Using Participatory Technical-action-research to validate a Software Sustainability Model

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***Abstract*—[Context and Motivation] In the last years, software engineering researchers have contributed to defining the notion of sustainability-aware software as a quality requirement. [Question/problem] The field is, however, still missing instruments supporting the design and assessment of software sustainability.**
[Objective] This research aims at providing a validated Sustainability Assessment Framework (SAF) through a long-term empirical study in close-collaboration with the software industry. [Methodology] By using the participatory technical action-research method, we validate the sustainability-quality model, one of the instruments of the SAF framework, by means of investigating its applicability in an industrial software project and detecting potential improvements.
[Results] Our results confirm the effective applicability of our model as most of its quality attributes (QAs) have been either addressed in the software project or acknowledged as relevant. The action-research method was also very useful for enriching our model by identifying QAs missing in the model (e.g. regulation compliance, data privacy).
[Contribution] The sustainability-quality model can be effectively used as an instrument for identifying sustainability-quality requirements, and creating awareness on the relevance of the multidimensional sustainability nature of certain quality attributes.

Keywords*—*sustainability-quality model, quality requirements, action research, software-intensive systems.

I. Introduction

In recent years, the concept of sustainability has been recognized as i) a timely important concern for researchers from different disciplines in computing (e.g. artificial intelligence [1], human computer interaction [2], software engineering [3], [4]; and ii) a key driver of innovation at software companies [5]. Thanks to this growing acknowledgment, several efforts have been put for understanding what software sustainability means (e.g. [6], [7], [8], [9]) and how software engineering can support sustainability (e.g. [10], [11], [12]]).

Lago et al. [8] and Venters et al. [7] agree on defining software sustainability in terms of multiple and interdependent dimensions (e.g. economic, technical, social, environmental, individual). However, despite this multidimensional nature of sustainability, most of the current efforts have been put on understanding what software aspects can impact on the environmental sustainability dimension [13].

In order to provide a better characterization of the sustainability dimensions, Condori-Fernandez and Lago [9] proposed a preliminary sustainability-quality model for software-intensive systems. It consists of quality attributes that contribute to each sustainability dimension, and their corresponding direct dependencies. According to the authors [9], software sustainability is defined in terms of four dimensions: the *social dimension* aims to allow current and future generations to have equal and equitable access to the resources in a way that preserves their socio-cultural characteristics and achieve healthy and modern society. The *environmental dimension* seeks to avoid that software-intensive systems harm the environment they operate in. The *technical dimension* is concerned with supporting long-term use and appropriate evolution/adaptation of software-intensive systems in constantly changing execution environment. And, the *economic dimension* aims to ensure that software-intensive systems can create economic value. It is taken care of in terms of budget constraints and costs as well as market requirements and long-term business objectives that get translated into requirements for the system under consideration.

As shown in Figure 1, the Sustainability-quality model is one of the key instruments of the Sustainability Assessment Framework (SAF) proposed by the authors and consisting of three main components: the sustainability-quality model [9], [14], the architectural decision map [15], and the metrics [16].

In order to validate SAF in close collaboration with software industry, we have designed a long-term empirical study supported by action-research methodology [17], [18]. In this paper, we present the overall overview of our empirical research strategy, as well as the first validation results as a consequence of applying the sustainability-quality model in a software project that focuses on the achievement of sustainability goals.

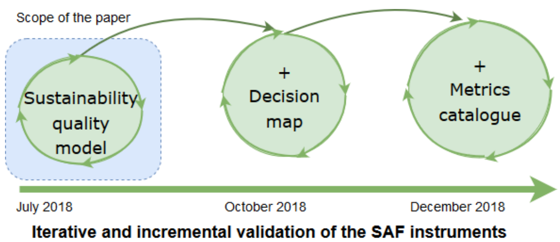

Figure 1: Timeline of the research cycles applied to validate the SAF framework

The following sections provide a detailed account of our study. Section 2 describes the research method. Section 3 reports our main findings. Then section 4 discusses the validity threats and section 5 the related works. Section 6 concludes the paper and discuss further work.

II. Research method

Our research strategy is inspired by the combination of two types of action research: (i) *technical action research* because we aim to scale up the action (treatment) to conditions of practice by actually using it in a particular problem [17]; and (ii) *participatory* because the researchers are active in making informed decisions throughout all aspects of the research process, as the participating organization shares experiences of applying the action [18], [19]. According to Petersen et al. [19], the action is the treatment introduced by the researcher to induce a positive change in the company. In our study, the action is the SAF framework.

The research strategy we use to validate the SAF framework consists of four stages (grey-colored in Figure 2): diagnosis, action, feedback collection and reflection. These stages are carried out at two different levels. We start the diagnosis at the *product-family level* with the purpose of understanding the common characteristics of the family of products and identifying sustainability-related issues. The output of the diagnosis is the selection of a product (software project), which is then used in the following three stages. At the *product level*, we plan the research to apply the SAF to the selected software project, then we collect the feedback from the participants and reflect on it to refine the design of the SAF framework. As shown in Figure 1, iterative and incremental research cycles are carried out at the product level, where each increment corresponds to the instruments of the SAF framework (Sustainability-quality model, the Decision maps, and the Metrics catalogue). Finally, the results emerging from the stage Reflection (at the product level) are fed back to the participating software company (at the product-family level).

