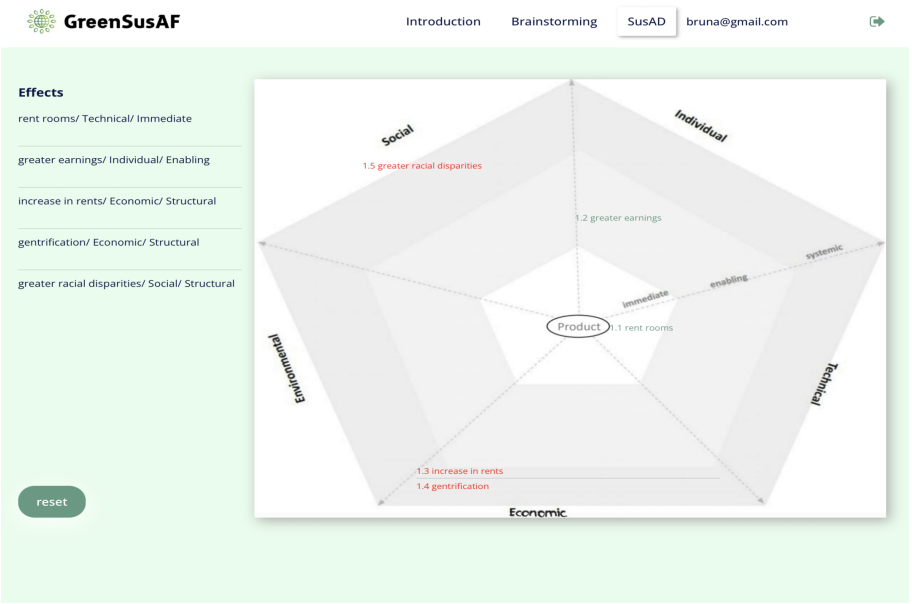


Figure 5.18: GreenSusAF's SusAD page with colors to translate effects into opportunities or threats

Lastly, figure 5.19 shows a screenshot of the final SusAD.

The numbers before each effect are the sequence numbers, indicating the chain of effects. In this example, the first effect "rent rooms" with the sequence number "1.1" causes the effect "greater earnings" with the sequence number "1.2", and so on.

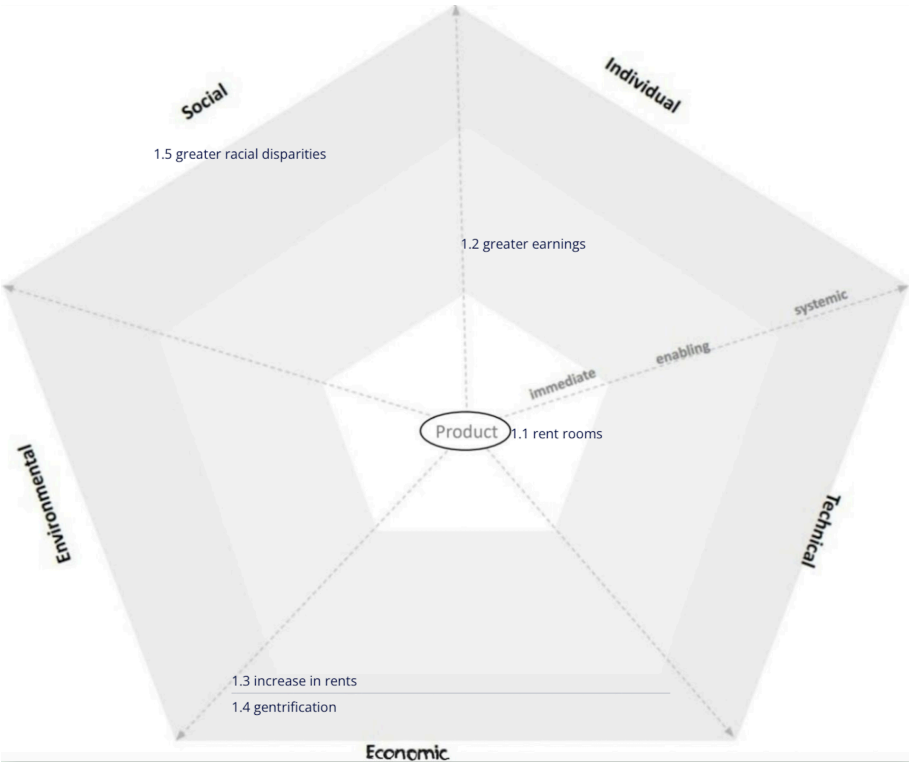


Figure 5.19: Final SusAD (Using a small part of an Airbnb example)

5.2 Applying the framework to a Case Study, using GreenSusAF

To apply GreenSusAF, let's take a look at an Uber Eats platform. Uber Eats is an American online food delivery platform created by Uber Technologies, Inc. (aka. Uber). Under the original name UberFresh, it started as a lunch delivery service in Santa Monica, California. In 2015, the name Uber Eats replaced UberFresh [35].

Starting on the introduction page, we begin by consolidating or acquiring the basic notions to apply SusAF. To this effect, we read about the 5 dimensions of sustainability, the 3 orders of effects, and about the diagram SusAD.

Moving on to the brainstorming page, we start by answering the 25 questions[3], which can help identify the possible effects that your system may have. In our real case, Uber Eats, the answers were created based on ideas formulated with the help of AI to speed up the process.

Figure, 5.20, shows how a product or service influences several factors regarding the social dimension, including the sense of community, trust, inclusiveness, equity, and participation. It presents the answers to the five questions provided to the social dimension, to evaluate the potential social implications of the system.

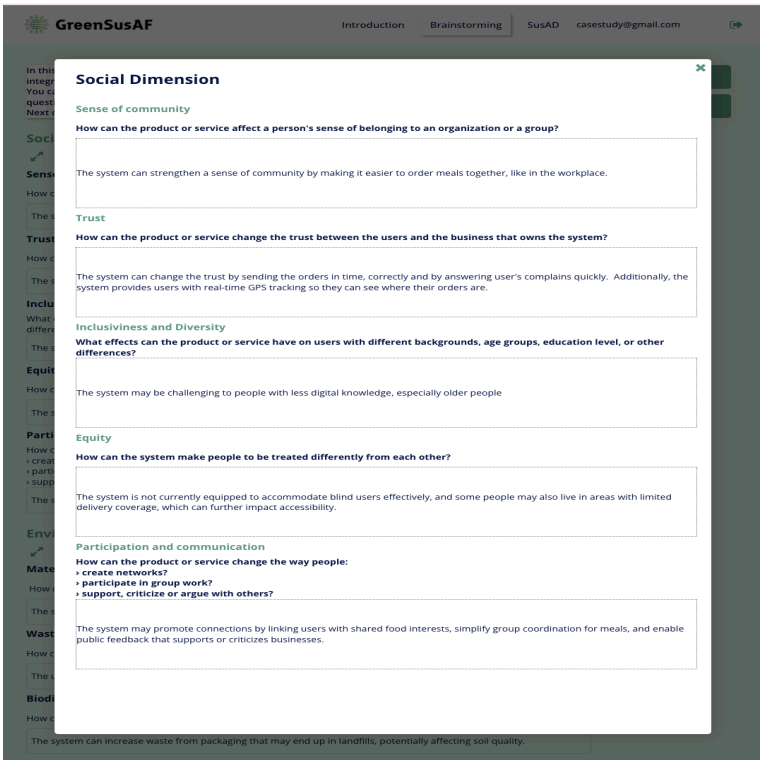


Figure 5.20: GreenSusAF's brainstorming page with the social questions, using the UberEats example

Following that, figure 5.21 illustrates how a product or service impacts several factors

[3]taken from https://www.suso.academy/en/sustainability-awareness-framework-susaf/

regarding the environmental dimension, including resources, waste, pollution, biodiversity, energy, and logistics. In order to assess the system's potential environmental effects, it provides the answers to the five questions pertaining to the environmental dimension.

Next, figure 5.22, reveals how a product or service affects multiple factors regarding the technical dimension, including maintainability, usability, adaptability, security, and scalability. It offers the answers to the five questions related to the technical component so that the possible technical effects of the system may be considered.

Moving to, figure 5.23, demonstrates how several aspects of a product or service, such as value, customer relationship management, supply chain, governance, and innovation are impacted by it. It provides the answers to the five questions pertaining to the economic dimension so that the system's potential effects on the economy can be taken into account.

Finally, figure 5.24, reveals how a product or service affects multiple factors regarding the individual dimension, including health, lifelong learning, privacy, safety, and free will. It offers the answers to the five questions related to the individual component so that the possible individual effects of the system may be considered.

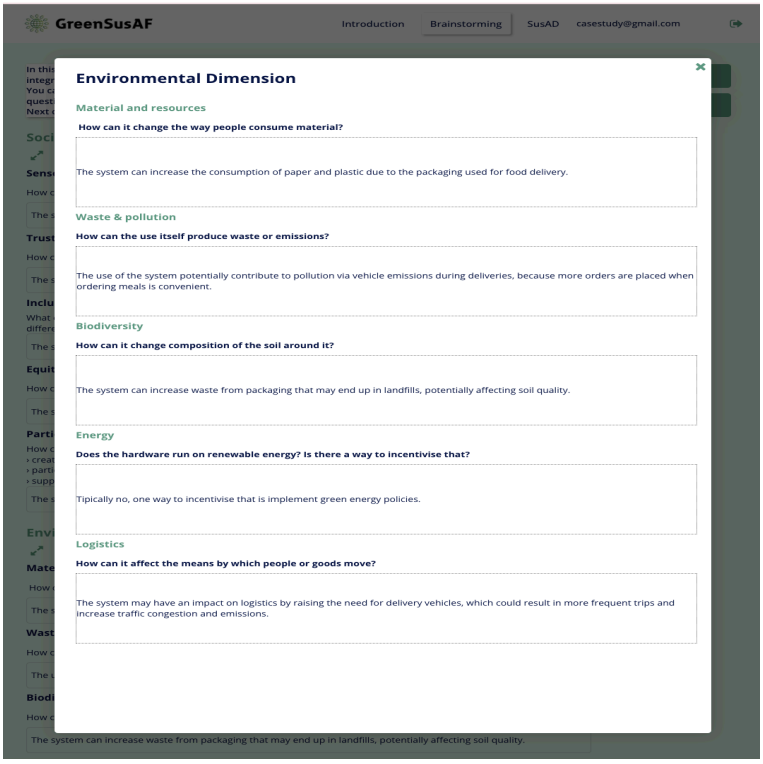


Figure 5.21: GreenSusAF's brainstorming page with the environmental questions, using the UberEats example

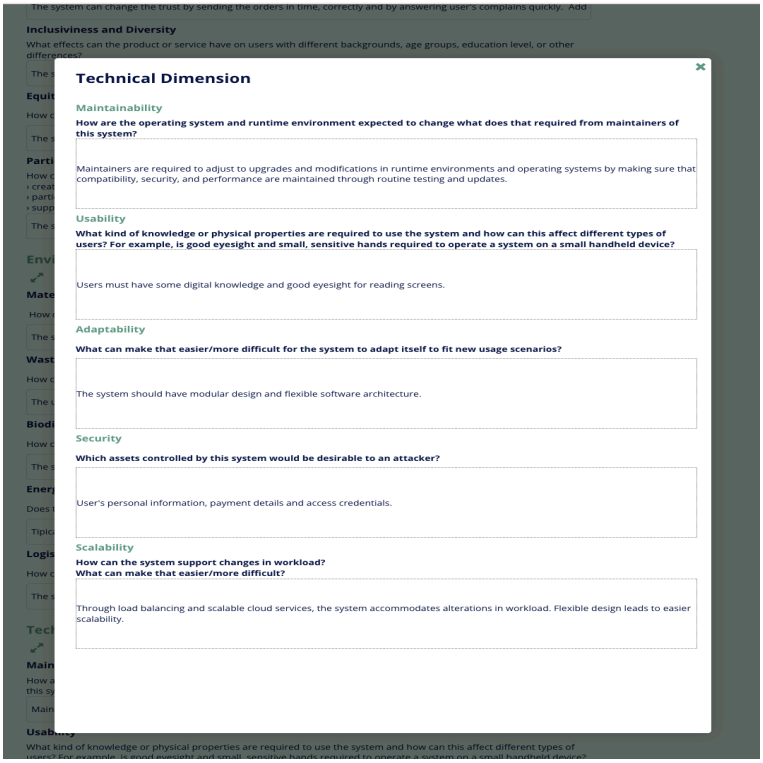


Figure 5.22: GreenSusAF's brainstorming page with the technical questions, using the UberEats example

