Transforming our World through Software – Mapping the Sustainability Awareness Framework to the UN Sustainable Development Goals

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Abstract: The Sustainable Development Goals (SDGs) of the United Nations focus on key issues for the transformation of our world towards sustainability. We argue for stronger integration of the SDGs into requirements and software engineering and for the creation of methods and tools that support the analysis of potential effects of software systems on sustainability in general and on SDGs in particular. To demonstrate one way of undertaking this integration, we report on how the Sustainability Awareness Framework (SusAF – a tool developed by the authors of this paper) can be mapped to the SDGs, allowing the identification of potential effects of software systems on sustainability and on the SDGs. This mapping exercise demonstrates that it is possible for requirements engineers working on a specific system to consider that system's impact with respect to SDGs.

1 INTRODUCTION

"The Sustainable Development Goals are the blueprint for achieving a better and more sustainable future for all. They address the global challenges we face, including those related to poverty, inequality, climate change, environmental degradation, peace and justice. The 17 Goals are all interconnected, and in order to leave no one behind, it is important that we achieve them all by 2030." (United Nations General Assembly, 2015)

The Sustainable Development Goals (SDGs) stimulate the transformation of our world towards sustainability (United Nations General Assembly, 2015) (see Fig. 1). Though the SDGs do not focus on software systems and software development, the transformation of our world is strongly driven by software as an integral part of modern societies. We already see that there are more and more software systems built to support one or more SDGs, such as systems helping to avoid food waste (SDG12) or to support online teaching (SDG4).

As software engineers who are concerned with socio-technical systems development as well as furthering the SDGs, we must understand if and to what extent a particular software system supports or hurts

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one or more of the SDGs. However, to our knowledge, currently, there are no systematic methods and tools (see Section II) which support such analysis.

While we consider the development of novel software systems that embrace the SDGs as essential for transforming our world, we are also aware that most software systems are built without sustainability in mind (Chitchyan et al., 2016). Yet, these "ordinary" software systems too will (positively or negatively) impact the world and the SDGs. The overarching question for our ongoing research is: How to systematically identify if and how a software system affects the SDGs?

The Sustainability Awareness Framework (SusAF) is a framework developed and validated by the authors of this paper (Duboc et al., 2019) (Duboc et al., 2020). It raises awareness of the potential effects of IT systems on the social, technical, economic, environmental and individual aspects of sustainability. Therefore, it can provide a starting point answer our overarching question. Thus, this paper focuses on exploring how SusAF can be linked with SDG-related impact identification and analysis. Therefore, our current concrete research question is: Can SusAF assist the identification of how software systems affect the SDGs? The result of investigating and answering this question will be a framework that enables requirements engineers to understand and analyse how a software system they develop would relate to the SDGs. Presenting this novel framework and applying it in a case study will result in a first full research contribution once this research is complete. The main contribution of the present paper (as part of the ongoing work towards the intended full contribution) is undertaking a pilot study for demonstrating the feasibility of linking SusAF with the SDGs.

In Section II, we provide an overview of the SDGs and their use. Section III presents our overall vision. Section IV presents SusAF. In Section V, we describe the mapping of SusAF to the SDGs. Section VI discusses lessons learned, and Section VII provides more details on the next steps.