Notice that the involvement of any other project from the product-family in the subsequent iterations (action, feedback collection and reflection) is allowed as long as the participants agree as part of the diagnosis stage.

The following subsections present the research questions shaping our study, the empirical research context (including the project and participants) and the unit of analysis.

A. *Research Questions*

In order to validate the SAF framework, the following research questions are formulated:

- **(RQ1)** How applicable is the SAF framework to assess the software architecture at hand?
- **(RQ2)** Which improvements to the SAF framework are realized as an outcome of implementing the action research?

In this paper, we focus on answering both research questions with a special focus on the sustainability-quality model as illustrated in Figure 1. As such, the answer to RQ1 aims at (i) identifying sustainability-quality attributes present in the model and already addressed in the selected project, and (ii) discovering sustainability-quality requirements that are not yet included in the model but are relevant for the selected project.

The initial sustainability-quality model proposed by Condori and Lago [9], [14] was used as the starting point for answering RQ1.

Naturally, its iterative application to the selected products can enrich the model itself with new insights and/or new attributes, and hence help answering RQ2.

Figure 3 summarizes the possible states that can be determined as a result of applying the sustainability-quality model: Quality Attribute (QA) discovered (orange cell), QA covered (green cell), QA missing (red cell), and n/a when a QA is not observable (grey cell). These states will be used in Section III and Tables II and III to present the study results.

B. *Research context*

The research context is characterized by six software products developed by the Database Laboratory (LBD),

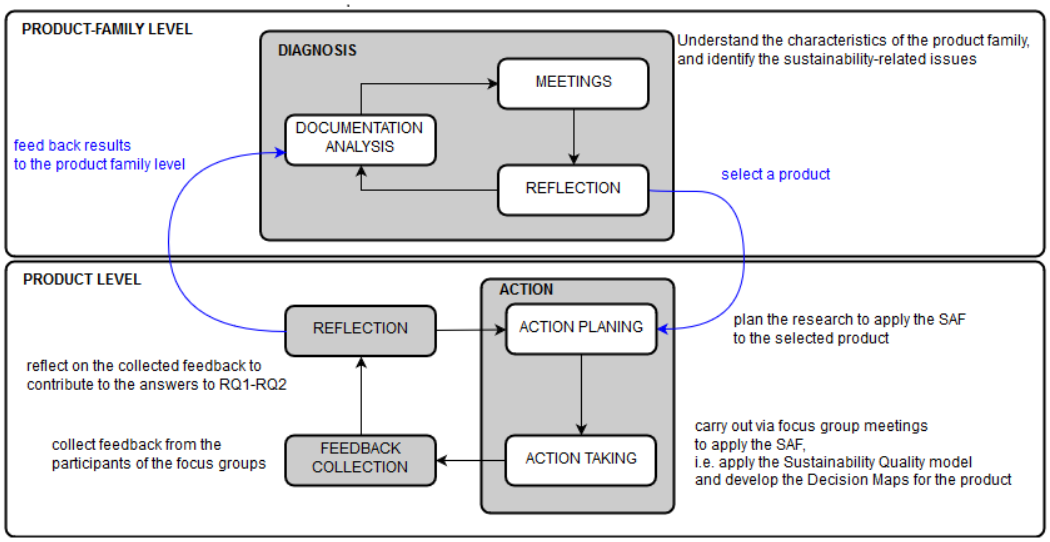

Figure 2: Participatory Technical-Action Research Process

a research group of the University Of A Coruña, as part of the GIRO Project[1]. A spin-off software company, Enxenio (ENX), will maintain the software products in the future.

1) The GIRO project: The GIRO Project, funded by the FEDER Interconnecta program, has a reference architecture, reused and adapted to addresses the specific requirements of the individual customer companies.

The customer companies of the GIRO consortium are leaders in the following market areas:

- Company A: treatment of meat by-products not intended for human consumption, particularly collecting dead animals in the northwest of Spain.
- Company B: management and valorization of organic waste by means of its transformation in biogas.
- Company C: installation and management of alarm systems in companies and domiciles.
- Company D: health and well-being services offered for elderly people residing in their own home.
- Companies E and F: prevention of occupational risks regarding health at work.

2) Participants: The participatory-technical action research team consisted of five participants. Two of them acted as responsible for planning and executing the application of the SAF framework. Both participants are researchers, who played three different roles in the action research [17]: (i) *Designer:* designing the instruments of the SAF framework; (ii) *Helper:* using the instruments of the SAF framework to help the software company in getting awareness on the sustainability-quality requirements that were addressed in the project; and (iii) *Researcher:* drawing lessons learned about the instruments of the SAF framework.

Two participants were practitioners from the Database Laboratory and the software company (Enxenio), who used the sustainability-quality model to identify relevant QAs that had not been considered in the project, as well as missing QAs that were not present in the Model. The roles of these participants were software analyst and software project manager. Besides the GIRO project counted with a software architect, the third practitioner from Enxenio, who contributed solving some doubts in the QAs identification process.

