Towards a Systematic Process for the Elicitation of Sustainability Requirements

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***Abstract*—In recent years, several approaches have been proposed in the area of sustainability requirements. They have classified sustainability into different dimensions and explored these dimensions as well as the relationships of sustainability requirements to functional requirements and quality requirements, other than sustainability. Furthermore, case studies were reported. Only a few papers describe a systematic process for deriving sustainability requirements for a specific system. In this paper, we report on work in progress on such a process. The main idea is to provide a checklist of general and IT-specific details for the sustainability dimensions and a checklist of general influences between the dimensions. These checklists can be used to iteratively refine the requirements of a specific system with sustainability considerations which balance the different dimensions. We sketch this process and illustrate it with an example.**

***Index Terms* — Sustainability dimensions, sustainability requirements elicitation, sustainability checklists.**

I. INTRODUCTION

Sustainable development is, according to [3], the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Attempts to comprehend this global challenge require the understanding of the interrelationships between social equity, economic growth, and environmental degradation. Redclif [9] studies these interrelationships and proposes policy solutions to integrate these three dimensions of sustainability. Today, sustainability is investigated also from the individual and technical dimensions, and it has become a key issue worldwide. Achieving sustainable software development is a challenge that must consider the above five distinct dimensions [7]: *individual, social, economic, environmental and technical*. Each dimension addresses different needs (e.g., reduce costs, guarantee efficient energy consumption, avoid unemployment, evolve the system easily) and impacts on other dimensions and their stakeholders. For example, the use of software for general improvement of people's lives affects individuals and society, memory and power efficiency impact on the environment, reduction of costs in software development and evolution influences the economic dimension, and the software's ability to cooperate with other systems impacts the technical dimension. These complex interrelationships require new approaches for requirements engineering to support appropriate decisions and actions while maintaining a balance between the five dimensions.

The goal of this work is to support the elicitation of sustainability requirements. In recent years, several approaches have been proposed in the area of sustainability requirements, e.g. [2,7,8,11]. They have explored the dimensions as well as the relationships of sustainability requirements to functional and quality requirements other than sustainability. Furthermore, case studies were reported. Only few papers describe a *systematic process for deriving sustainability requirements* for a specific system. In this paper we report on work in progress on such a process. The main idea is to provide a *checklist of general and IT-specific details for the sustainability dimensions and a checklist of general influences between the dimensions*. These checklists can be used to iteratively refine the requirements of a specific system with sustainability considerations which balance the different dimensions.

The rest of the paper is structured as follows: in section II, we present the process model and a metamodel of our concepts. Section III and IV present the needs and effects checklists, respectively. Section V discusses an example and Section VI examines related work. Section VII concludes the paper and discusses directions for future work.

II. METAMODEL AND PROCESS

In the following we first present the metamodel and then the process model. The metamodel is shown in Figure 1.

Sustainability is divided into 5 sustainability dimensions [1]. Each *Dimension* corresponds to a main *Surrogate Stakeholder*. This surrogate stakeholder has *Needs* which must be satisfied by the system. (We introduce this surrogate stakeholder, because it is more natural for a stakeholder to have needs than for a dimension.) These needs describe the main sustainability issues for each dimension. For example, the environmental dimension has the surrogate stakeholder *nature* which has the need *little waste.* Similarly, the economic dimension has the surrogate stakeholder *company* with the need *high revenue*. Needs can be of two kinds: they hold in general or they are specifically related to IT-Systems. IT-specific needs detail in which way the system can influence a general need. For example, *trust* in the system is an IT-specific need of the surrogate stakeholder *individual* which details the general need *agency*. We emphasize IT-specific needs, because we propose a process to deal with IT-requirements. The needs influence each other by means of *Effects.* An effect is a positive or negative or neutral relationship between needs. So, a need can trigger an effect or be affected by the effect. For example, there is an effect between *little waste* and *revenue*. *Little waste* can lead to less *revenue*, if it is costly to avoid waste. Thus, *little waste* triggers this effect and *revenue* is affected by it. Note that these effects are different from those in [1], where the software system has systemic effects. *Requirements* should to *satisfy* the needs.