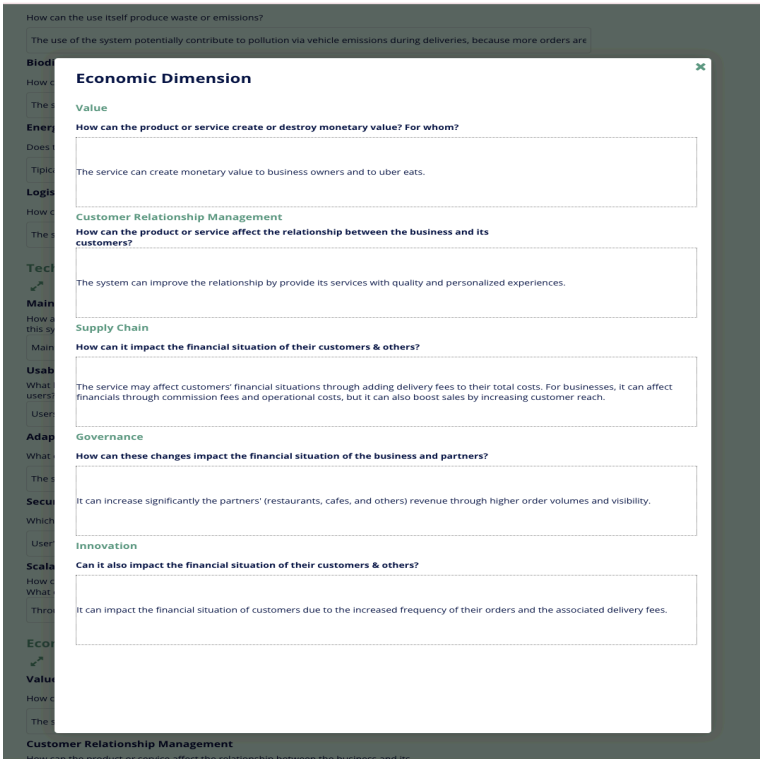


Figure 5.23: GreenSusAF's brainstorming page with the economic questions, using the UberEats example

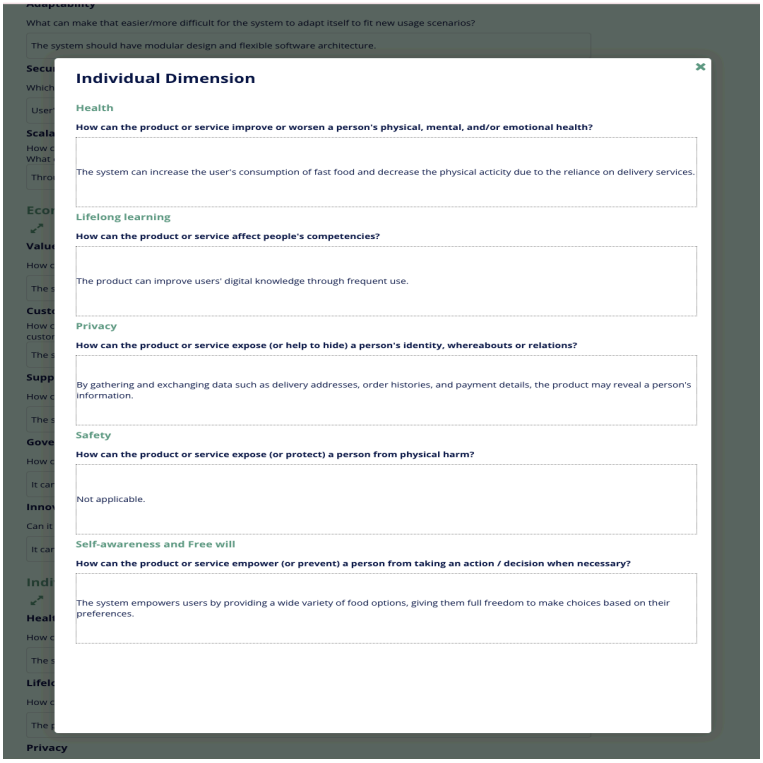


Figure 5.24: GreenSusAF's brainstorming page with the individual questions, using the UberEats example

Following the completion of all the questions, we review the answers while considering any possible effects the system might have. Figures 5.25, 5.26, 5.27 contain the table with the identified effects.

The primary function of the Uber Eats platform is food delivery, which directly leads to the first effect identified: the ability to "deliver food." This is an immediate effect within the technical dimension. However, this effect can trigger several other effects. For example, the platform may unintentionally exclude blind individuals due to insufficient accessibility features- an immediate effect on the social dimension. Additionally, Uber Eats' convenience can develop user dependency on delivery apps, an enabling effect on the social dimension. Finally, the platform's digital nature may exclude people with less digital knowledge, creating another enabling effect within the social dimension.

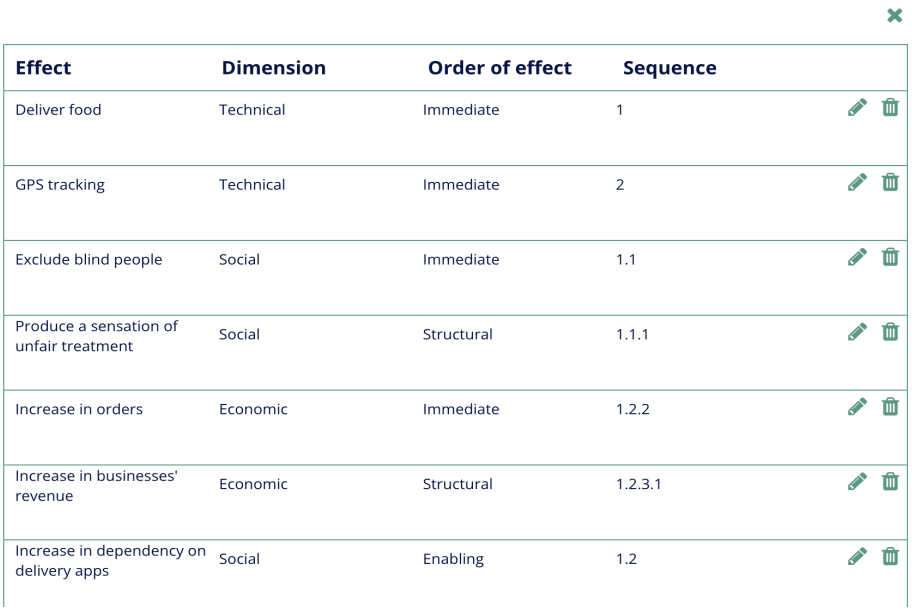
Each of these effects, subsequently, has further effects of their own. For instance, the exclusion of blind people can produce a sensation of unfair treatment- a structural effect on the social dimension. Furthermore, the rising dependency of users on delivery apps can lead to higher consumption of fast food and decreased physical activity of users- a structural effect on the social dimension. This dependency also drives a boost in orders- a structural effect on the economic dimension, which can contribute to increasing consumption of paper and plastic due to the packaging used for food delivery- an enabling effect on the environmental dimension, and to more pollution via vehicles emissions during deliveries because more orders are placed when ordering meals is convenient- a structural

effect on the environmental dimension. The last consequence of the users' dependency on delivery apps is the enhanced visibility of business partners- an enabling effect on the economic dimension, that ultimately elevates revenue for those businesses- a structural effect within the economic dimension.

One important feature of this system is that it allows consumers to track their orders using GPS, which is an immediate effect on the technical dimension. This functionality strengthens trust between users and the system by providing real-time updates and transparency, a structural effect on the social dimension.

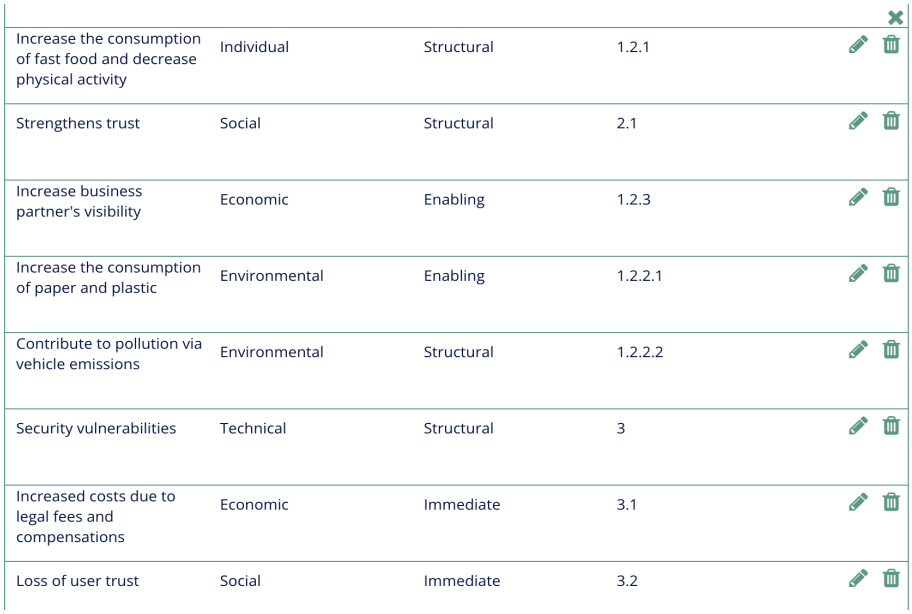
Since Uber Eats handles personal information such as users' addresses and emails, as well as payment details like card numbers, there are associated risks, leading to the immediate effect of "Security vulnerabilities", on the technical dimension. This effect subsequently cascades into several additional effects: increased costs due to legal fees and compensations- an immediate effect on the economic dimension; loss of user trust- an immediate effect on the social dimension; risks to users from the exposure of personal information and payment details- a structural effect on the individual dimension; and damage to the company's reputation- an enabling effect on the social dimension.

The sequence number assigned to each effect helps track which effects cause others. For example, an effect with sequence number "1" causes effects with sequence numbers "1.1", "1.2", and "1.3", Additionally, the effect with sequence number "1.2" leads to effects with sequence numbers "1.2.1", "1.2.2", and "1.2.3".



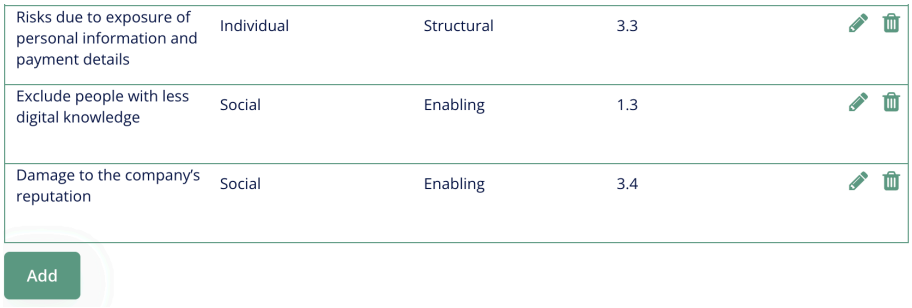
Effect	Dimension	Order of effect	Sequence
Deliver food	Technical	Immediate	1
GPS tracking	Technical	Immediate	2
Exclude blind people	Social	Immediate	1.1
Produce a sensation of unfair treatment	Social	Structural	1.1.1
Increase in orders	Economic	Immediate	1.2.2
Increase in businesses' revenue	Economic	Structural	1.2.3.1
Increase in dependency on delivery apps	Social	Enabling	1.2

Figure 5.25: GreenSusAF's table of effects, using the Uber Eats example



Increase the consumption of fast food and decrease physical activity	Individual	Structural	1.2.1	
Strengthens trust	Social	Structural	2.1	
Increase business partner's visibility	Economic	Enabling	1.2.3	
Increase the consumption of paper and plastic	Environmental	Enabling	1.2.2.1	
Contribute to pollution via vehicle emissions	Environmental	Structural	1.2.2.2	
Security vulnerabilities	Technical	Structural	3	
Increased costs due to legal fees and compensations	Economic	Immediate	3.1	
Loss of user trust	Social	Immediate	3.2	

Figure 5.26: GreenSusAF's table of effects, using the Uber Eats example



Risks due to exposure of personal information and payment details	Individual	Structural	3.3	
Exclude people with less digital knowledge	Social	Enabling	1.3	
Damage to the company's reputation	Social	Enabling	3.4	

Add

Figure 5.27: GreenSusAF's table of effects, using the Uber Eats example

Especially in more complex systems, where we can identify many of the effects, is very important to correctly prioritize them. It's important to evaluate each effect, taking into account both its likelihood and its impact, the effects that are considered very likely to happen and have a significant impact are the ones that really must be analyzed.

Finally, moving on to the SusAD page, we can find the SusAD with all identified effects accurately placed, Figure 5.28. The diagram facilitates the visualization of the chain of effects, typically represented by arrows, but in this case, it uses sequence numbers displayed at the beginning of each effect.