C. Unit of analysis and Procedure

The unit of analysis of the study is the product family developed under the GIRO project, whose documentation was analyzed and discussed in several meetings as part of the *diagnosis* stage. The software company is interested in knowing how sustainable is the reference software architecture used for the GIRO product family.

In this paper, we focus on the software product required by the company A, which is a Mobile Workforce Management (MWM) System developed to support the

[1] Acronym used for the project name: ”Generating, Managing and Integrating Routes using OLAP”

Table I: Focus groups conducted during the first research cycle

FG	Purpose	LBD/ENX	ENX
FG1	Social sustainability	2	
FG2	Technical sustainability	2	1
FG3	Economic-Environmental sustainability	2	
FG4	Generic	1	1

dead animal collection. Its selection was as a result of the activities carried out at the *diagnosis* stage. In order to answer our research questions, the next research activities (*action planning* and *-taking, feedback collection* and *reflection*) were carried out at the product level. Through an *action plan* defined for allowing the application of our sustainability-quality model [14] (action/treatment) to the selected product, we carried out *action taking* (i.e. technical-documentation analysis and four focus group meetings [20]). Each focus-group meeting was planned by the researchers (the first author played the moderator's role). The purpose of the corresponding focus groups and participants are shown in Table I. Although these focus groups were small, the participants reflected on the analyzed QAs, by explaining their relevance for the selected project and giving examples on how some of the QAs were addressed. Because of this active discussion among participants (practitioners and researchers), we considered the four sessions as a focus group and not an interview. Each focus group had an average duration time of 60 minutes, and notes were taken during the focus group meetings by the moderator (*feedback collection*). The following section presents the results obtained from the *reflection* on the collected feedback to contribute to the answers to RQ1-RQ2.

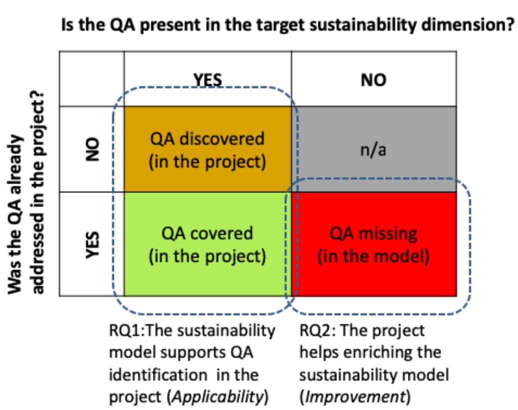

Figure 3: Specific research questions investigated through the action research

III. Results and Discussion

A. RQ1: Applicability of the model

The following presents our study results. They refer to Table II for the QAs already covered by the Model (i.e. addressed in the project or relevant but not yet addressed), and Table III for the new QAs that were missing in the Model.

1) Quality attributes covered in the project: These are:

Compatibility. This QA in terms of *interoperability and co-existence* was addressed in the project since there was a need of sharing information with some existing systems (i.e. Libra, active directory) used by the customer company. The relevance to the social sustainability dimension was acknowledged because of the greater access of information (from different systems) that can then be used by users (e.g. administrator, planner). Moreover, the compatibility's relevance to the technical dimension was also confirmed since as long as the MWM system performs efficiently, while both environment and resources are shared with other software system, its use will last longer.

Effectiveness. This QA was addressed in the project and its relevance to the technical, social and economic dimensions was confirmed. Thanks to the 1-month testing period, developers found that the MWM system provides a good support to accurately perform user tasks that achieve all specified stakeholders goals such as: the planner is able to schedule new requests from the insurance company; the driver is able to store/track requests until such time as they are complete, etc. It is technical because effectiveness contribute to the long-term usage of the MWM system. It is social because of the accurate performance of all user tasks contribute to their own well-being (e.g. drivers less stressed using the MWM system for tracking new requests). Moreover, the achievement of stakeholders goals contribute to one of the long-term business objectives of the software company (i.e. customer satisfaction), as well as the saving costs for fixing failures (economic dimension).

Efficiency. Relevance of Efficiency to the environment dimension is confirmed and also partially addressed, by having a good usage of certain resources when users perform their tasks supported by the system. For instance, the average time used for completing user tasks (e.g. administrator/planner for scheduling new requests, drivers register attended requests) was according to the expectations of the customer company. However, other type of resources, like the amount of energy, used by the MWM system when users perform certain tasks, has not been yet evaluated. Similarly to effectiveness, this QA also contributes to the economic dimension because of the saving costs for fixing failures.

Freedom from risk. It is addressed in terms of: *environmental risk mitigation*, by means of the timely use of the MWM system, which aims to provide support for collecting dead animals under the European regulations (CE 999/2001). By doing so, the MWM system helps (i) avoid exposing people to potential disease-causing pathogens (social dimension); and (ii) reduce environmental concerns like potential contamination of air, soil, surface and sub-surface water (environmental dimension). In a similar way, the relevance of *Health and safety risk mitigation* to the social dimension was confirmed. The health risks to people like farmers and potential meat consumers, can be mitigated by means of the timely use of the MWM system. Regarding the safety risk mitigation, this QA has not been yet addressed for certain type of stakeholders that directly interact with the MWM system. For instance, for drivers who are exposed to road safety risks, the system could allow an adaptive multimodal interaction to show the route for reaching a target place (e.g. a farm).