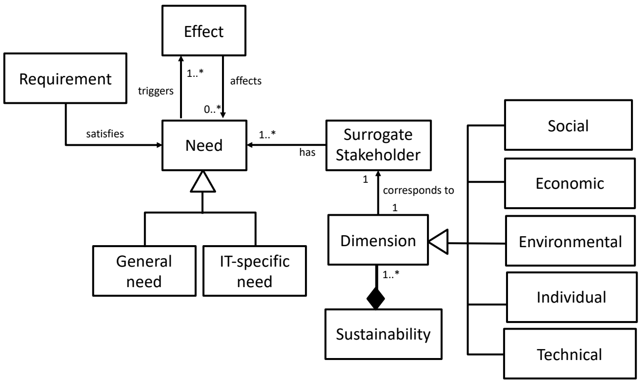

Fig. 1. Sustainability metamodel, extended from [2]

The process model is shown in Figure 2. We envision an iterative process which starts identifying some requirements (functional or non-functional, high-level or detailed) about the core functionality of the system. To understand the sustainability issues of the system, first the relevant needs from the dimensions are identified based on a **checklist of needs**. Then the effects between these needs are identified based on the **effect checklist**. For each need affected by the effects on the list it is checked whether the given requirements satisfy this need. All requirements satisfy the involved needs as far as possible. It is necessary to make tradeoff-decisions balancing the dimensions, meaning that not all needs can typically be fully satisfied at the same time. The sustainability requirements are new requirements considering a need which has not been considered before. In addition, there can be changes of existing requirements to make the core functionality more sustainable by satisfying the involved needs. The requirements are integrated into the pool of requirements and the next iteration of the process can start with the new or refined requirements and/or further needs. Thus, needs and effects play a role similar to, e.g., threats for safety. They structure the elicitation according to standard issues.

III. Needs Checklist

When developing a system, it is useful to have at hand a checklist for the issues to be considered for each dimension. We phrase these issues as needs of the surrogate stakeholder. We think this is helpful because many of these needs, especially for the environmental dimension and partly for the others, are not represented by real stakeholders. We have collected a first list of needs based on the definition of the dimensions and related work (see Table 1). A general discussion of the contents in this table for each dimension is presented next.

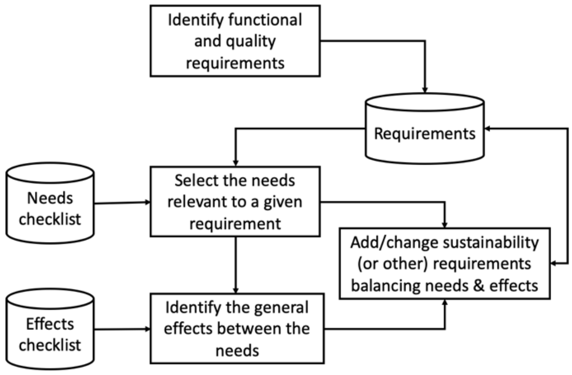

Fig. 2. Process model

The **environmental** dimension "covers the use of and stewardship of natural resources. It includes questions ranging from immediate waste production and energy consumption to the balance of local ecosystems and concerns of climate change" [1]. This can be summarized as *respect nature in the use of resources*. Thus, the nature is the surrogate stakeholder. Its needs are little waste, little pollution and little resource consumption, and positive influences to reduce climate change. Note that compared to the definition we have added "pollution" and generalized "energy" to "resource".

The **technical** dimension "covers the ability to maintain and evolve artificial systems (such as software) over time. It refers to maintenance, evolution and resilience, as well the ease of system transitions [1]. This can be summarized as *respect longevity of the system*. Here, the surrogate stakeholder is the system itself. Its needs are easy maintenance, evolution and resilience, as well the ease of system transitions.

The **social** dimension "covers relationships between individuals and groups. For example, structures of mutual trust and communication in a social system and the balance between conflicting interests" [1]. This can be summarized as *respect society*. Thus, the surrogate stakeholder is the society. Further needs were derived from the indicators gathered in [4], particularly: high trust and communication between people, little conflict of interests (for society as a whole or subsets like municipality, state, region, community, citizen), good employment good health, equity, good education, good security, good services and facilities, good resilience, high-level of human rights, good social acceptance of technology, good social cohesion, good preservation of culture, good governmental laws and trust of the people in them.