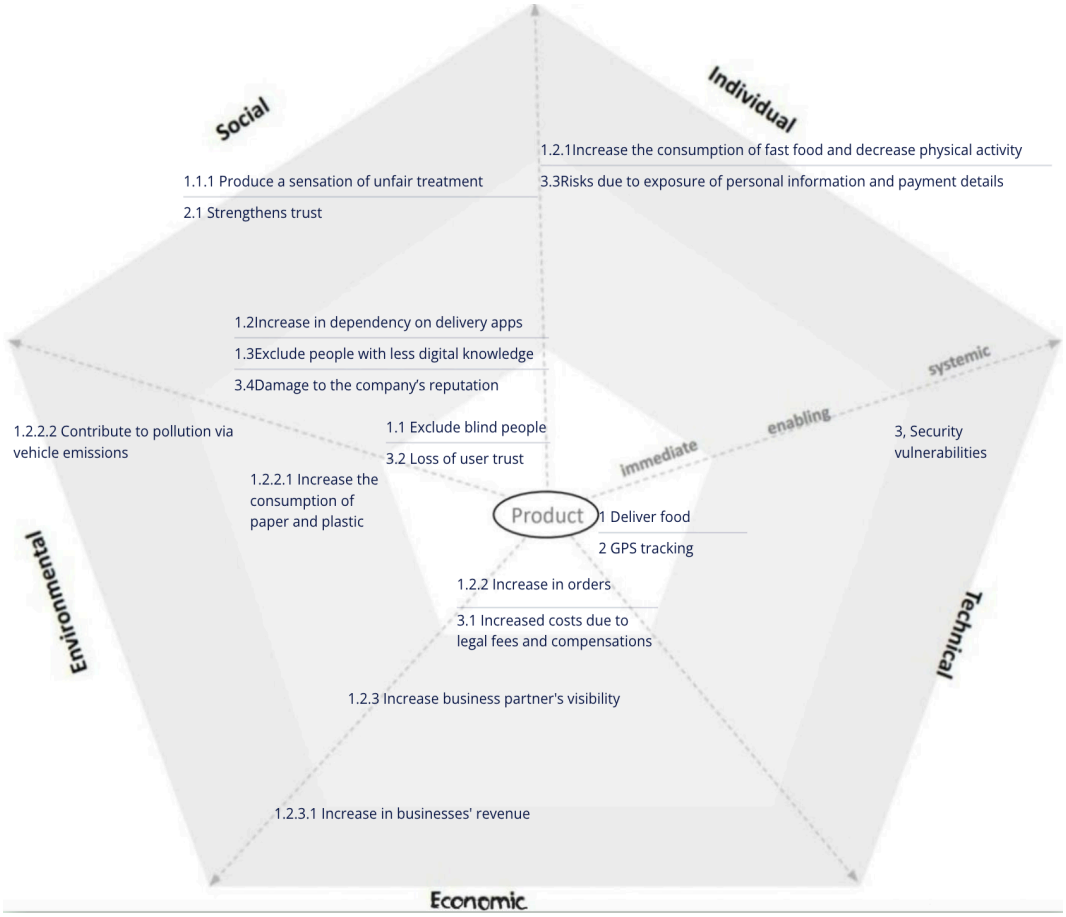


Figure 5.28: GreenSusAF's SusAD, using the Uber Eats example

To facilitate a clearer understanding of the threats and opportunities associated with the system, we distinguish the current effects using color coding (figure 5.29): green for positive effects and red for negative effects.

The process of GreenSusAF ends here. After using the tool and gathering and distinguish all positive and negative effects, its time to take actions. In the case of a positive effect, we should develop a strategy to take advantage of it. However, in the event that the effect is negative, we must come up with measures to mitigate it.

5.3 Summary

In this chapter, we began with an overview of GreenSusAF, presenting its implementation, architecture and explaining its structure and functionalities, after that we applied SusAF to a real case, Uber Eats, using GreenSusAF.

We started by consolidating or acquiring knowledge about the five dimensions of sustainability, the three orders of effects, and the SusAD. Following this, we answered the twenty-five questions regarding the system and initiated brainstorming sessions to identify the possible effects that the system could have. We observed that most responses contained valuable information, which provided significant assistance in identifying these

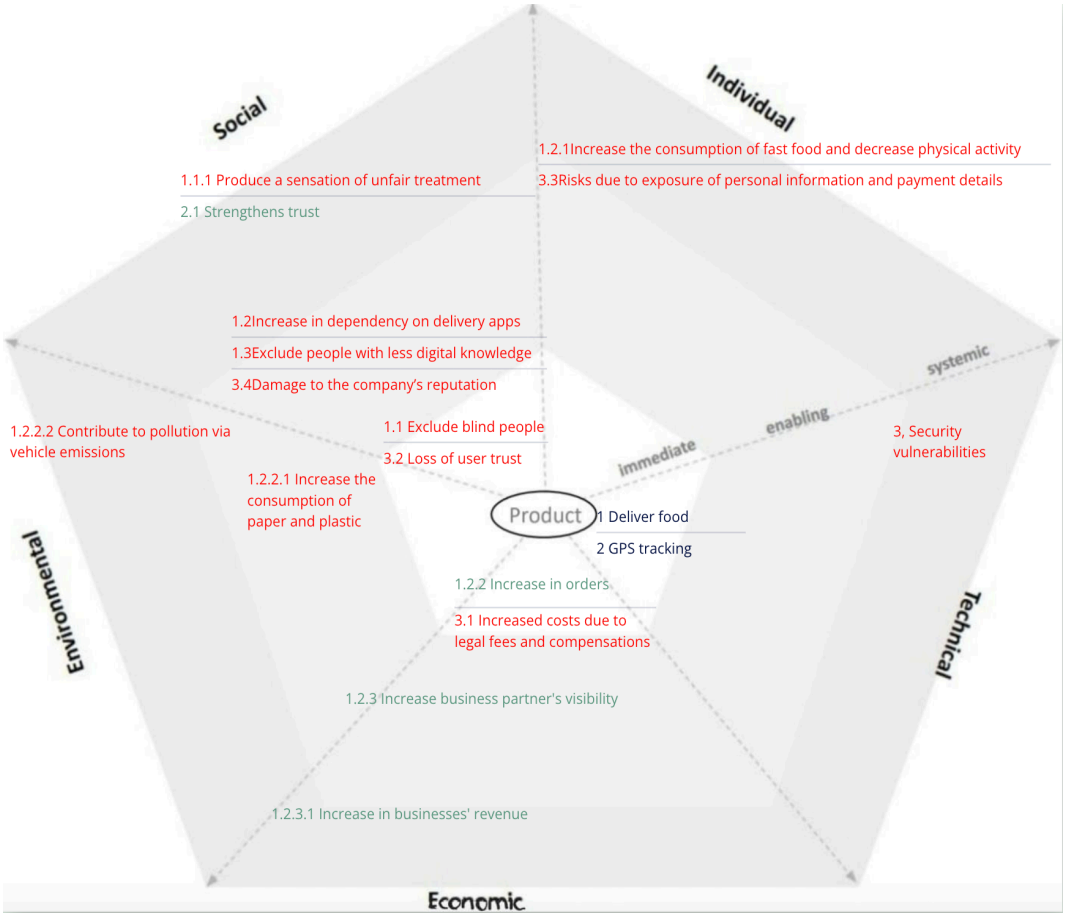


Figure 5.29: GreenSusAF's SusAD with positive and negative effects, using the Uber Eats example

effects. Finally, we reached SusAD and we distinguished the effects that present opportunities and the effects that pose threats, and developed actions to explore the beneficial effects and minimize the negative ones.

GreenSusAF thus proved to be a useful tool, making the SusAF application easier to apply.

6

Evaluation

In this chapter, we present the evaluation of the GreenSusAF tool, developed based on the conceptual model (figure 4.5). The questionnaire was answered solely online, so we had no direct access to those involved. Participants were first introduced to the tool with an overview of SusAF, supported by a brief explanatory video and a practical example. Following this introduction, they were asked to reply to some prepared questions. A step-by-step tutorial video was then provided to show participants how to use GreenSusAF, followed by another set of questions.

This chapter begins with a discussion of the questionnaire's creation. Following that, the results are displayed, along with an accompanying discussion. Ultimately, we discuss threats to the validity of the evaluation, concluding with a summary of the chapter.

6.1 Evaluation Planning

The objectives of this evaluation are:

- Understand if GreenSusAF is effectively beneficial in promoting awareness of the existence of SusAF and its application;
- Comprehend the general knowledge of people about SusAF, as well as their perceptions regarding its ease of learning, practicality, and the time required to use it;
- Determine if people feel the need for a tool to help the utilization of SusAF;
- Assess the proposed tool, GreenSusAF, by gathering perceptions regarding its ease of learning, its usefulness in supporting SusAF, and its potential to encourage the adoption of SusAF.
- Gather suggestions or constructive criticism regarding the tool's functionalities and any issues encountered.

The questionnaire was created using Google Forms, a free application launched by Google that allows the creation and management of online questionnaires.

To explore both people in the IT area with some knowledge of SusAF and people who are completely unaware of the existence of SusAF, this questionnaire was available to a vast range of participants. The questionnaire was shared by LinkedIn and WhatsApp.

The form includes two short videos: one introducing SusAF and another demonstrating how to use GreenSusAF. Both videos were uploaded to YouTube, and the links[1] were shared in the corresponding sections.

6.1.1 Questionnaire

The questionnaire[2] has five sections:

- **Section 1- Sustainability Awareness Framework: An assessment of the GreenSusAF Tool:** In this section, we begin by explaining the objectives of the evaluation, the types of questions that will be asked, and the estimated time required to complete the assessment. We also emphasize that the evaluation is completely anonymous and can be stopped at any time. Following this, participants will be asked a few demographic questions, such as gender, age, education level, and field of study or work, none of which will compromise their anonymity;

- **Section 2- Sustainability Awareness Framework- SusAF:** In this section, we differentiate between people who are familiar with SusAF and those who have little to no knowledge about it. Participants will be redirected to different sections of the evaluation based on their responses. A brief explanatory video of SusAF is provided, along with an example to illustrate how the SusAD is used within SusAF;

- **Section 3- About SusAF- Familiar participants:** This section is available to individuals already familiar with SusAF, and the questions presented are designed to gather their opinions, experiences, and feedback on the framework. To assess SusAF, participants must evaluate factors including how easy it is to learn, how long it takes to use, what challenges they encounter while using it in their projects, and how effectively it raises awareness of the sustainability effects of software systems. There are also specific questions concerning the SusAD in this section, with an emphasis on its practical application, the advantages of constructing it digitally, and the value of an auxiliary tool to help with the creation of this diagram;

- **Section 4- About SusAF- Unfamiliar participants:** This section is intended for individuals who have little to no knowledge about SusAF. The questions presented here allow participants to share their first insights about SusAF based only on the explanation provided in Section 2. Although the factors assessed are similar to those in the previous section, the questions are framed differently to accommodate participants' limited familiarity with the framework;

[1] https://youtu.be/P3XovMyvPT4, https://youtu.be/mHEBJea0xu0
[2] https://forms.gle/pqKswrHu3NqN8dZb7

- **Section 5- GreenSusAF:** Finally, this section is meant to assess the proposed tool, GreenSusAF. This section starts with a tutorial video, showing step-by-step how GreenSusAF works. Following the video, participants are asked to evaluate the user guide, suggest additional functionalities, and assess the overall impact of GreenSusAF on the usability and efficiency of SusAF. They should also consider the balance between reducing paper usage and the potential increase in energy consumption, rating this impact positively or negatively. Furthermore, participants are asked to evaluate the ease of learning GreenSusAF and its effectiveness in promoting the use of SusAF, explaining their answers when they feel comfortable doing so.

6.1.2 Prototype Guide

To facilitate the participants' understanding of the utilization of our tool, we produced a comprehensive video guide that is easy to follow and comprehend. The video[3] has a duration of 2:27 minutes, in English.

6.2 Results and discussion

The results and discussion follow the same structure as the questionnaire, ensuring a consistent flow between the questions and the corresponding analysis. Within a period of 15 days, we collected 41 answers. All questions were numbered to facilitate analysis and organization.

6.2.1 Participants demographic

The following questions relate to participants' characteristics, including gender, age, field of study, and level of education.

Question: **1.1. Please specify your gender:** Regarding the distribution of gender, we observed that 70.7% are men, while 29.3% are women, revealing a certain discrepancy.