2 BACKGROUND

The UN SDGs have been analysed from different perspectives and integrated into different analysis frameworks. The 17 SDGs, which are decomposed to 169 targets, can be achieved through their supporting actions (United Nations General Assembly, 2015). These together have the potential to transform the nature of human development and make environmental and social sustainability a defining characteristic of economic activity (Stevens and Kanie, 2016). However, researchers also argue that the utilisation and prioritisation of SDGs requires a proper level of systems thinking (Morton et al., 2017). Filho et al. have shown how these SDGs can be used for better understanding sustainability challenges (Filho et al., 2019). Their primary goal is to increase the understanding of the different SDGs and their utilisation for policymaking. Morton et al. (Morton et al., 2017) state that even though the SDGs can be divided into five areas of critical importance (people, planet, prosperity, peace and partnership), the way that different countries pursue these SDGs will be different based on locally assessed impacts (both positive and negative) on other goals (Fleming et al., 2017). Consequently, analysing SDGs requires an understanding of both each individual goal as well as the inter-goal interactions. The study of various interactions, both positive co-benefits and negative trade-offs, between different SDGs has been under analysis in various domains. Many presume that the SDGs and targets are mutually supporting, i.e. to progress in one area requires progress in other areas (Nilsson et al., 2017). However, both researchers and policymakers have already highlighted that there can be conflicts as well as support between SDGs. The work of Nilsson et al. (Nilsson et al., 2016), for instance, focuses on seven different interaction types between SDGs – from indivisible to cancelling. They also show the implications of their framework (Nilsson et al., 2018) in various contexts (governance, geographic, and time) in different application domains (health, energy and oceans) and propose a web-based knowledge platform that takes their research as well as policymaking into account. The work of Singh et al. on SDG14 (Life Below Water) shows the full complexity of cross-SDG effects with 267 relationships (both positive and negative as well as a prerequisite and optional) between the targets of SDG14 and the other SDGs (Singh et al., 2017). Similar kinds of interactions could be seen in other domains like health (Morton et al., 2019). An SDG integration framework has also been proposed for the corporate value creation process (Adams, 2017), though this approach does not emphasise accountability as emphasised by Morton et al. (Morton et al., 2017). Stafford-Smith et al. show how the interdependencies among the SDGs work across various sectors, societal actors and between countries (Stafford Smith et al., 2017).

To summarise, the SDGs and their interlinkages have been analysed from different perspectives and in different domains. In addition to our more general overview of the use and impact of the SDGs presented above, we have also started a literature review of work

Figure 1: The 17 SDGs of the UN.

on SDGs and software and requirements engineering specifically. Based on an initial analysis, we see that there exists only limited work on studies or models that link the SDGs to software system development or software systems effects to the SDGs such as (Brooks, 2020). We are aware that we are drawing early conclusions, but these findings strongly motivated us to pursue the research described in this paper.

3 VISION: SUSTAINABILITY AS A KEY ASPECT FOR ALL SOFTWARE SYSTEMS

Software systems have an important role in society, and as such, they should support one or more Sustainable Development Goals. While the importance of the SDGs is widely recognised, we as requirements engineers are often unaware or neglect that existing software systems also have an effect on sustainability. In addition to building systems targeting specific SDGs, it is also essential to understand how a system may affect different SDGs. The most obvious way is to look at the vision (key features) for a software system and compare it with the SDGs. This could identify contributions of software systems to the SDGs that were not known before or lead to the change of some features to better align the system with an SDG. Consider, for example, a software system supporting teaching activities at a university, which has a clear relation to the SDG4 – Quality Education. Such a system could either be built with SDG4 in mind, or if it already existed, a comparison of the system purpose with this and other SDGs could be used to understand how the system is contributing to sustainable development. Therefore, it is clear that supporting SDGs is strongly linked with the overall purpose of the application and that SDGs are relevant for software systems that have been built with sustainability in mind. However, this level of consideration is not enough. We also need methods and tools that allow us to investigate the potential sustainability effects of ordinary software systems and relate them to SDGs. This starts with their requirements (Becker et al., 2016), which need to be analysed to understand their potential effects on sustainability. Doing so allows us to go beyond building systems that are intentionally developed to support one or more SDGs: it allows us to make any software system more sustainable. Ideally, these novel methods and tools would allow us to connect the insights gained about a system to the SDGs and, with this, to understand how the software system supports or jeopardises them.

4 THE SUSTAINABILITY AWARENESS FRAMEWORK (SUSAF)

There exist methods and tools which allow a discussion of the sustainability effects of ordinary systems (e.g., (Hilty and Aebischer, 2015) (Alharthi et al., 2018) (Seyff et al., 2018)). We selected the Sustainability Awareness Framework (SusAF) (Duboc et al., 2020) as the basis for our ongoing research because it is well described in the literature, and relevant artefacts for working with SusAF are publicly available (Penzenstadler et al., 2020).