The **economic** dimension "covers financial aspects and business value. It includes capital growth and liquidity, questions of investment, and financial operations" [1]. This can be summarized as *respect involved companies and governmental institutions*. Thus, the surrogate stakeholders are the companies involved in the production and operation of the system and the responsible governmental institutions. To detail the benefits, we looked at the balanced scorecard [5] which distinguishes the financial perspective, the innovation and learning perspective, the customer perspective and the internal business process perspective. The financial perspective can be refined into ownership, simple financial operations, little cost and high revenue.

The **individual** dimension "covers individual freedom and agency (the ability to act in an environment), human dignity and fulfillment. It includes the ability of individuals to thrive, exercise their rights and develop freely" [1]. This can be summarized as *respect individuals*. Thus, the surrogate stakeholders are the individuals such as the system users or workers in the system production or operation. We added to these general needs IT-specific needs, which detail in which way a technical system can affect the general needs. 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). Similarly, equal access to the system by the users is needed for agency, while fair treatment of users by the system will support human dignity.

TABLE I. INITIAL CHECKLIST FOR THE NEEDS FOR EACH DIMENSION

Environmental (Surrogate stakeholder Nature) • Little resource consumption • Little pollution (emission, noise, visual) • Little waste • Positive influence on climate change
Technical (Surrogate stakeholder System) • Easy maintenance of a system (e.g., quality/durability of material; skills of workers, easy disassembling: modular structure; predictive maintenance) • Easy evolution of a system (e.g., modular structure; skills of workers; adaptability; customization) • Easy resilience • Easy of system transitions
Social (Surrogate stakeholder Society or parts thereof such as municipality, state, region, community, citizen) • Good trust and communication between people • Little conflict of interests • Good social indicators: employment (full-time work, women employment, working time arrangements, job opportunities, wages); health; equity; education; security; human rights, social cohesion, preservation of culture, governmental laws and trust of people in them
Economic (Surrogate stakeholders Companies and Governmental Institutions) • Good distribution of ownership of parts • Simple financial operations • Little cost • High revenue (for capital growth, liquidity, financial investment) • High customer satisfaction • High level of innovation and learning • Stable business processes
Individual (Surrogate stakeholder Individuals such as users or workers in system production or operation) • High freedom • High agency • High human dignity • High fulfillment • High trust of the user in the system (e.g., safety, privacy, transparency of the lifecycle) • Equal access of the system by the users • Fair treatment of users by the system

This list is not complete but covers many important needs.

IV. EFFECT CHECKLIST

The needs are very diverse and influence each other. It is a lot of work to look at all needs and influences for each system. We think that the influences can be generalized to typical influences between needs called *effects*. These effects can be derived from typical ways in which the stakeholders influence each other. For example, nature is influenced by the behavior of the system and of the users or workers. Thus, there are effects between some environmental and technical or individual needs. The companies have indirect influence on nature through the system. Similarly, the society does not directly influence nature, but through influence on people or companies. Companies clearly have influence on the system, and the system makes the difference for the well-being of the companies. People and companies influence society, and also the other way around.

Based on the general influences between the stakeholders we can reason about the effects. We want to provide a checklist of typical effects for each need. Figure 3 gives an example for such a checklist derived in a discussion session between the authors. It shows three effect groups. The green effect group comprises the effects of high employment, the black group comprises effects of good evolvability, and the blue group of little waste. In the following we explain the groups.

Good Evolvability of the system:

- supports that little waste and little pollution are produced during the system lifecycle (production and operation and demolition);
- can decrease or increase the business value for the customer. It will increase the customer satisfaction and the stability of the processes, and therefore maybe also the revenue. However, if the mechanisms for evolvability are expensive, it will lower the revenue.

High Employment rate:

- supports dignity and freedom of individuals;
- can decrease/increase financial aspects of the company. If the company employs more humans instead of machines, the cost might be higher and thus the revenue lower. But on the other hand, people have more money to buy new products. It supports stable processes within the company.

Little waste (or No waste):

- supports the health of society. It reduces, however, the freedom of individuals, as they have to take care of waste. This can be expensive for the production, resulting in lowering the revenue, or, in contrast, it can increase the revenue, if less material is needed. Also, the stability of the processes is negatively affected, because processes need to be changed. A high level of innovation (shown in bracket) is not result of little waste, but good innovation needs to be present to achieve little waste.