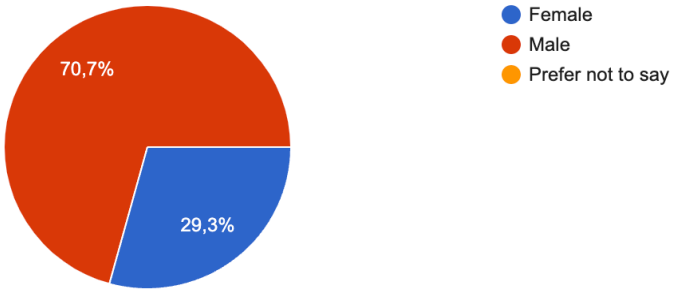


Figure 6.1: Percentage of participants by gender

[3]https://www.youtube.com/watch?v=mHEBJea0xu0

Question: **1.2. Please specify your age:** In terms of age, 65.9% of participants are between 18-24 years, 22% are between 25-34 years, 4.9% are either between 35-44 or 45-54 years, and 2.4% are between 55-64 years.

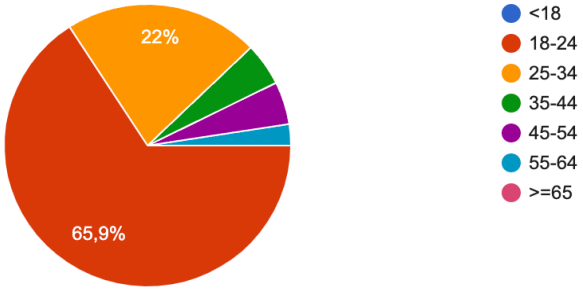


Figure 6.2: Age of participants

Question: **1.3. What is your field of study/work?** Moving on to the field of study/work, most participants are in the field of computer science, comprising 56.1%, engineering comes next with a percentage of 14.6%, then medicine/ health sciences with 7.3%, followed by social sciences with 4.9%, and some other fields comprise a percentage of 2.4%.

Figure 6.3: Field of study/work

Question: **1.4. Please indicate your level of education:** Concerning the level of education of participants, 46.3% hold a bachelor's degree, 26.8% have a master's degree, 17.1% have completed a technical course, 4.9% have only finished high school, and 2.4% have either completed middle school or have a doctorate's degree.

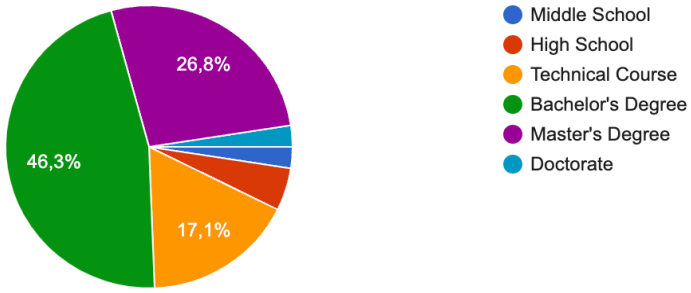


Figure 6.4: Level of education

6.2.2 Familiarity with SusAF

The next questions aim to distinguish participants who are familiar with SusAF and those who have no prior knowledge of it, and also to assess the video that briefly explains on what SusAF consists on.

Question: **2.1. Do you have any knowledge about SusAF?** The majority of participants, 73.2%, have no knowledge about SusAF, 17.1% have some knowledge about it, and only 9.8% are familiar with SusAF.

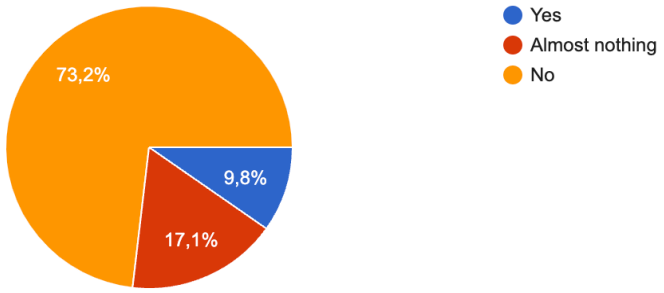


Figure 6.5: Familiarity with SusAF

Question: **2.2. Was this video helpful?** Regarding the video about SusAF, participants rated its helpfulness on a scale from 1 (Not helpful) to 5 (Very helpful). 41.5% of participants rated it as ”5”, 48.8% rated it as ”4”, 7.3% rated it as ”3” and 2.4% rated it as ”2”.

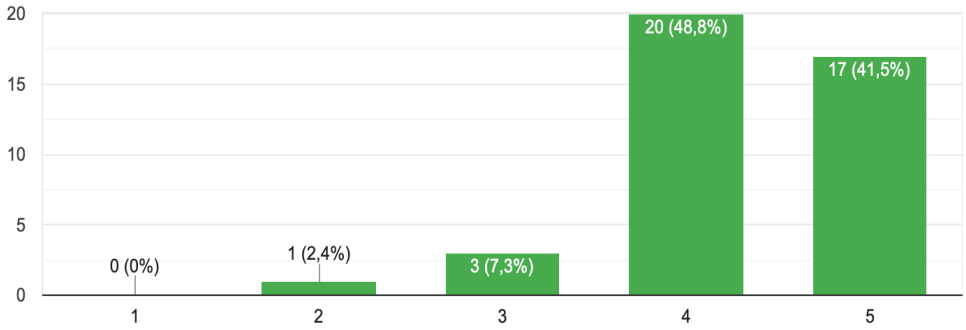


Figure 6.6: SusAF's video assessment

6.2.3 Insights about SusAF from participants familiar with the framework

The following questions are intended to obtain comprehensive insights and perspectives from those who are already familiar with SusAF.

Question: **3.1. Do you think that SusAF is easy to learn?** Regarding the ease of learning and applying the framework, participants rated it on a scale from 1 (Very hard) to 5 (Very easy). The majority considered the framework easy to learn, with 25% rating it as ″5″ and 75% rating it as ″4″. This indicates that most participants perceive SusAF as a framework that doesn't present significant learning challenges.

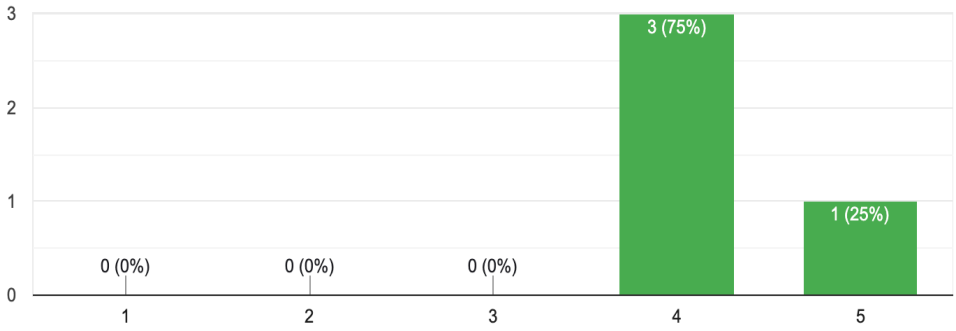


Figure 6.7: SusAF's ease of learning

Question: **3.2. Do you think utilizing the SusAF requires a lot of time?** Concerning the time that is required to apply SusAF, participants were asked to rate it on a scale from 1 (Not very time-consuming) to 5 (Very time-consuming). The results clearly show that everyone considers the framework to be at least a little time-consuming, with 50% rating it as ″5″, and with an equal distribution of 25% rating it as ″3″, and ″4″.

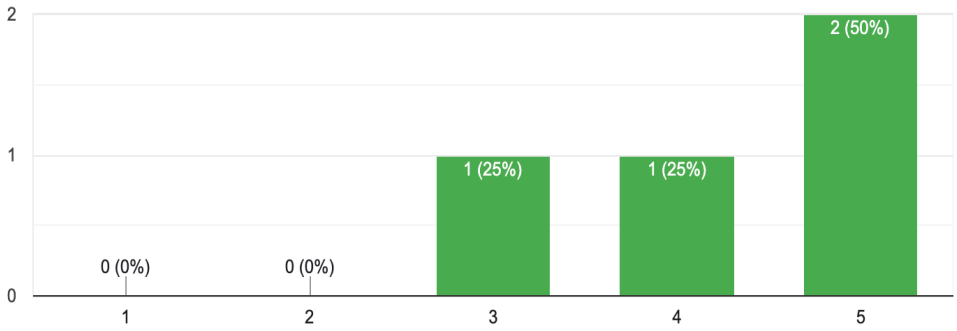


Figure 6.8: SusAF's time consumption

Question: **3.3. What are the main challenges you face when using SusAF in your projects?** When asked about the main challenges that SusAF brings, participants answered with the following sentences:

- *"Having in mind all the use cases possible. Sometimes there can be lots of scenarios we are not contemplating";*
- *"The main challenge I faced was distinguishing what order of effect my requirements had";*
- *"There are no available tools to help with SusAF".*

Question: **3.4. Do you think SusAF is useful for raising awareness of the sustainability impacts of software systems?** To analyze SusAF's usefulness in raising awareness of sustainability impacts, participants were provided with a scale ranging from 1 (Not useful) to 5 (Very useful) to rate their perception. The results show that everyone finds usefulness in SusAF, with an equal distribution of 50% rating it as "4" and "5".

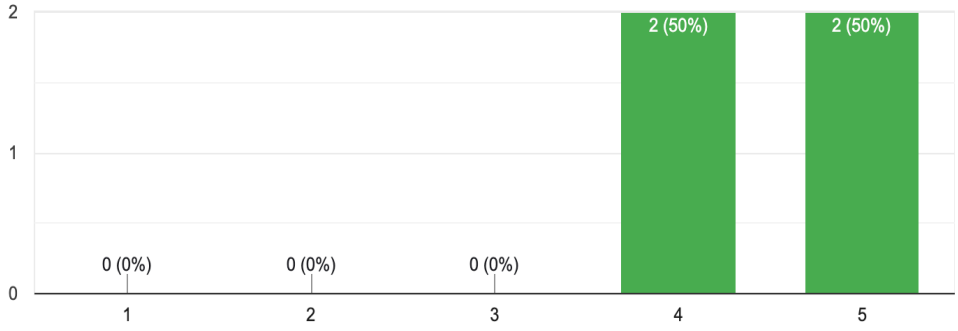


Figure 6.9: SusAF's usefulness to raise awareness of sustainability impacts

Question: **3.4.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)** To better understand why participants consider SusAF useful or not, we asked them to explain their answers.
The answers are:

- *"SusAF effectively highlights the sustainability impacts of software systems, helping to raise awareness among developers and stakeholders. It provides a structured approach to consider environmental, economic, and social factors. However, it could be improved by offering more practical tools and examples to implement sustainable practices more easily in everyday development processes";*

- *"I think it helps raise awareness but in practice it has a tendency to get very cluttered";*

- *"It helps to think about the effects in the long term that a system can have".*

Turning our attention to SusAD, the diagram used in SusAF, the next four questions aim to evaluate its practicality and determine the potential need for a digital tool to support its creation.

Question: **3.5. Do you think that is practical to create the SusAD manually, taking into account more complex systems with multiple effects?** Participants were presented with a scale from 1 (Not practical) to 5 (Very practical) to rate the practicality of SusAD, with a focus on its creation for complex systems. The results showed that 25% rated it as "3", 50% rated it as "2", and 25% rated it as "1".

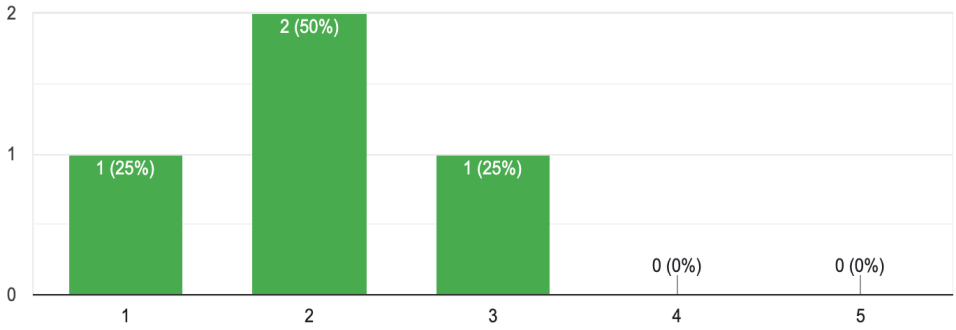


Figure 6.10: SusAD's practicality

Question: **3.5.1 Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)** To get more insight, participants were asked to explain their answers regarding the practicality of SusAD.
The following sentences are the participants' answers:

- *"Creating the SusAD manually for complex systems with multiple effects is impractical. The process is time-consuming and can become overwhelming due to the complexity and interdependencies involved. To improve this, automation tools or software that can assist in mapping out these complexities more efficiently would be beneficial";*

- *"Complex systems will make the diagram very cluttered, manually creating it will probably lead to some mistakes being made";*

- *"The diagram gets very full and is hard to comprehend".*

Question: **3.6. Would it have a positive impact if SusAD was created digitally?** When requested to rate the impact that building SusAD digitally would have, on a scale from 1 (Not at all) to 5 (For sure), 100% of participants rated it as "5", indicating unanimous agreement on its positive impact.