Functional Suitability. This quality is addressed in terms of *functional appropriateness and functional correctness*. Practitioners confirmed the contribution of both QAs to the technical and economic sustainability dimensions.
Both quality requirements were verified through one-month testing. All the functionalities implemented as part of the MWM system facilitate the accomplishment of tasks performed by the planner, driver, and system administrator. For example, the planner, main component of the MWM system, consider all relevant parameters to provide an optimum route planning to be used by the drivers.
Functional suitability is relevant to the technical dimension since both QAs contribute to the long-term use of the system. It is also relevant to the economic dimension because the software company do not have to dedicate much effort on corrective maintenance actions.

Maintainability. The relevance of this requirement is acknowledged with respect to the *modifiability, modularity and reusability* attributes. As a common architecture is planned to be used for the six software systems of the GIRO project, modifiability and modularity are key to facilitate the adaptation of the reference software architecture to be used in the product family and its evolution (technical dimension).
Moreover, as the company aims to create a flexible architecture for addressing all relevant requirements of each software system of the product family, modifiability and reusability should contribute also to reduce redesign costs and allow quicker response to company customers. However, as the relevance of both QAs to the economic dimension was not identified in the original model, in Table II we mark both contributions with an "+".

Performance efficiency. This requirement in terms of *time behaviour* was acknowledged as a good contributor to both technical and environmental dimensions. While the system shows an efficient performance (e.g. processing and response time) in delivering the main functionalities (e.g. finding optimum route, allocating new requests in the planning), its use will last longer (technical sustainability dimension).

Reliability. There was a consensus that the MWM system must be reliable when perform not only under normal operations (*maturity*), but also whenever it is required by end-users (*availability*). Although both QAs contribute to the technical dimension, a greater availability of the MWM system (e.g. visualization of the route planning, tracking driver behaviour) will contribute not only to the environmental and economic sustainability dimensions, but also to the social dimension. It is social because the environmental and social sustainability goals of this kind of systems can be achieved only if the software services are available. The social contribution was marked with an "+" since it was not considered in the original model.

Satisfaction. This requirement in terms of *trust and usefulness* is relevant to address both social and economic sustainability dimensions. As practitioners consider that the direct relation between user satisfaction and the technology acceptance([21], [22]) has a positive impact on the social sustainability dimension since satisfied users will be in a much better position for getting access to social resources provided by the corresponding software system. Also, the practical relevance of both QAs to the economic dimension was confirmed since customers satisfaction is considered as one of the primary business objectives of the software company. Moreover, as long as the usefulness and trust of the system are valued by the end-users, the acceptance to use the system will be prolonged, which means that both QAs contribute to the technical dimension as well.

Security. This requirement in terms of accountability, authenticity, confidentiality and integrity was considered as a good contributor to the social sustainability. *Confidentiality* was addressed thanks to the Role Based Access Control implementation, where roles previously defined are assigned only to group of users that are authorized to have access to the system. *Authenticity* was also addressed since the login of each user has been used as identifier. And as several user actions can be traced, *accountability* was also addressed but only for certain actions (i.e. updates of new routes). Regarding the *integrity* of the system, this requirement was also considered as a good contributor to the technical dimension because the MWM system is able to prevent (in certain extent) unauthorized access to the system, and does so to the extent that security controls specified for that system cannot be compromised. This new contribution was also marked with an "+".

Usability. As expected usability attributes like appropriateness recognizability, operability, and user error protection were clearly considered as relevant to the social sustainability dimension. *User error protection* was addressed through the use of field-validation methods, mandatory fields, and action confirmation. Protecting users against making errors it is social because it contributes not only to satisfy usability requirements but also to the quality of user experience [23]. However, this QA was also considered as good contributor to both technical and economic dimensions, which were also confirmed by two case studies. As both contributions were not considered in the original model, they are marked with an "+". During the testing period, issues related to *operability* of the system were fixed. Moreover, as end-users recognized that the system is appropriate for meeting their corresponding needs (i.e. drivers need to attend all assigned requests per day), *appropriateness recognizability* was also addressed.

2) Quality Attributes discovered in the project: In this section, we discuss the QAs that were discovered as relevant for the selected project as a result of using the sustainability-quality model.

Context Coverage. Practitioners agreed on the relevance of addressing context coverage requirement in terms of *context completeness and flexibility*. Despite issues related to effectiveness and efficiency were verified during the one-month testing period, it is possible that some contexts where the system could be used were not covered by the testing process. The need of explicit specifications about the different contexts of use was acknowledged as a relevant requirement that should be considered as good contributor to both technical and economic dimensions. Moreover, if the system is not able to work at any other potential context of use (not explicitly specified), a higher effort and costs would be needed to improve the flexibility of the MWS system.

Modifiability and Reusability. Although both maintainability attributes were considered as relevant to contribute to the environmental dimension, they were not addressed because of the lack of facilities/tools for determining in which extent the software artefacts (e.g. modules) of the system that are modifiable or reusable contribute to reduce environmental impact.