SusAF (Duboc et al., 2020) increases awareness of the relationship between software systems and sustainability by supporting the identification and discussion of the potential effects of such systems on five dimensions: economic, environmental, social, individual and technical (described in Table 1). SusAF is composed of a set of questions, a visualisation tool, guidelines and examples, which are used together to support the identification and discussion of the potential effects. We briefly discuss these elements below.

The questions are grouped into the five sustainability dimensions, covering the topics described in Table 1. The main results of the discussion can be visualised in the Sustainability Awareness Diagram (SusAD). The SusAD is an adapted radar chart that is divided into five slices – one for each sustainability dimension – and three concentric areas, representing the immediate, enabling and systemic effects of a software system (see Table 2). It aims to ease the visualisation and discussion of the potential chains-of-effects, which describe how effects can lead to one another over time. The guidelines and examples enhance the understanding, and support the application, of SusAF.

5 MAPPING OF SUSAF TO THE SDGS

The first contribution of our ongoing research is an initial, piloted mapping between the SDGs and SusAF. We carried out a thematic analysis of the topics and questions tackled by the SusAF framework (as shown in Table 1) and those addressed by the SDGs (see below, the examples in Stage 1 and 2). One of the authors conducted the deductive qualitative content analysis based on (Mayring, 2000) where the coding guides or category systems are based on the SusAF topics and the 17 SDGs. The analysis was conducted in two stages: in the first stage, a general feasibility of the mapping was considered, after which a detailed mapping was carried out. Both mappings are briefly discussed below:

Stage 1: The general feasibility of mapping. Here one of the authors analysed the 25 SusAF topics[9] (e.g., participation) and their corresponding questions in order to identify their relationships with the 169 targets of the 17 SDGs. The topics were considered related to the SDG where at least one of the SusAF topic's questions could be linked to a target of that SDG. For example, for SusAF's social dimension and its topic equality, the question "Can the system make people be treated differently from each other?" was mapped to the SDG target 5.1, "End all forms of discrimination against all women and girls everywhere." which is part of SDG 5 "Gender Equality" because discrimination against women and girls is an example of how 'people can be treated differently'. Therefore, SusAF's "equality" topic was linked with the SDG 5 "Gender Equality". In this way, all SusAF topics were mapped to one or more SDGs. Having ascertained the overall relatedness of concepts across SusAF and SDGs, a more detailed mapping was conducted by the same author at the second stage to investigate if the SusAF does cover all points of the SDGs in detail.

Stage 2: The detailed mapping. At this stage, one of the authors carried out a systematic and transparent deductive qualitative content analysis using maxqda tool[10]. Here, the 95 questions of SusAF and the 169 SDG targets were independently coded into semantic categories, which were then compared. If the same code appeared both in the codeset of a SusAF question and in an SDG target, the topic belonging to this question and the SDG belonging to this target were mapped. For example, the code "Nature: plants and animals" can be found in SusAF question "Can the system impact the plants or animals around it?" of the topic biodiversity of the environmental domain, as well as in SDG target 15.4 "By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development" of SDG 15 Life On Land. The detailed mapping confirmed that SusAF largely corresponds to the targets of the SDGs. Details can be found in (Lammert and Betz, 2021).

In this piloted detailed mapping, we observed that 5 of the SusAF topics were not directly linked with any of the SDG targets. These topics are Maintainability, Adaptability, Security and Scalability (Technical Dimension) and Trust (Social Dimension). We

[9] These are listed under Dimensions:Topics heading of Table 1.

[10] https://www.maxqda.com/

Table 1: Coverage and Questions of the Five Sustainability Dimensions in the SusAF based on (Duboc et al., 2020)