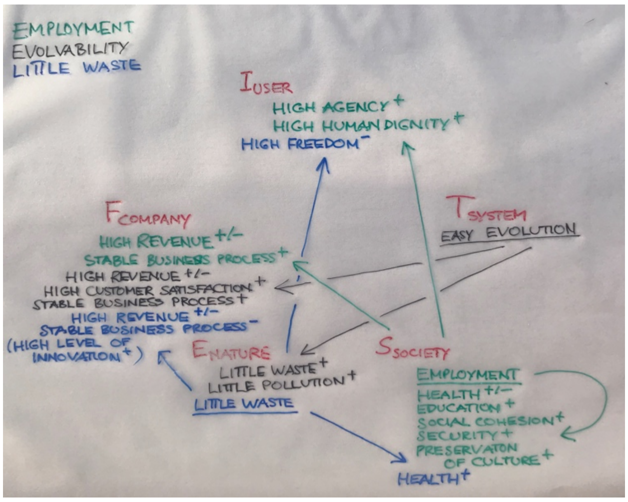

Fig. 3. Screenshot from a meeting between the authors. Effect groups for *employment* (in green), *evolvability* (in black) and *little waste* (in blue). (The identifiers of the nodes in the graph are composed of the dimension initial together with the name of the stakeholder, e.g., Tsytem means the stakeholder system of the Technical dimension. The economic dimension uses the initial F, as E was already taken).

For a specific system these general effects must be detailed so that the value (positive, negative, neutral) of the effect can be determined.

V. EXAMPLE

Let us now apply the metamodel and the process exemplarily to a Toll Gate System, a simplified version of the Via Verde toll collection system in use since 1991 on the Portuguese highways. In this system, drivers of authorized vehicles are charged at toll gates automatically, when passing in special lanes, known as green lanes. A gizmo device must be installed at the windscreen of the vehicle. After registration, the gizmo is sent to the client to be activated using an ATM (this associates the gizmo identifier with the car owner bank account number for direct debits). A gizmo is read by the toll gate sensors and the information is stored by the system and used to debit the car owner account. The amount paid depends on the class of the vehicle, and on motorways it also depends on the distance travelled. If an exception is detected (e.g., the vehicle is non-authorized, the gizmo identifier is invalid, or the vehicle's class does not correspond to the registered one) a yellow light is turned on, an alarm sounds, and the plate number is photographed (to initiate a legal procedure to fine the owner of the vehicle later).

We demonstrate one cycle of the iterative process. We assume the functional and quality requirements are defined from the point of view of the toll gate system stakeholders. One of these requirements is "a car shall be identified by a gizmo". We flip through the checklist to find needs, which are heavily influenced by this requirement: we take little waste. It is of importance because of the huge number of registered vehicles, each one with one device (or gizmo) on its windscreen. There will be about 1.5 million if one third of all cars in Portugal are equipped with it. (And the system is already in use in other countries.)

Looking at the effect group "little waste" we see that the most related needs according to our effect checklist are: "health of society, high freedom of the user, and revenue and stable process of the company". Therefore, which sustainable requirements can we propose to handle the selected need and what is their influence on the effects group needs (i.e., do they confirm the identified impacts)? We propose to address the "little waste" need by adding sustainability requirements like "expendable materials shall be replaceable by the driver", "the gizmo shall have a modular/easy-to-repair structure", "the gizmo shall have a hardened case". In this way, the device and its parts have a long lifetime and hence we reduce waste. We can mark the need "little waste" as changed to the better. So, the requirements seem to satisfy this need.

Now, we have to check whether the new sustainability requirements have a negative effect on the needs of the remaining dimensions. From the "little waste" effects group, "health" is in general positively influenced by "little waste" and we think this also holds true in our example, particularly regarding the requirements "the gizmo shall have a modular, easy-to-repair structure" and "the gizmo shall have a hardened case". We decide that in this case the requirements can also be satisfied by not so expensive materials. Therefore, we think that the revenue will be higher due to less material needed. Now we have to think about the two negative influences: little waste may lower the freedom of the users. However, in this case the waste of the production is reduced, and the individuals do not have to change their behavior. Regarding the requirement "materials shall be replaceable by the driver", we think that, in fact, allowing the vehicle owner to change, for example, the batteries of the gizmo will have a positive impact on her behavior as she does not need to drive to the nearest Via Verde shop for something so simple (and this with extra positive effect for the environment and the vehicle owner finances). Thus, the potentially negative influence is not important and does not require an additional tradeoff. However, to accommodate the new sustainability requirements, the company's production has to be adapted, leading to unstable processes. This negative impact requires a tradeoff. However, we think this will only be a short instability, and thus we prioritize little waste and accept this instability. Altogether, we have made sure in our process that all needs of this effect group are satisfied by the given and the new requirements.