Resource utilization. This requirement was discovered as relevant to the project and its contribution to the environmental dimension was confirmed. However, despite the contribution of the planner module to the optimization of resources utilization(e.g. trucks needed for collecting dead animals, gasoline consumed by trucks), this requirement was not fully addressed because of the lack of a manager that could help in determining the actual amount of resources used by the system.

Testability. It is another relevant attribute that was acknowledge as relevant for the technical sustainability dimension, but it was not addressed since we could not find any evidence on how testable are the software artefacts (MWM system, module) to find (critical) faults.

Capacity. This QA was acknowledged as relevant for the technical dimension but not addressed. Load or stress testing could have been carried out for determining the weak points of the system architecture.

Accessibility. Although the company has knowledge on existing standard accessibility guidelines (e.g. ISO/IEC 40500:2012), this QA was not addressed in the project since was not considered as very relevant for the project. However, participants agreed that implementing some accessibility features that can help certain users like "deaf and hearing impaired drivers" could be beneficial to our society in long term, by removing interaction/communication barriers.

Learnability. Although this QA was not implemented, its relevance was acknowledged not only for the social dimension but also for the economic dimension. By implementing features that aid novice users to quickly learn and also allow steady progression to expertise, it could results on saving training costs to the company. (This new contribution to the economic dimension is marked with an "+").

Robustness. Given that the MWM system could be affected by several unexpected situations (e.g. GPS signal is lost), robustness is consider as relevant to address the technical sustainability dimension.

B. RQ2: Improvements in the model

This section reports on the missing QAs that were identified as relevant to be included in the Model as well as their corresponding contributions to the sustainability dimensions (see Table III):

1) Quality attributes missing in the Model: These are:

Data Privacy. Given MWM system needs data to be stored and shared for enabling the management of work assignments and the tracking of real-time field workers, data privacy is a key requirement that should be considered as good contributor to the social sustainability dimension. **Timeliness.** With MWM systems, timeliness of information is needed for allowing field workers to continue with their job successfully (rapid collection of dead animals). As this QA concerns on the favourable time of having the right information(a social resource), it has been also considered as a good contributor to the social sustainability.

Table II: Sustainability-quality analysis of the MWM system (Green cell= QA is addressed, orange cell= QA is discovered as relevant, light-gray cell= QA is in the model but not relevant for the project, += new contribution)

Characteristics	Attributes	Definition according to [9]	TECH	SOC	ENV	ECON
Compatibility	Co-existence	product can perform its functions efficiently while sharing environment and resources with other products.	green	green	orange	
	Interoperability	a system can exchange information with other systems and use the information that has been exchanged.	green	green		
Context coverage	Context completeness	system can be used in all the specified contexts of use	orange			orange
	Flexibility	system can be used in contexts beyond those initially specified in the requirements.				orange
Effectiveness	Effectiveness	accuracy and completeness with which users achieve specified goals.	green	green		green
Efficiency	Efficiency	resources expended in relation to the accuracy and completeness with which users achieve goals.	green		green	green
Freedom from risk	Economic risk mitigation	system mitigates the potential risk to financial status in the intended contexts of use.				orange
	Environmental risk mitigation	system mitigates the potential risk to property or the environment in the intended contexts of use.		green	green	
	Health and safety risk mitigation	system mitigates the potential risk to people in the intended contexts of use.		green		
Functional suitability	Functional appropriateness	the functions facilitate the accomplishment of specified tasks and objectives.	green			green
	Functional correctness	system provides the correct results with the needed degree of precision.	green			green
	Functional completeness	degree to which the set of functions covers all the specified tasks and user objectives.				gray
Maintainability	Modifiability	system can be effectively and efficiently modified without introducing defects or degrading existing product quality	green		orange	green +
	Modularity	system is composed of components such that a change to one component has minimal impact on other components.	green			
	Reusability	an asset can be used in more than one system, or in building other assets			orange	green +
	Testability	effectiveness and efficiency with which test criteria can be established for a system.	orange			
Performance efficiency	Capacity	the maximum limits of a product or system parameter meet requirements.	orange			
	Resource utilization	the amounts and types of resources used by a system, when performing its functions, meet requirements.			orange	
	Time behaviour	response, processing times and throughput rates of a system, when performing its functions, meet requirements.	green		green	
Portability	Adaptability	system can effectively and efficiently be adapted for different or evolving hardware, software or usage environments.	orange			
	Replaceability	product can be replaced by another specified software product for the same purpose in the same environment.				gray
Reliability	Availability	system is operational and accessible when required for use.	green	orange +	green	orange
	Fault tolerance	system operates as intended despite the presence of hardware or software faults.	orange			
	Maturity	system meets needs for reliability under normal operation.	green			
	Recoverability	system can recover data affected and re-establish the desired state of the system is case of an interruption or a failure.	orange			orange
Satisfaction	Trust	stakeholders has confidence that a product or system will behave as intended.	green	green		green
	Usefulness	user is satisfied with their perceived achievement of pragmatic goals.	green	green		green
Security	Accountability	actions of an entity can be traced uniquely to the entity.		green		
	Authenticity	the identity of a subject or resource can be proved to be the one claimed.		green		
	Confidentiality	system ensures that data are accessible only to those authorized to have access.		green		
	Integrity	system prevents unauthorized access to, or modification of, computer programs or data.	green	green		
Usability	Appropriateness recognizability	users can recognize whether a system is appropriate for their needs, even before it is implemented.		green		
	Learnability	system can be used to achieve specified goals of learning to use the system.		orange		orange +
	Operability	system has attributes that make it easy to operate and control.		green		
	User error protection	system protects users against making errors.	green +	green		green +
Accessibility	Accessibility	system can be used by people with the widest range of characteristics and capabilities.		orange		
Robustness	Robustness	Refers to the capability of the sytem to behave in an acceptable way in unexpected situations	orange			
Survivability	Survivability	The degree to which a system continues to fulfil its mission by providing essential services in a timely manner in spite of the presence of attacks	gray			