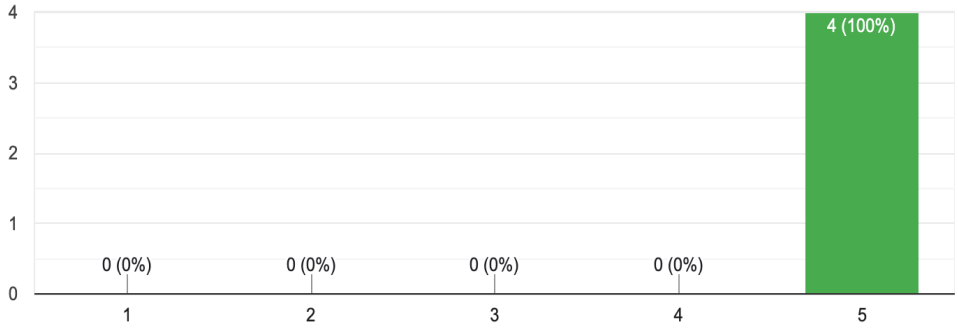


Figure 6.11: Impact of creating SusAD digitally

Question: **3.7. If there was a tool to assist with the application of SusAF, especially facilitating the creation of the SusAD, would it be beneficial?** To assess the impact of a new tool on facilitating the utilization of SusAF, participants were asked to rate this impact on a scale from 1 (Not beneficial) to 5 (Completely beneficial). The results revealed unanimous agreement, with 100% of participants rating it as "5".

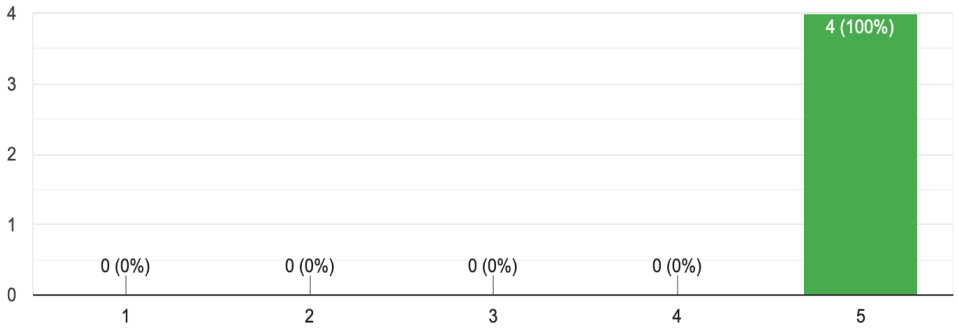


Figure 6.12: Impact of using a tool to apply SusAF

6.2.4 Perceptions of SusAF from participants unfamiliar with the framework

To gather perceptions and opinions about SusAF from individuals with no prior knowledge about the framework, we provide the following questions. These are similar to those presented in the previous section but have been adapted to allow participants to answer based only on the explanation provided in this questionnaire.

Question: **4.1. Do you think that SusAF is easy to learn?** Regarding the ease of learning, this time the answers were not that unanimous. Participants rated it using a scale from 1 (Very hard) to 5 (Very easy), with 10.8% rating it as ”2”, 59.5% rating it as 3, 24.3% rating it as ”4” and 5.4% rating as ”5”. These results reveal that the majority of participants think that the ease of learning of this framework is intermediate.

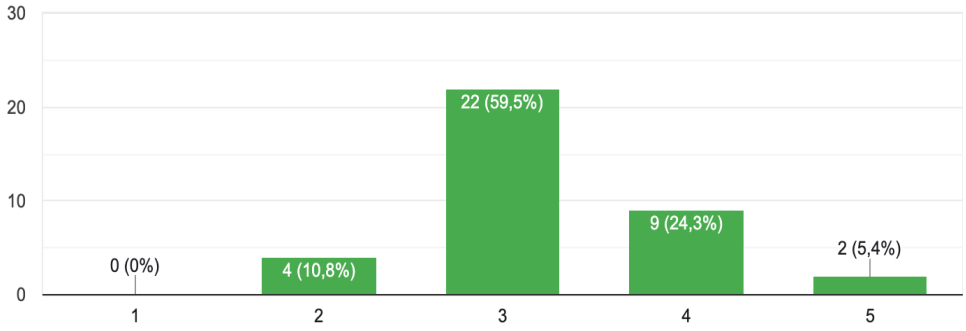


Figure 6.13: Perceived ease of learning SusAF

Question: **4.2. Based on what you know or have seen in the previous section, how time-consuming do you think applying SusAF might be?** As for the time required to apply SusAF, participants rated it on a scale from 1 (Not time-consuming) to 5 (Very time-consuming). The results show distributed responses, with 2.7% rating it as ”1”, 10.8% rating it as ”2”, 35.1% rating it as ”3”, 48.6% rating it as ”4” and 2.7% rating it as ”5”.

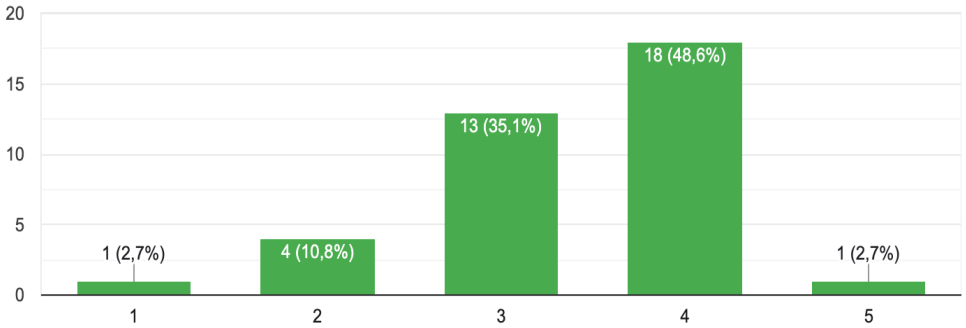


Figure 6.14: Perceived time consumption of SusAF

Question: **4.3. What do you think would be the most difficult part of using SusAF, if you decided to start?** To identify the potential challenges of using SusAF, participants were asked to select one or more challenges from a list, with the option to add any additional challenges not included in the predefined options. The outcomes demonstrate that 37.8% considered understanding the concepts to be a challenge, 32.4% found the time required to apply SusAF to be an issue, 40.5% felt the framework’s complexity makes it difficult to use, 40.5% indicated the need for an auxiliary tool to support SusAF and 2.7% considered it difficult to convince managers to adopt SusAF.

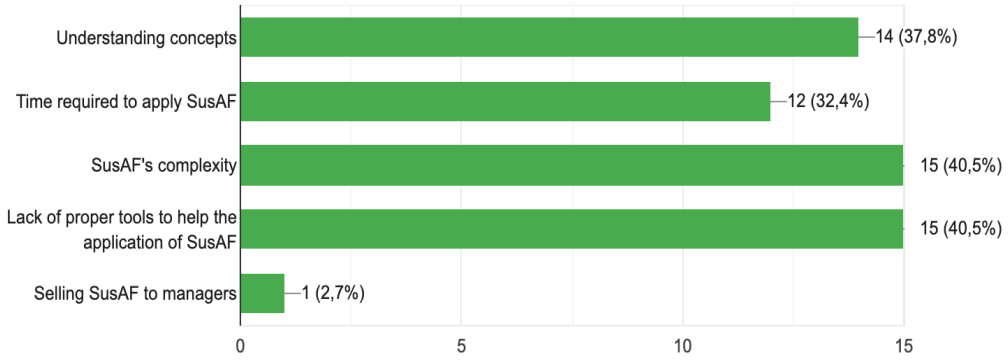


Figure 6.15: Perceived challenges in Using SusAF

Question: **4.4. Based on what you know or have seen in the previous section, do you think SusAF could be useful for assessing the overall impact of software systems?** When it comes to how useful SusAF can be for raising awareness of sustainability impacts, participants rated it on a scale from 1 (Not useful) to 5 (Very useful). The results indicate that all participants find SusAF at least a little useful, with 13.5% rating it as ”3”, 54.1% rating it as ”4”, and 32.4% rating it as ”5”.

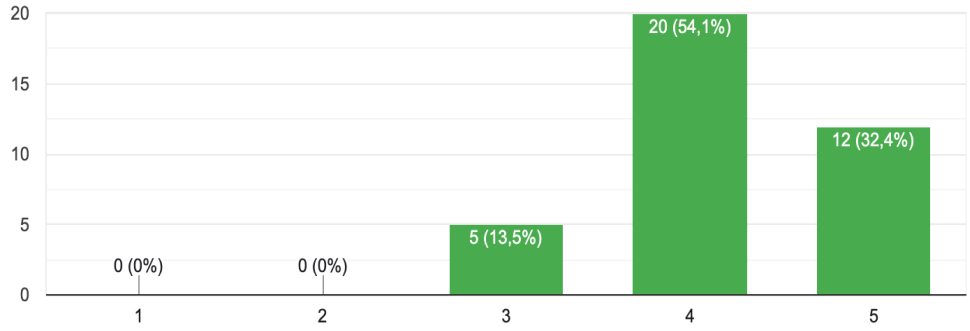


Figure 6.16: Perceived usefulness of SusAF for raising awareness of sustainability impacts

Question: **4.4.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)** To properly comprehend what participants think about SusAF’s usefulness, we requested that they elaborate on their responses.
The following sentences are the participants’ explanations of their answers:

- *”Because it could allow companies to better understand which is their group target. Improvements may educate companies that this possibility may help them and why”;*
- *”It is a bit unclear to me how the social concepts involved in the SusAF concept could be practically applied to software systems”;*
- *”It shows what can happen but doesn’t actually return a solution. That would be a good Path to follow”;*

- *"Overall, I think this tool is useful in assessing the several impacts of software systems. However, I think it doesn't account for all the factors that are inherent to the impact of these software systems";*

- *"I think it's very useful to understand the impact of the system since it provides us the option to categorize a system in different dimensions. We get a better understanding of how the system will impact the different dimensions, and after completing the evaluation we can decide if we want to change something";*

- *"Would it be easy to obtain the data to use with SusAF? Other than that, it would be very useful and anything that helps the environment is welcome";*

- *"SusAF allows you to visualize the impact of software systems in a simple manner";*

- *"Understanding relations between different "sustainability domains" could always be beneficial";*

- *"I believe SusAF could be useful for assessing the overall impact of software systems because it offers a comprehensive framework that considers various sustainability aspects, such as environmental, economic, and social factors. By using SusAF, organizations can systematically evaluate and score their existing systems, identifying areas for improvement and ensuring that their IT solutions align with sustainability goals";*

- *"It is not yet so clear to me how the framework works";*

- *"Awareness of the impact of the software is useful".*

The following four questions focus on SusAD, the diagram that is utilized in SusAF, and try to assess its practicality as well as if a digital tool would be appropriate to assist in its creation.

Question: **4.5. Do you think that it is practical to create the SusAD manually, taking into account more complex systems with multiple effects?** Participants were asked to rate SusAD's practicality when thinking about its creation with complex systems, using a scale from 1 (Not practical) to 5 (Very practical). The outcomes are very scattered, with 16.2% rating it as "1", 43.2% rating it as "2", 24.3% rating it as "3", 10.8% rating it as "4", and 5.4% rating it as "5".