Dimensions: Topics	*Coverage and Questions*
Economic: value, CRM, supply chain, governance, innovation	The financial aspects and business value. The questions are about how the system creates or destroys value, how it affects the relationship between businesses and customers, whether it alters a business supply chain, governance, processes, or R&D.
Environmental: material & resources, waste & pollution, bio- diversity, energy and logistics	The use and stewardship of natural resources. The questions are about how the system may affect the consumption of resources, the production of waste, pollution and emissions and biodiversity.
Social: community, trust, inclusiveness, equity and participation	The relationships between individuals and groups. The questions are about how the system may affect people's sense of belonging, their trust in its surroundings, their perception of others, how they participate in social groups, or whether they are receiving the same treatment as others.
Individual: Health, lifelong learning, privacy, safety & agency	The individual's ability to thrive, exercise their rights, and develop freely. The questions are about how the usage of the system may affect the individual themselves, that is, a person's physical and mental health, on their level of knowledge, on their privacy, safety and ability to act on its surroundings.
Technical: maintainability, usability, adaptability, security & scalability	The technical system's ability to accommodate changes. The questions aim to identify how the system is maintained and used over time, and to illustrate the system's ability of change and adaptability of the functionalities into the change environment, and whether the security of the system and privacy of its users are considered.

postulate that topics referring to the Technical dimension of SusAF relate to the specific technical solutions through which many of the SDGs will be delivered, but, given that technical solutions are not discussed at the abstraction level of the SDGs, the direct links were not immediately identifiable. Additionally, Trust, though essential for social sustainability and functioning of the society, appears not to be explicitly addressed in the SDG targets.

Furthermore, we found 42 SDG targets that could not be mapped to SusAF questions. This is a significant number (25% of the overall targets). We postulate that one possible reason is that many of these targets are focusing partially on developing countries and specific industries. For example, target "10.a Special and differential treatment for dev. countries" and "3.a Tobacco control in all countries". The other reason is that SusAF was deliberately designed not to be comprehensive; it aims to kick-start a first exploration of how technology products and services may affect sustainability; study of the more detailed aspects of each system would follow on from this initial exploration (Duboc et al., 2019).

The two tables showing targets and questions that could not be mapped in this pilot study are provided in (Lammert and Betz, 2021). Further study and validation of these mapping results and their causes is a key part of our immediate future research.

The diagram in Fig. 2, showing the mapping, can be read from the inside out as follows:

- The inner-circle shows the five interrelated dimensions targeted by SusAF: the individual, social, economic, technical and environmental dimension.
- The second circle shows the five topics that drive the questions for each of the five dimensions. The individual dimension, for example, concerns privacy, agency, safety, lifelong learning and health.
- Finally, the third (outer) circle lists the SDGs where we have found a mapping between SusAF topic and SDG Target level. The targets for which we found a mapping can be seen in the data folder for this paper (Lammert and Betz, 2021). For example, health in the individual dimension can be connected with six SDGs: 1 No Poverty, 3 Good Health and Well-Being, 5 Gender Equality, 9 Industry, Innovation and Infrastructure, 12 Responsible Consumption and Production and 6 Clean Water and Sanitation.

Table 2: Definition of the order of effects (Betz et al., 2015)

Order of effects	*Definition*
Immediate (or 'first order') effects	"Are concerned with the immediate impacts resulting from the production, use and disposal of software systems, such as energy use. This can be measured using metrics based on performance requirements or network bandwidth, for example."
Enabling (or 'second order') effects	"Are concerned with the benefits and impacts of ongoing use of the software system. E.g. This might be, for example, how a web search engine reduces the cost of access to information."
Structural (or 'third order ') effects	"Are concerned with changes resulting from the use of software systems by a very large number of people over medium to long term, leading to substantial changes in societal structures such as new laws, politics, or social norms., or economic structures such as the networked economy."

6 LESSONS LEARNED AND OPEN ISSUES

Overall, we distill several lessons learned through conducting this pilot mapping:

1. **Commonality of concerns is revealed, fostering transparency and accountability.** We observe that although SusAF is focused on the analysis of technical products and services and SDGs address country or planetary level concerns, the vast majority of issues considered across both frameworks are common. As a result, there can be a clear mapping established across these two frameworks. We expect that this, in turns, means that it is possible to identify which SDGs an individual software system would impact. This provides both transparency and accountability to the SE profession in general and RE practitioners in particular: we can and must consider which SDGs we affect through our software development activities.
2. **SusAF is at a different level of abstraction from the SDGs.** As the SDGs specify the high-level goals and targets that countries need to work towards, they, by necessity, do not detail the specific technical or other solutions that would be used to achieve the set goals. However, the impact of the technical solutions themselves must also be considered on the SDGs.
3. **The relation of technical systems to SDGs may not be obvious at first sight.** Our mapping suggests that technical systems have positive and/or negative impacts on the SDGs that are not related to their purpose. For example, research has shown that the peer-to-peer short-term accommodation rental platform Airbnb induces racialized gentrification in New York, which is negatively related to SDG 10 (Reduce Inequalities) and in particular with the target 10.2 ("promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status") (Wachsmuth and Weisler, 2018). Thus, the SusAF can help to identify potential hidden effects of technical systems on the SDGs.
4. **Empirical Evidence is needed to validate the mapping.** The domain and system context might have an influence on the mapping between SusAF and SDGs, as presently, these were carried out without case study-based validation. Take, for example, the educational system exemplified in Section III. The main functionality of the system is to support teaching activities at a university to improve quality education. Additionally, the system may also support lifelong learning if it provides content for a wider public, not only the students. When applying SusAF we identify that the system supports "lifelong learning" (a topic of SusAF) that is linked to SDG4 Quality Education.
5. **Threats to the study validity.** The work presented in this paper fosters a better understanding of how software solution choices can contribute to/hurt the broader SDGs, and while we present the above preliminary findings, we must also note several threats to this pilot study's validity:
   - As noted above, this preliminary mapping is presented with no validation case studies; thus, it is possible that we have missed and/or misrepresented various areas in which SusAF questions can help us see how software systems could impact SDGs. Thus, the mapping must undergo case-study based validation.
   - Furthermore, as discussed in the Background section of this paper, we have strong evidence of (positive and negative) interaction among SDGs. However, at this pilot study, the interactions consideration has not been included into