Regulation compliance. As the main business requirement of the customer company is to get that dead animal removal requests can be attended without delays according to the European regulations, the software designers/developers should be aware on them to meet this requirement. Regulation compliance can be relevant for contributing to i) social sustainability since health risks are minimized, and ii) environmental sustainability since potential contamination of natural resources (e.g. water, air) is reduced.

Scalability. As the customer company could be interested in scaling up number of clients(currently collection services are offered only at the Galician region), this would have an impact on the architecture because it should meet efficiently the increased workload as well. Thus, scalability is considered as a relevant QA for the economic sustainability dimension because of the significant costs saving.

Tailorability. Enabling new configuration of functionality as well as control information provision contributes to the technical and social sustainability dimensions. It is technical because the environments in which users can both interact and engage with software can contribute to the long-term usage. And it is social because giving users the tailoring capability in their own context of use can contribute to get a better access of the information provided by the system.

C. Discussion

This study focused on validating the sustainability-quality model by means of investigating its applicability in a real software project (RQ1) and detecting related improvements (RQ2).

The results shown in Table II confirm the effective applicability of our sustainability-quality model (RQ1) because of the following facts: (i) the quality requirements addressed in the project are covered by most of the QAs present in the model in the indicated sustainability dimension/s (cells coloured in green); (ii) the participants were able to become aware of the relevance of certain QAs that were already present in the model but that had not been addressed in the project with respect to a certain sustainability dimension (cells coloured in orange).

We also found that many QAs (e.g. co-existence, efficiency, availability, reusability, modifiability, trust, usefulness) contribute to more than one sustainability dimension of the model. This finding confirms the multi-dimensional nature of sustainability (one of the principles of the Kaslskrona Manifesto [24]) and the relevance level of the QAs that can be considered by software engineers when performing certain activities like design, assessment, and prioritization [9].

With respect to RQ2, the application to the MWM system helped us enrich our model in two ways:

- by adding new QAs that had not been considered in the model. As shown in Table III, many of these QAs were added to the social sustainability dimension (i.e. data privacy, timeliness, regulation compliance, tailorability). Most importantly only one QA (tailorability) was added for the technical dimension. Overall, this result shows how important can be to make explicit which sustainability dimension is relevant for which QA, so that significant metrics can be identified and monitored.
- by uncovering new direct dependency relations[2] as a consequence of identifying new contributions. The QAs that were included in this type of relations are shown in Table II, whose cells are marked with an "+". For example, as modifiability and reusability are new contributors to the economic dimension, the direct dependency between environmental and economic dimensions consists of four ordered pairs (whose QAs are efficiency, availability, modifiability, and reusability).

Finally, we argue that if a QA is found to contribute to multiple sustainability dimensions, its definition should be specialized for each dimension: in this way, the specific contribution is made explicit and hence helps identifying the best-fitting influencing factors, and metrics. This observation addresses both RQ1 (cf. model applicability) and RQ2 (enriching the model).

IV. Threats to Validity

Here we discuss the threats to the validity of the action research study [19] and provides rationale for related design decisions.

Internal validity. Action research is highly context dependent. To mitigate this threat, the design of our study considered a family of software products that are from different application domains, which is useful to analyze the sensitivity of the SAF framework in different contexts.

Construct validity. Action research is subjective as the results highly depend on the reflection of the action researcher. Several biases may occur due to: (i) two participants are also part of the software company and they could not have provided an objective/external view of the situation. (ii) The researchers as the designers of the action may interpret the results positively (selective bias) when reporting the results. Both issues were partially solved by involving multiple practitioners in the iterative discussions. In this first research cycle, a

[2]A direct dependency is defined as a finite set of ordered pairs of QAs, which is reflexive, symmetric and transitive [9].

Table III: New quality attributes and corresponding contributions to the sustainability dimensions

Characteristics	Attributes	Definitions	TECH	SOC	ENV	ECON
Data Privacy	Data Privacy	privacy concerns arise wherever personally identifiable information is collected, stored, or used.		■		
Timeliness	Timeliness	the fact or quality of being done or occurring at a favourable or useful time.		■		
Regulation compliance	Regulation compliance	allows to draw conclusions about how well software adheres to application related regulations in laws.		■	■	
Scalability	Scalability	the ability of a computing process to be used or produced in a range of capabilities				■
Tailorability	Tailorability	system's capability to allow users to create or enable new configuration of functionality as well as control information provision.	■	■		

third practitioner was involved in some of the meetings. Moreover, the researchers reviewed carefully the existing technical documentation to triangulate the data collected from the focus-group meetings.