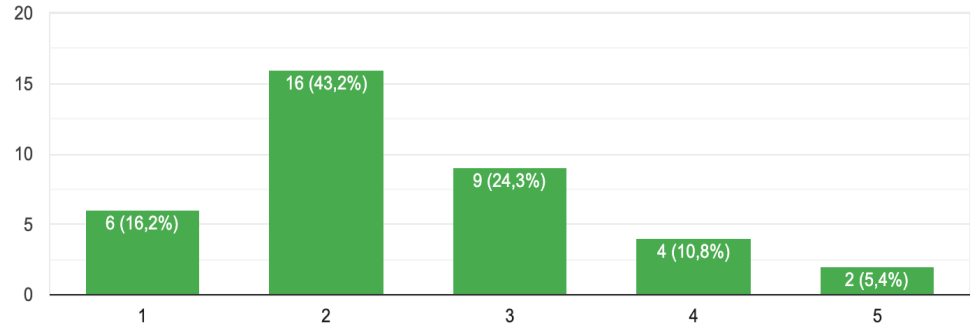


Figure 6.17: Perceived practicality of SusAD

Question: **4.5.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)** To fully understand participants' opinions of SusAD's practicality, we asked them to include more details in their answers. Participants' explanations are the following:

- *"An algorithm with computer and software assistance would take away some of the complexity of the subject";*
- *"An intuitive online tool would significantly help";*
- *"For simple systems it may be practical, nevertheless for more complex systems that present multiple chains of effects it may turn into an unreadable diagram";*
- *"The SusAD diagram seems to take into consideration several social dimensions, and manually evaluating all of those dimensions when creating the diagram requires a lot of time investment";*
- *"Too much time-consuming";*
- *"Automation would be an asset";*
- *"The connections between dimensions might become rather complex and hard to analyze. Also, the verbose needs to be very summed up in order to fit in the pentagon. In the end, it becomes very 'crowded' with information and difficult to understand";*
- *"If the system is too complex, it can become harder to organize the information to display in the diagram";*
- *"I think the visual aspect of SusAF is very useful. As humans, we process visual information a lot better. For example, in the previous section, the text was clear, but still, only after seeing the Pentagon did I truly begin to comprehend better what the text was saying and the true impact of renting rooms. That said, I don't believe it's viable for complex systems. In my case, it would take too much time to account for everything";*
- *"There are many parameters. This process should be easy for non-experts to use";*

- *"Manually could be too over the board, since there are many variables";*
- *"Creating diagrams manually is never optimal. Some tooling and connection to scrum/kanban boards would help";*
- *"It would be great if somehow we could automate a little bit using certain parameters depending on the subject";*
- *"It seems that intense brainstorming would be needed to identify the following effects in a more challenging scenario";*
- *"To improve practicality, automated tools, and software could be developed to assist in generating the SusAD, ensuring more accurate and efficient assessments";*
- *"Any tool should aim to eliminate manual work";*
- *"Still quite confused about how it works".*

Question: **4.6. Would it have a positive impact if SusAD was created digitally?** Using a scale from 1(Not at all) to 5 (For sure), participants rate the impact of creating SusAD digitally. The overall perception of that influence is positive, with 8.1% rating it as "3", 37.8% rating it as "4" and 54.1% rating it as "5".

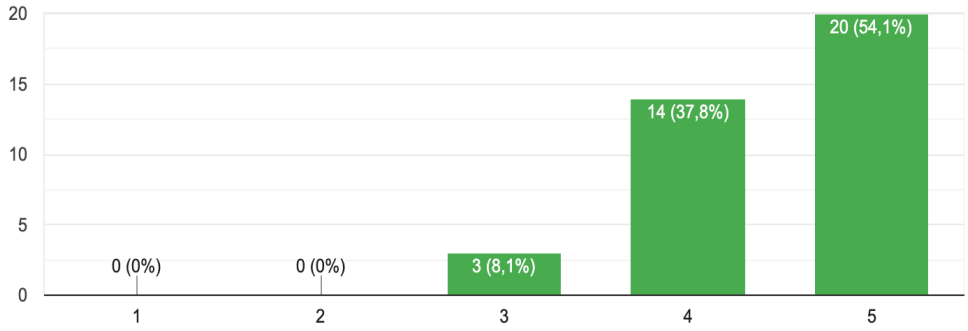


Figure 6.18: Influence of creating SusAD digitally

Question: **4.7. If there was a tool to assist with the application of SusAF, especially facilitating the creation of the SusAD, would it be beneficial?** To assess the influence that a supporting tool would have when applying SusAF, participants rated it using a scale from 1 (Not beneficial) to 5 (Completely beneficial). The results indicated that the majority considered the auxiliary tool very beneficial to the utilization of SusAF, with 5.4% rating it as "3", 29.7% rating it as "4" and 64.9% rating it as "5".

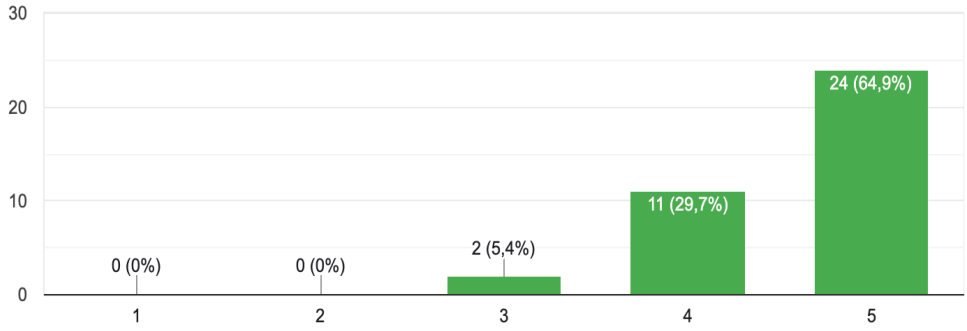


Figure 6.19: Influence of Using a Tool to Apply SusAF

6.2.5 Opinions and suggestions about GreenSusAF

The final set of questions is meant to assess GreenSusAF and gather suggestions about changes or new features.

Question: **5.1. Was this user guide helpful?** We start by providing a step-by-step tutorial video demonstrating how GreenSusAF works. Next, to assess if the video was helpful we requested participants to rate it on a scale from 1 (Not helpful) to 5 (Very helpful). The results are mostly positive, with 7.3% rating it as ”3”, 39% rating it as ”4”, and 53.7% rating it as ”5”.

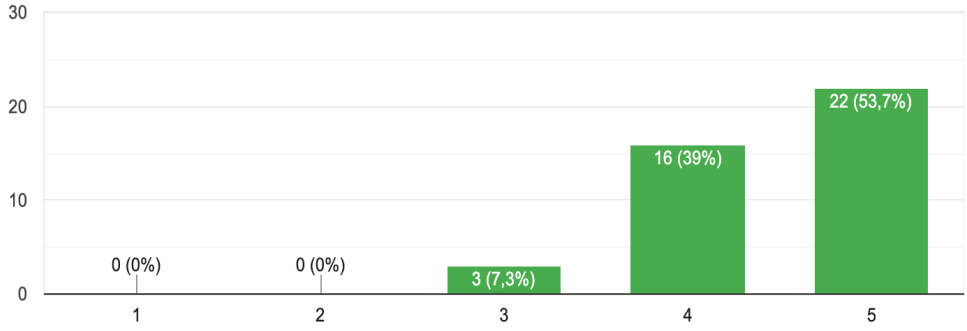


Figure 6.20: GreenSusAF’s video helpfulness

Question: **5.2. Do you have any suggestions for functionalities not currently present in GreenSusAF that you find relevant?** After having some knowledge of how GreenSusAF works, we wanted to ask participants if they had any suggestions for features that they considered necessary or interesting. For this effect, we presented an open-ended question.
The answers are:

- *”It seems good”;*

- *"A feature that automatically assesses the environmental and social impact of software systems based on real-time data would be really valuable, especially with the advancements in AI and machine learning. These technologies could analyze vast amounts of data, identify patterns, and predict sustainability outcomes more accurately and efficiently. This would allow for dynamic adjustments to software development practices, ensuring that sustainability goals are met continuously, not just at specific checkpoints";*
- *"Having a download button for an image is probably better than having to take a screenshot";*
- *"Maybe the sequence ordering could be more dynamic. Also, it would be nice to be able to enable/disable visualizing the relations between effects (the arrows)";*
- *"No, I think that the tool has everything that is essential";*
- *"Maybe the option to save an image instead of taking a print screen";*
- *"Save the file as png/jpeg/PDF instead of taking a screenshot";*
- *"No".*

Question: **5.3. Would the GreenSusAF be a significant improvement if it reduced the time required to use SusAF?** To determine how important it is to participants that GreenSusAF decreases the time required to apply SusAF, they rated this aspect on a scale from 1 (Not significant) to 5 (Very significant). Results indicate that the majority consider this reduction important, with 4.9% rating it as "3", 29.3% rating it as "4", and 65.9% rating it as "5".

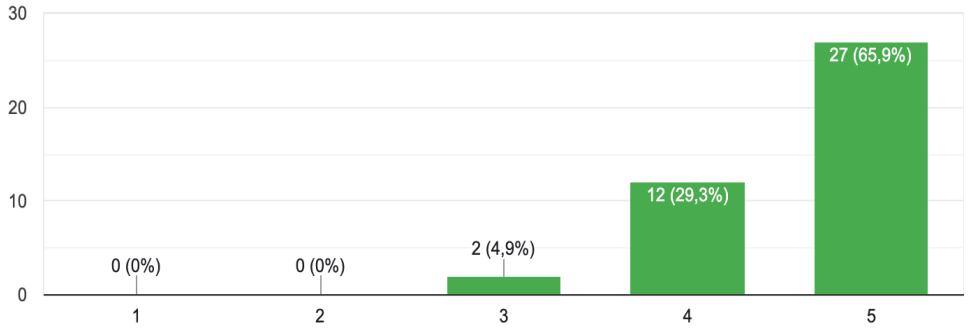


Figure 6.21: Influence of decreasing SusAF's time consumption

Question: **5.4. Considering both the reduction in paper usage and the potential increase in energy consumption from using an automated tool, how do you think GreenSusAF would impact the environment overall?** Taking into account that GreenSusAF will certainly reduce paper waste by digitizing the process, but may also increase energy consumption, we aimed to understand whether participants still believe that this tool would have a positive overall impact on the environment. To analyze this balance, participants rated it on a scale from 1 (Very negative) to 5 (Very positive). The outcomes are

somewhat dispersed, but the majority of responses lean towards the positive side, with 2.4% rating it as ”1”, 4.9% rating it as ”2”, 17.1% rating it as ”3”, 29.3% rating it as ”4”, and 46.3% rating it as ”5”.

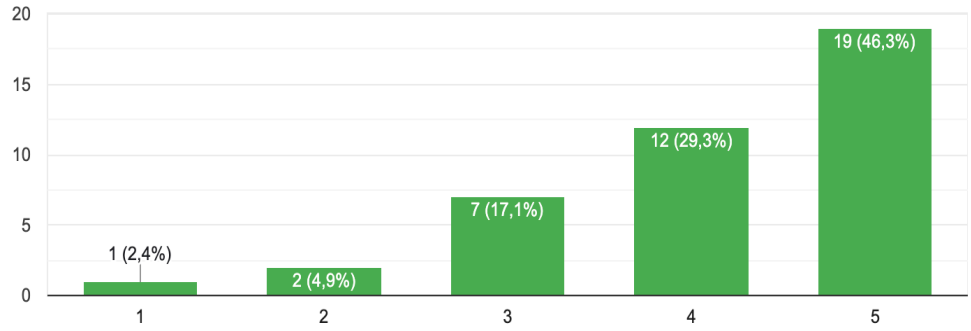


Figure 6.22: GreenSusAF’s sustainable balance between paper reduction and increased energy consumption

Question: **5.5. Do you think that GreenSusAF is easy to learn?** Assessing how easy to learn is GreenSusAF, participants rated this aspect using a scale from 1 (Very difficult) to 5 (Very easy). The results indicate that participants found GreenSusAF accessible, with 2.4% rating it as ”2”, 22% rating it as ”3”, 34.1% rating it as ”4”, and 41.5% rating it as ”5”.

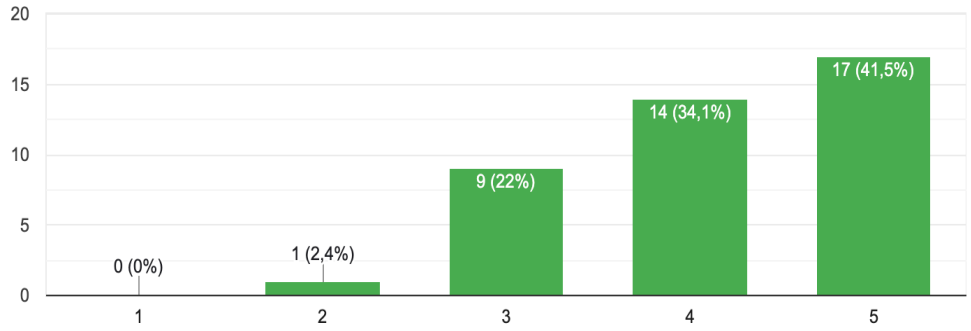


Figure 6.23: GreenSusAF’s ease of learning

Question: **5.5.1. If you answered 1 or 2 in the previous question, please explain why:** In case participants found the tool difficult to learn, we wanted to know why so we could improve. Therefore, we asked those who rated the learning difficulty as ”1” or ”2” to explain their answer. However, only one person rated it as ”2” and no explanation was provided.