This process needs to be repeated and new iterations performed for all the needs considered relevant for the problem under analysis. The result is an extended set of requirements, as well as a set of priorities and respective tradeoffs that need to be taken into consideration in the development phases that follow.

When thinking about the need and effects, it can be that new needs or effects are discovered. A new effect can be a totally new relationship or an added positive or negative value. This means that the checklists should be updated.

Knowing the effects on all needs, the team must decide whether the specification is now acceptable. If not, further iteration is necessary resulting in different requirements (sustainability or others). Obviously, traceability between needs, effects and requirements is essential.

Of course, this exercise serves for illustrative purposes only, for a system that exists and works well for almost 30 years now. Given the current advances in plate number recognition technologies, for example, a more sustainable solution for the part of the problem discussed above, would be to equip the toll gates with recognition technology. This would avoid the need for the gizmo, even though it would, of course, still require the registration of the vehicle in the system to allow automatic bank debits. However, our point is: overall, the process helps a team to design a sustainable system by providing them with a systematic way of considering all relevant information.

VI. RELATED WORK

In the following we discuss related work which also gives guidance for the elicitation of sustainability requirements.

Work proposing a metamodel for sustainability (e.g., [7,2, 10]) mainly defines meta-concepts and applies them directly to a case. In this paper we make an effort to standardize the *needs* and *effects* of the dimensions.

Penzenstadler and Femmer [7] introduce a reference metamodel used to instantiate generic models for sustainability, decomposing it into the five dimensions. The aim of the model is to serve as a reference model for both process and requirements engineer who instantiates the model for a software development company or for a specific system under development, respectively. Detailed guidance for the dimensions is not given.

Brito et al. [2] extend Penzenstadler and Femmer's metamodel to accommodate concern responsibilities and tradeoff management. The authors treat sustainability as concern and specify the five dimensions as concerns based on a template. This template is based on their extended metamodel. Again, detailed guidance for the dimensions is not given. We take their idea of effects.

Saputri and Lee [11] proposed a GQM-based approach to define sustainability requirements from stakeholders needs. Sustainability property analysis is performed to evaluate impact and trade-off analysis of those requirements. A metamodel for sustainability is provided, but without considering effects at a more fine grained level.

Penzenstadler et al. [8] propose an approach to identify successful sustainability interventions using leverage points (LPs), which are "locations within a system where a small change in one aspect can result in significant system-wide changes". LPs provide an analysis tool to help software engineers to face sustainability challenges through insights on transformation mechanisms or strategies to find alternatives. They do not give guidance on the dimensions.

Oyedeji et al [6] propose a sustainability design catalogue to assist software developers and managers in eliciting sustainability requirements. It is based on the Karlskrona manifesto principles and the indicators (related to the sustainability dimensions and their order of impacts) of sustainability associated with each criterion. The orders of impact cover the positive and negative effects of software on the environment, including immediate effects, enabling effects and structural effects. They do not cover the effects between all dimensions.

VII. CONCLUSION AND FUTURE WORK

We have outlined a process and two checklists to support the systematic elicitation of sustainability requirements. We introduced needs and effects as main concepts to structure the elicitation. Clearly, a lot of work is necessary to apply this fully to a real example. The work should continue by extending the need checklist. On one hand we should look for detailed indicators, similarly to the societal dimension for all other dimensions to derive more detailed lists. On the other hand, we should look into each dimension for IT-specific needs. Similarly, the effect checklist should be extended. For each need we should derive an effect group. If new needs emerge, the groups have to be updated. Furthermore, the iterative process has to be tested. How many needs are typically relevant for a system? Should we first look at the needs of one dimension and then iterate through the other dimensions? Or is it better to iterate through the effects' groups? How much work is it to get to specific requirements from the general needs and effects? If we succeed in providing comprehensive checklists, elicitation of sustainability requirements will be adopted more easily in practice.

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