External validity. The action is implemented in a specific social setting, which can hinder the generalization of the results. However, we could apply our findings to other projects with similar characteristics. Moreover, the transferability within the setting studied may be high if the context is similar. On the other hand, as our initial sustainability-quality model was defined based on the ISO/IEC 25010 standard [25], we consider that its generality could be more easily adaptable to other domains, such as those that were considered by the GIRO project.

V. Related Work

Being able to identify the relevant quality requirements on sustainability is the first step towards developing software-intensive systems that fulfill sustainability concerns *by design* [9].

Venters et al. [26] discussed the notion of software sustainability based on the analysis of the literature. After debating if it should be considered as a non-functional requirement or an emergent property, the authors conclude it to be a multi-faceted concept and argue for a quantitative approach.

Based on the ISO/IEC 25010 Standard, Calero et al. [6] provide a preliminary discussion of which quality characteristics should be considered in addressing software sustainability. As a next step, they propose the definition of a quality model where sustainability is part of the quality of software products. In contrast to our work, Calero et al. defined sustainability only in terms of energy consumption, resource optimization and perdurability (reusability, modifiability, and adaptability). Originated in the 2013 GREENS workshop [27], Lago et al. [8] defined a four-dimensional model that extends the social, environmental and economic dimensions (rooted in the Brundtland report [28]) with the technical dimension. Later on, Lago introduced the Software Sustainability Assessment (SoSA) method [29], which helps scoping architectural concerns and quality requirements along the four dimensions above.

Becker et al. [30] have a similar approach but grounded in requirements engineering instead. In addition to the above four sustainability dimensions, they add the individual as a fifth sustainability dimension. We argue that the social dimension and the individual dimension share the same *social nature*. Differently, the first takes a broader perspective (e.g. organizations, society, stakeholder types). This is especially relevant in software architecture, which aims at capturing "the big picture". The second dimension, instead, is appropriate whenever the concerns of the individual (e.g. end-user, citizen) should be addressed. This naturally comes forward more frequently in requirements engineering and human-computer interaction.

VI. Conclusions and Further Work

The present empirical study was designed to validate the Sustainability Assessment Framework (SAF) within an action-research setting. This paper focused mainly on the sustainability-quality model, one of the instruments of the SAF framework, that has been applied in one of the software products developed under the GIRO project. As a result of this application, from a practitioner perspective (RQ1), the proposed sustainability-quality model was found as a useful instrument for (i) identifying the relevance level of QAs that contribute to different sustainability dimensions (e.g. trust, modifiability, efficiency), and (ii) discovering quality requirements that had not yet been addressed in the project at hand (e.g.context-completeness, flexibility, testability, capacity). From a researcher perspective (RQ2), the study has helped uncovering new missing QAs that were identified as relevant to be included in the sustainability-quality model (e.g. regulation compliance, data privacy).

As a further work, we plan to apply the decision maps and the metrics, by using the same software product, and replicate the validation of the sustainability-quality model, by involving a new GIRO software product within the same action-research environment. Our sustainability model will be also enriched with the findings obtained from the case study reported in [31].

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REFERENCES

[1] M. De-Arteaga, W. Herlands, D. B. Neill, and A. Dubrawski, "Machine learning for the developing world," *ACM Trans. Manage. Inf. Syst.*, vol. 9, pp. 9:1–9:14, Aug. 2018.

[2] O. Bates, V. Thomas, C. Remy, L. Nathan, S. Mann, and A. Friday, "The future of hci and sustainability: Championing environmental and social justice," in *CHI EA '18 Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, vol. 2018-April, ACM, 4 2018.

[3] B. Penzenstadler, L. Duboc, C. C. Venters, S. Betz, N. Seyff, K. Wnuk, R. Chitchyan, S. M. Easterbrook, and C. Becker, "Software engineering for sustainability: Find the leverage points!," *IEEE Software*, vol. 35, pp. 22–33, July 2018.

[4] R. Chitchyan and et al, "Sustainability design in requirements engineering: State of practice," in *ICSE Companion*, pp. 533–542, 2016.

[5] R. Nidumolu, C. Prahalad, and M. Rangaswami, "Why sustainability is now the key driver of innovation," *IEEE Engineering Management Review*, vol. 43, no. 2, pp. 85–91, 2015.

[6] C. Calero, M. Á. Moraga, and M. F. Bertoa, "Towards a software product sustainability model," *CoRR*, vol. abs/1309.1640, 2013.

[7] C. Venters and et. al, "The blind men and the elephant: Towards an empirical evaluation framework for software sustainability," *Journal of Open Research Software*, vol. 2, no. 1, 2014.

[8] P. Lago, S. A. Koçak, I. Crnkovic, and B. Penzenstadler, "Framing sustainability as a property of software quality," *Communications of the ACM*, vol. 58, no. 10, pp. 70–78, 2015.