Question: **5.6. In your opinion, does GreenSusAF promote the use of SusAF?** To evaluate the effectiveness of GreenSusAF in promoting the use of SusAF, participants were asked for their opinions on whether the tool facilitates the adoption of SusAF. Responses were collected on a scale from 1 (Absolutely not) to 5 (Yes, for sure). The results

suggest that GreenSusAF indeed promotes the application of SusAF, with 7.3% rating it as ”3”, 34.1% rating it as ”4”, and 58.5% rating it as ”5”.

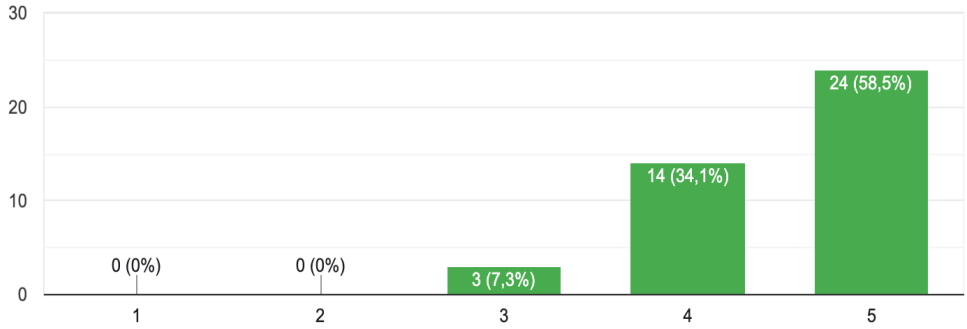


Figure 6.24: Impact of GreenSusAF on promoting the application of SusAF

Question: **5.6.1. Could you elaborate on the previous answer? (Why do you think so? What improvements could help?)** We asked participants to expand on their previous responses in order to obtain a more thorough understanding of their opinions regarding whether GreenSusAF promotes the use of SusAF. We specifically asked for explanations for their ratings as well as suggestions for possible improvements. The purpose of this open-ended question was to gather qualitative input in order to better understand the factors impacting their perceptions and identify areas in need of improvement.

The collected responses are:

- *”It takes the complexity out of the SusAF and allows people to review their company impact more efficiently”;*
- *”It turns what can be a complex and elaborated task that can take hours to complete into a more user-friendly one, while also easing the explanation of the created diagrams”;*
- *”In a way, automating the complicated diagram making process, as well as carefully explaining the social concepts to new users, has a considerable impact on time consumption. Thus making the system appealing to use. Thus, people using the system will be more likely to embrace SusAF concepts”;*
- *”Makes it easier to apply”;*
- *”It promotes the use of it because I only discovered about SusAF because of the GreenSusAF project”;*
- *”Because GreenSusAF makes it easier and more practical to understand SusAF. Essentially, more user-friendly”;*
- *”GreenSusAF effectively promotes the use of SusAF by providing clear, practical guidance that makes integrating sustainability into software development easier. It’s comprehensive and user-friendly, which encourages adoption. To improve, adding more real-world examples*

and industry-specific guidelines could make it even more accessible and applicable across different sectors";

- *"SusAF is not a very practical tool, having a digital version that requires no effort to set up will motivate more developers that are unsure if they want to use it";*
- *"It's much better to do something on a tool than on paper, it saves a lot of time";*
- *"All the tools that make a job easier encourage its use or at least don't put it aside because it's too much work";*
- *"It serves as a tool that not only popularizes SusAF but also makes it easy to learn/implement, besides having the sustainability quality";*
- *"It helps make it a little easier to work with";*
- *"Appears to be an easy intuitive and agile way to elaborate the diagram";*
- *"GreenSusAF could encourage more people to apply SusAF";*
- *"Really helps the usage of the SusAF system";*
- *"The tool provides a structured way to generate diagrams for custom scenarios, making it easier to visualize and understand the sustainability aspects of IT systems. However, since GreenSusAF is not a fully automated tool, there is still a need for manual input and adjustments. To improve GreenSusAF, it could benefit from enhanced automation features that reduce the need for manual adjustments. Additionally, incorporating more intuitive user interfaces and providing templates for common scenarios could further streamline the process and make it more user-friendly";*
- *"Any tool that automates manual work is always well received";*
- *"If it makes it easier to apply the method it promotes the use".*

6.2.6 Discussion of results

After analyzing the responses, we can highlight several important insights that emerged from the data. Currently, the majority of participants were unfamiliar with SusAF and likely had not even heard of it before this study. Despite this, SusAF was considered beneficial to raise awareness of sustainability impacts by most participants, both those who were familiar with it and those who weren't. Perceptions of ease of use differed between participants who had previous knowledge of SusAF and those who did not. Participants already familiar with the framework found it easy to learn and the main challenges that they faced were related to the lack of tools to support this framework and its complexity. On the other hand, participants unfamiliar with SusAF felt it was not as easy to learn, identifying their main challenges as understanding the concepts, dealing with the framework's complexity, and the lack of appropriate tools to assist in applying SusAF. Most

participants consider creating SusAD manually in the context of more complex systems to be impractical. With both perspectives in mind, we believe that GreenSusAF could effectively minimize these challenges by helping users understand concepts, minimizing complexity and time, and providing a digital manner to create SusAD. Most participants agreed that having a tool to assist the use of SusAF would be beneficial. GreenSusAF was positively evaluated, the majority of participants considered it important to decrease the time required to apply SusAF and to reduce paper usage. Participants rated the ease of learning GreenSusAF from medium to easy. Finally, participants found GreenSusAF helpful in promoting the use of SusAF, as it facilitated and sped up the process. Participants' main suggestions to GreenSusAF were: a feature that automatically assesses the impacts of software systems based on real-time data, using AI and machine learning; a download button for the image instead of having to take a screenshot; making the sequence ordering more dynamic, with the option to enable/disable the visualization of the relationships between effects; enhanced automation features that reduce the need for manual adjustments; and the incorporation of more intuitive user interfaces, along with templates for common scenarios. These suggestions are very relevant and may be useful for future work.

6.3 Threats to validity

Following the results and discussion of our questionnaire, it is time to discuss the threats to its validity. There are various ways to discuss the aspects of threats to validity in the literature, we choose to follow the guidelines proposed in [36]. They distinguish four aspects of the validity: internal, external, construct, and conclusion validity.

6.3.1 Internal and External Validity

Threats to internal validity are influences that can affect the independent variable with respect to causality, without the researcher's knowledge [36].

Considering that the topic of SusAF is not familiar to most participants, the questionnaire may feel intimidating to them. To try to mitigate this, we provided a video and an example to introduce participants to SusAF. Consequently, while trying to provide an accessible and understandable questionnaire, it ended up being a little overextended, besides having to watch 2 videos (with approximately 2 min each), we had a total of 32 questions, which could cause participants to be bored or tired. In an effort to mitigate this threat, most of our questions are multiple-choice and the few that are open-ended are not mandatory, which helps participants to make the questionnaire process faster and to feel free to choose whether or not they want to answer open-ended questions.

Threats to external validity are conditions that limit our ability to generalize the results of our experiment to industrial practice [36].

Our questionnaire was available to a controlled range of participants, even though participants from computer science are the majority, participants from other fields were not excluded. Although we collected insights from many participants, we did not have many answers from individuals familiar with SusAF, which could indicate that this sample is non-representative. To mitigate this threat, we provided 2 videos and one example to participants, one video introducing SusAF, an example introducing SusAD, and a step-by-step tutorial video of GreenSusAF.

6.3.2 Construct Validity

Construct validity concerns generalizing the result of the experiment to the concept or theory behind the experiment [36]. Although we phrased our questions not to be unambiguous or unclear, participants' interpretations are unique and difficult to predict. Therefore, we divided the questionnaire into sections referring only to the subject in question and also provided an introduction, if we thought it necessary, at the beginning of the section.

6.3.3 Conclusion Validity

Threats to conclusion validity are concerned with issues that affect the ability to draw the correct conclusion about relations between the treatment and the outcome of an experiment [36]. Choosing the wrong questions could directly affect the results, and consequently, the conclusion is compromised. To mitigate this threat, we meticulously formulated the questions to assess the subjects of the questionnaire. The size of the sample can lead to false positives or false negatives because, due to the low number of answers, the individuals who responded could have different characteristics from those who did not respond. In our questionnaire, we tried to reach the maximum number of participants possible to mitigate this threat, but in a controlled environment, because we wanted to reduce the risk of random or inattentive responses.

6.4 Summary

In this section, we go through the evaluation of the tool, starting with the evaluation planning to the results and discussion. We decided to elaborate on a questionnaire using Google Forms. The questionnaire was completed by 41 individuals and their responses indicated the general lack of knowledge about SusAF, their good perception of the usefulness of SusAF, and their perception of associated challenges to apply this framework. The use of GreenSusAF was considered beneficial to assist in the application of SusAF.

Finally, we close this chapter by providing threats to validity and a summary.

7

Conclusions

In this final chapter, we provide an overview of how we arrived at our solution, we also talk about our solution and the contributions of this dissertation, moving to the limitation of our work, and finally, we suggest possible paths for future work.

7.1 Problem solution

In this dissertation, we propose an auxiliary tool for SusAF and its conceptual model. The main objective of this tool, the GreenSusAF, is to facilitate the effective application of SusAF during Requirements Engineering, providing introductions to important concepts and digitizing the SusAD creation process. Therefore, with the help of GreenSusAF, even users with less experience can apply SusAF more easily.

The conceptual model of the tool was created taking into consideration the performed systematic mapping study. After that, we started to build the tool to help apply SusAF, specifically with the identification and analysis of sustainability impacts and to support the integration of sustainability concerns into the initial phase of the development of software systems. We then carried out an evaluation of the developed tool regarding its ease of learning and its usefulness to support SusAF, along with participants' perceptions about SusAF. The results were encouraging and showed that this subject is considered important, which indicates possible paths for future work.

7.2 Contributions

Our main contributions are:

- A conceptual model for the tool. We started by defining the target audience and stating its primary goals. Then we moved to the development of the conceptual model. It provides an outline for the compositions of the tool.

- A auxiliary tool for SusAF. After developing the conceptual model, we started to

build the tool. GreenSusAF was created based on the SusAF Workbook[1] and aims to assist the application of SusAF.

- An evaluation of the tool, with 41 participants. This evaluation aimed to gather insights about GreenSusAF, and also gather the participants' perceptions about SusAF. The results indicated positive insights about GreenSusAF and relevant suggestions for future work.

7.3 Limitations of the work

Although this dissertation is a step closer to the integration of sustainability in software systems by helping the application of SusAF, it is important to highlight some limitations that may have influenced the reach of the conclusions.

Firstly, using an automatic search process to collect literature has some risks. Although we try to choose the most complete and precise search strings, we cannot be sure that they are complete or precise enough, and since the automatic search process depends severely on the choice of search strings, we may run the risk of not having adequate or sufficient literature.

Considering the assessment process, and as SusAF is unfamiliar to most participants, the questionnaire may have been confusing and overwhelming, although we attempted to resolve the issue by providing an introductory video for SusAF along with an example, which also led to the questionnaire being a bit long. Although the questions are mostly multiple choice questions, the answers to the questionnaire may have been influenced by these factors and may be less accurate. Additionally, due to the low number of participants who are familiar with SusAF, the section aimed at participants familiar with SusAF had few responses, which does not allow significant conclusions to be drawn.

7.4 Future work

The creation of the conceptual model and the auxiliary tool represents an initial contribution. There are many ways to contribute to the integration of sustainability into software systems. We list some suggestions for future work:

- The tool itself is a step to integrate sustainability into software systems, however, improvements are always beneficial. For example, an improvement for identifying effects in the 5 dimensions of sustainability that use artificial intelligence, or to generate a document with the questions and answers, effects, and SusAD;

- A feature that automatically assesses the impacts of software systems based on real-time data, using AI and machine learning;

[1]https://www.suso.academy/en/sustainability-awareness-framework-susaf/

- A usability assessment of SusAF would be beneficial to better understand where support is needed.
- Investigate how the SusAF and the auxiliary tool can be adapted and integrated into various software development methodologies such as Agile, DevOps, or Waterfall. That could promote the use of SusAF in different development methodologies.

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A

Questionnaire

Sustainability Awareness Framework: An assessment of the **GreenSusAF** Tool

This questionnaire aims to evaluate a tool to support the Sustainability Awareness Framework (SusAF), called GreenSusAF, developed as part of a master thesis in Computer Engineering at the Faculty of Science and Technology of NOVA University Lisbon. This evaluation is an important part of the dissertation, and it will help us improving and adapting the tool to better meet users' needs.

Participation in this questionnaire is completely voluntary and can be stopped at any time. All responses will be kept confidential and anonymous, ensuring that no individual response is identifiable. The questionnaire consists of several sections and includes a mixture of multiple choice, checkbox, and optional open questions, designed to be answered in approximately 10 minutes.