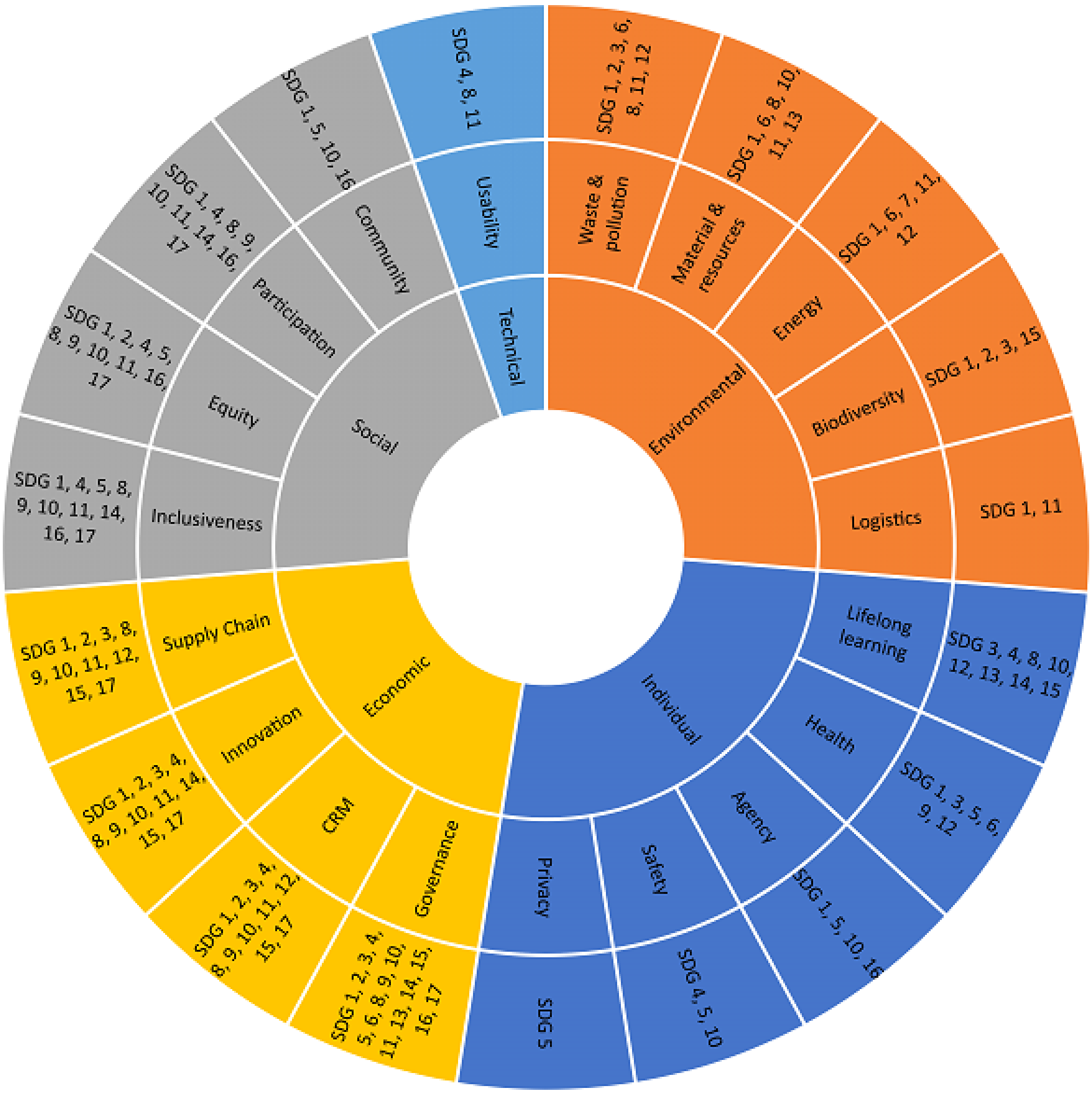

Figure 2: Mapping between SusAF and the SDGs.

our mapping process, which may necessitate future revisions.

- Equally important, we have not involved SDGs experts in the mapping process. Also, since the mapping is created from the perspective of a single person, it could have resulted in biased impact representation and interpretation of mapping. However, the mapping has been reviewed by two other researchers on a random basis and by one researcher thoroughly, if discrepancies in the mapping emerged, they were discussed until a consensus was reached. Nevertheless, external SDG expert validation and the participation of multiple people is another open issue to address for this work.

Yet, despite the possible researcher and validation biases, this paper demonstrates the feasibility of mapping SusAF to the SDGs, helping to bridge the abstraction gap that software practitioners must face when contemplating the impacts and contributions of their software systems to SDGs and sustainability.

7 NEXT STEPS AND CONCLUSION

As discussed above, we piloted our mapping study using thematic analysis across SuSAF questions and SDG targets and actions. We intend to both validate the initial results presented above, and refine them using a case study (to be conducted in collaboration with an industry partner). We envision this in the context of software systems evolution to support the industry partner in better understanding whether their proposed changes will support or violate specific SDGs. With this first application, we expect to validate our mapping in the context of a specific system and domain. We also envision a second more sophisticated mapping involving multiple authors and an SDG expert – still knowing that any mapping might have a subjective character influenced by the opinions and knowledge of the people conducting the mapping. In the course of this planned research, we will also explore the reasons for the 25% of SDG targets not being mapped by exploring whether there are areas where SusAF could be enhanced or whether some targets are simply not amenable to mapping to software-supported solutions as well as looking into other possible reasons.

We conclude that this pilot mapping shows a strong relatedness between the SusAF requirements analysis framework and the UN SDGs. Consequently, the socio-technical impacts of each individual software system can be directly attributed to specific SDGs. We hope that, armed with this knowledge and the SuSAF tool, software system owners, engineers and stakeholders could now start to consider how their systems contribute to the SDGs and take more responsibility for the systems they create or own.

It is worth emphasizing that with this work, we do not want to suggest that software systems are the only means through which one could achieving the SDGs, but they are one of the tools in the toolbox of transition to sustainability. By presenting our work at ENASE as a position paper, we hope to generate a deeper discussion on the operationalisation of the SDGs and to gain new insights into how to proceed with our research. Furthermore, with this contribution, we want to stimulate the software engineering community to develop new methods and tools for contributing to the SDGs through software.

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