[9] N. Condori-Fernandez and P. Lago, "Characterizing the contribution of quality requirements to software sustainability," *Journal of systems and software*, vol. 137, pp. 289–305, 2018.

[10] B. Penzenstadler, "Infusing green: Requirements engineering for green in and through software systems," in *Proceedings of the Third International Workshop on Requirements Engineering for Sustainable Systems, RE4SuSy 2014, co-located with 22nd International Conference on Requirements Engineering, Sweden, August 26, 2014.*, pp. 44–53, 2014.

[11] N. Condori-Fernández and P. Lago, "The influence of green strategies design onto quality requirements prioritization," in *International Working Conference on Requirements Engineering: Foundation for Software Quality*, pp. 189–205, 2018.

[12] R. Chitchyan, J. Noppen, and I. Groher, "What can software engineering do for sustainability: Case of software product lines," in *International Workshop on Product Line Approaches in Software Engineering*, pp. 11–14, May 2015.

[13] G. A. García-Mireles, M. Á. Moraga, F. García, C. Calero, and M. Piattini, "Interactions between environmental sustainability goals and software product quality: A mapping study," *Information & Software Technology*, vol. 95, pp. 108–129, 2018.

[14] N. Condori Fernandez and P. Lago, *A Sustainability-quality Model: (version 1.0).* VU Technical Report, 11 2018.

[15] P. Lago, "Architecture design decision maps for software sustainability," in *International Conference on Software Engineering, Software Engineering in Society Track (ICSE SEIS)*, 2019.

[16] N. Condori-Fernández, A. Bagnato, and E. Kern, "A focus group for operationalizing software sustainability with the MEASURE platform," in *4th International Workshop on Measurement and Metrics for Green and Sustainable Software Systems (MeGSuS), Co-located at ESEM, Oulu, Finland*, 2018.

[17] R. Wieringa and A. Moralı, "Technical action research as a validation method in information systems design science," in *Design Science Research in Information Systems. Advances in Theory and Practice*, (Berlin, Heidelberg), pp. 220–238, Springer Berlin Heidelberg, 2012.

[18] C. MacDonald, "Understanding participatory action research: A qualitative research methodology option," *Canadian Journal of Action Research*, vol. 13, no. 2, p. 34–50, 2012.

[19] K. Petersen, Ç. Gencel, N. Asghari, D. Baca, and S. Betz, "Action research as a model for industry-academia collaboration in the software engineering context," in *ACM International Workshop on long-term Industrial collaboration on Software Engineering (WISE)*, pp. 55–62, 2014.

[20] R. Krueger, *Focus groups: a practical guide for applied research.* Sage Publications, 1994.

[21] B. H. Wixom and P. A. Todd, "A theoretical integration of user satisfaction and technology acceptance," *Info. Sys. Research*, vol. 16, pp. 85–102, Mar. 2005.

[22] G. Assefa and B. Frostell, "Social sustainability and social acceptance in technology assessment: A case study of energy technologies," *Technology in Society*, vol. 29, no. 1, 2007.

[23] Y. I. Ormeno, J. I. Panach, N. Condori-Fernndez, and O. Pastor, "Towards a proposal to capture usability requirements through guidelines," in *IEEE 7th International Conference on Research Challenges in Information Science (RCIS)*, pp. 1–12, May 2013.

[24] C. Becker, R. Chitchyan, L. Duboc, S. Easterbrook, B. Penzenstadler, N. Seyff, and C. C. Venters, "Sustainability design and software: The karlskrona manifesto," in *Proceedings of the 37th International Conference on Software Engineering - Volume 2*, ICSE '15, (USA), pp. 467–476, IEEE Press, 2015.

[25] ISO/IEC, "ISO/IEC 25010 - Systems and software engineering - Systems and software Quality Requirements and Evaluation (SQuaRE) - System and software quality models," tech. rep., 2010.

[26] C. Venters, C. Jay, L. Lau, M. K. Griffiths, V. Holmes, R. Ward, J. Austin, C. E. Dibsdale, and J. Xu, "Software sustainability: The modern tower of babel," in *RE4SuSy: Third International Workshop on Requirements Engineering for Sustainable Systems*, 2014.

[27] P. Lago, N. Meyer, M. Morisio, H. A. Müller, and G. Scanniello, "Leveraging energy efficiency to software users: summary of the second GREENS workshop, at ICSE 2013," *ACM SIGSOFT Software*, 2014.

[28] G. Brundtland, M. Khalid, S. Agnelli, S. Al-Athel, B. Chidzero, L. Fadika, V. Hauff, I. Lang, M. Shijun, M. Morino de Botero, M. Singh, and S. Okita, "Our common future (brundtland report)," tech. rep., World Commission on Environment and Development, 21 May 1987.

[29] P. Lago, "Software and sustainability [inaugural lecture]." http://dare.ubvu.vu.nl, Jan. 2016.

[30] C. Becker and et al, "Requirements: The key to sustainability," *IEEE Software*, vol. 33, no. 1, pp. 56–65, 2016.

[31] N. Condori-Fernandez and P. Lago, "Towards a software sustainability-quality model: Insights from a multi-case study," in *International Conference on Research Challenges in Information Science*, IEEE, 2019.