The data collected will be used exclusively for research purposes, specifically to refine the GreenSusAF tool. The contribution of each participant will be fundamental to achieving this goal.

If you have any questions or concerns about the questionnaire or the dissertation, please feel free to contact me at b.arroja@campus.fct.unl.

Thank you in advance for your time and participation.

Best regards,
Bruna Arroja

* Indica uma pergunta obrigatória

1. 1.1. Please specify your gender: *

   Marcar apenas uma oval.

   - ◯ Female
   - ◯ Male
   - ◯ Prefer not to say
   - ◯ Outra: _____

2. 1.2. Please specify your age: *

Marcar apenas uma oval.

- ◯ <18
- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55-64
- ◯ >=65

3. 1.3. What is your field of study/work? *

Marcar apenas uma oval.

- ◯ Arts
- ◯ Biology
- ◯ Chemistry
- ◯ Computer Science / Software Engineering
- ◯ Economics
- ◯ Engineering (e.g., Civil, Mechanical, Nanotechnology)
- ◯ Finances
- ◯ Mathematics
- ◯ Medicine / Health Sciences
- ◯ Law
- ◯ Social Sciences
- ◯ Sports
- ◯ Outra: _____

4. 1.4. Please indicate your level of education: *

Marcar apenas uma oval.

- ◯ Middle School
- ◯ High School
- ◯ Technical Course
- ◯ Bachelor's Degree
- ◯ Master's Degree
- ◯ Doctorate

Sustainability Awareness Framework- SusAF

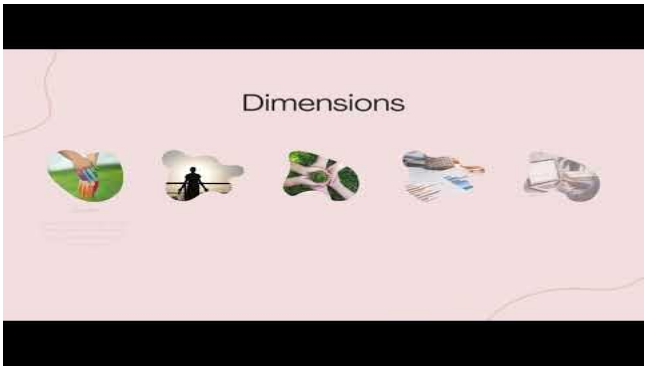
Please watch the video below to learn about SusAF. Participants already familiar with SusAF have the option to skip to the next section. Additionally, there is an explanation of the Sustainability Awareness Diagram (SusAD) to complement your understanding. Familiarity with the basic concepts will facilitate the accurate completion of the form. Thank you for your cooperation!

5. 2.1. Do you have any knowledge about SusAF? *

Marcar apenas uma oval.

- ◯ Yes *Avançar para a pergunta 7*
- ◯ Almost nothing *Avançar para a pergunta 16*
- ◯ No *Avançar para a pergunta 16*

SusAF- video



http://youtube.com/watch?v=P3XovMyvPT4

6. 2.2. Was this video helpful? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very helpful

Introduction to the Sustainability Awareness Diagram (SusAD) used in SusAF.

SusAD is a pentagon-shaped diagram divided into five equal parts, each representing a dimension of sustainability (environmental, social, economic, technical, individual). Each of these parts is subdivided into three sections, each corresponding to one of the three orders of effects (immediate, enabling, structural).

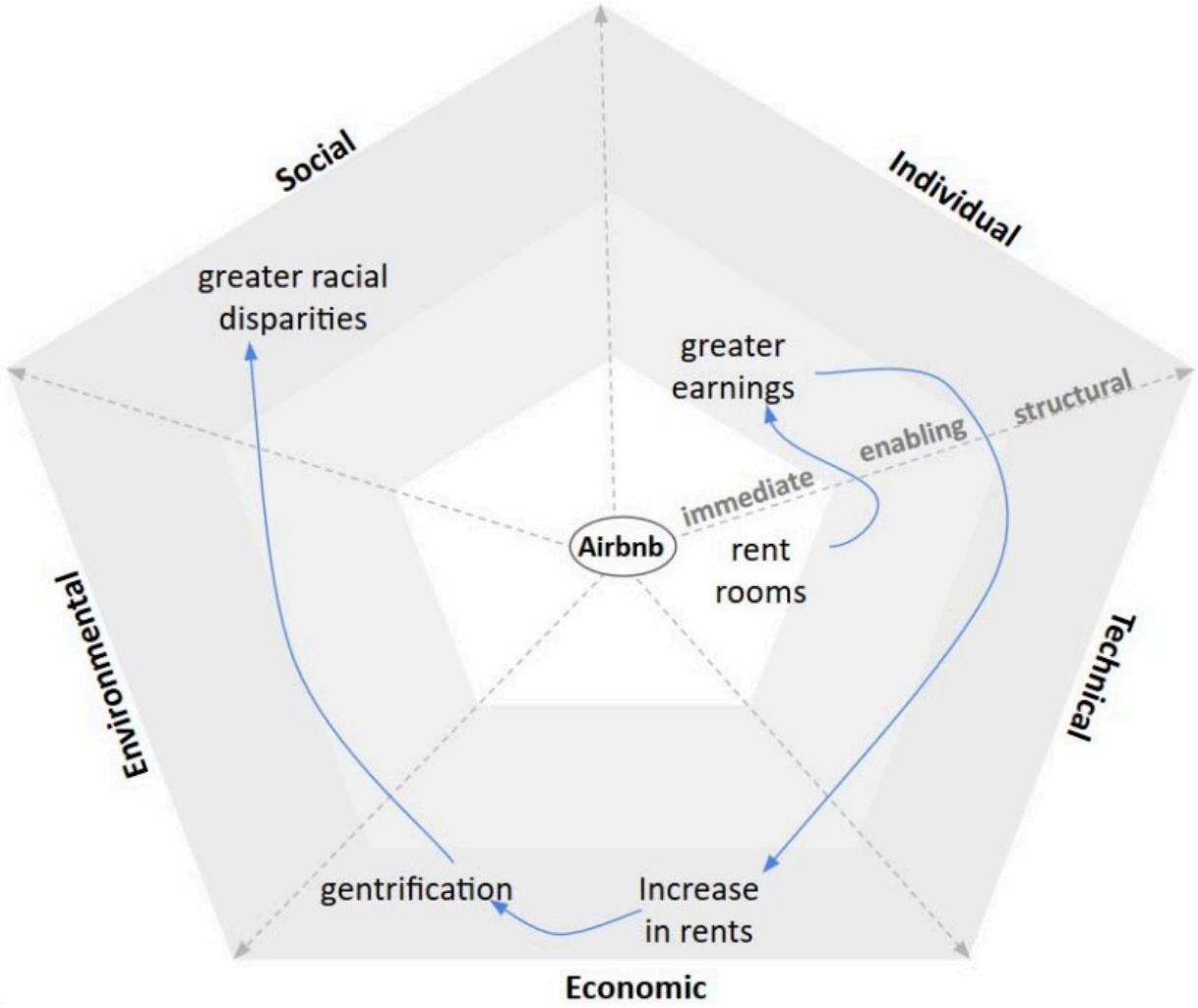
The figure below illustrates an example of SusAD for the Airbnb platform, taken from a study of the impact of the platform in the USA. Airbnb allows owners to rent houses or rooms to guests worldwide.

The main functionality of the platform, rental of houses and rooms, generates the immediate effect "rent a room" of the technical dimension, as it is the direct consequence of implementing this service.

Once the service is deployed, owners rent out their spaces, what enables "greater earnings" as an effect in the individual dimension.

After several years, an increase in the average long-term rent was detected as a result of the decrease in the number of properties available to rent. Such an "Increase in rents" is categorized under the economic dimension as a structural effect, reflecting its profound and lasting influence on the real estate market.

Additionally, this increase promoted the "gentrification" of predominantly ethnic minority from certain locations. Such economic structural effect leads, in turn, to "greater racial disparities", a structural effect in the social dimension.



About SusAF- Familiar Participants

This section is designed for those who are familiar with SusAF. It allows you to share your insights and opinions about the framework.

7. 3.1. Do you think that SusAF is easy to learn? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very easy

8. 3.2. Do you think utilizing the SusAF requires a lot of time? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very time-consuming

9. 3.3. What are the main challenges you face when using SusAF in your projects?

10. 3.4. Do you think SusAF is useful for raising awareness of the sustainability impacts of software systems? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very useful

11. 3.4.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)

The next three questions are about the diagram- SusAD, used in SusAF

12. 3.5. Do you think that is practical to create the SusAD manually, taking into account more complex systems with multiple effects? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Yes, no problem

13. 3.5.1 Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)

14. 3.6. Would it have a positive impact if SusAD was created digitally? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Sure

15. 3.7. If there was a tool to assist with the application of SusAF, especially facilitating the creation of the SusAD, would it be beneficial? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Completely

Avançar para a pergunta 25

About SusAF- Unfamiliar participants

This section is designed for those who are not yet familiar with SusAF. It contains questions intended for users who have never used the framework before, It allows you to offer your initial thoughts and opinions based on the previously provided information.

16. 4.1. Do you think that SusAF is easy to learn? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very easy

17. 4.2. Based on what you know or have seen in the previous section, how time-consuming do you think applying SusAF might be? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very time-consuming

18. 4.3. What do you think would be the most difficult part of using SusAF, if you decided to start? *

Marcar tudo o que for aplicável.

- [ ] Understanding concepts
- [ ] Time required to apply SusAF
- [ ] SusAF's complexity
- [ ] Lack of proper tools to help the application of SusAF
- [ ] Outra: _____

19. 4.4. Based on what you know or have seen in the previous section, do you think SusAF could be useful for assessing the overall impact of software systems? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very useful

20. 4.4.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)

The next three questions are about the diagram- SusAD, used in SusAF

21. 4.5. Do you think that is practical to create the SusAD manually, taking into account more complex systems with multiple effects? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Yes, no problem

22. 4.5.1. Could you elaborate on the previous answer? (For example, why do you think so? What improvements could help?)

23. 4.6. Would it have a positive impact if SusAD was created digitally? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Sure

24. 4.7. If there was a tool to assist with the application of SusAF, especially facilitating the creation of the SusAD, would it be beneficial? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Completely

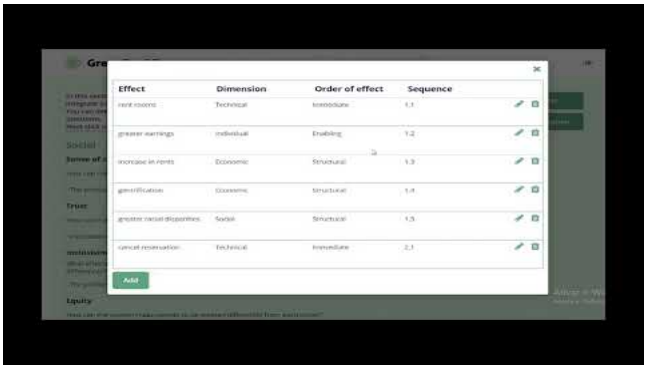
Avançar para a pergunta 25

GreenSusAF

GreenSusAF is an auxiliary tool that has been developed to help the utilization of SusAF in a way that makes it easier, faster, and more intuitive for users, whether they are experienced or not.

In this section there is a video to illustrate the use of GreenSusAF. Watching this video is important for answering the rest of the questions correctly.

GreenSusAF- User guide



http://youtube.com/watch?v=mHEBJea0xu0

25. 5.1. Was this user guide helpful? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very helpful

26. 5.2. Do you have any suggestions for functionalities not currently present in GreenSusAF that you find relevant?

27. 5.3. Would the GreenSusAF be a significant improvement if it reduced the time required to use SusAF? *

Marcar apenas uma oval.

	1	2	3	4	5	
Not	◯	◯	◯	◯	◯	Very significant

28. 5.4. Considering both the reduction in paper usage and the potential increase in energy consumption from using an automated tool, how do you think GreenSusAF would impact the environment overall? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very positive

29. 5.5. Do you think that GreenSusAF is easy to learn? *

Marcar apenas uma oval.

	1	2	3	4	5	
Very	◯	◯	◯	◯	◯	Very easy

30. 5.5.1. If you answered 1 or 2 in the previous question, please explain why:

31. 5.6. In your opinion, does GreenSusAF promote the use of SusAF? *

Marcar apenas uma oval.

	1	2	3	4	5	
Abs	◯	◯	◯	◯	◯	Yes, for sure

32. 5.6.1. Could you elaborate on the previous answer? (Why do you think so? What improvements could help?)

Google Formulários