Sustainable Systems *by* Sustainable Methods

A conceptual framework

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Abstract

As humankind recognizes the magnitude of contemporary environmental problems, the need for truly sustainable systems is more pronounced than ever. Amid the prevailing techno-optimism, created by the proliferation of advanced digital technology, it is comfortable to defer the burden of understanding and assessing sustainability to digital technology, such as AI and big data. However, digital technology itself is a major contributor to environmental problems, and it might defeat the purpose of sustainable systems engineering if used without care. In this work, we argue that the sustainability of systems is inextricably linked to the sustainability of the methods employed in the design, development, and operation of those systems. We call for holistic approaches that promote the development of sustainable systems by sustainable methods.

Keywords

circular economy, digitalization, digital transformation, green transition, sustainability, sustainability assessment, twin transition

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1 Introduction

Sustainability—the ability to progress and meet the needs of humankind without accumulating debt of environmental, social, technological, and economic kinds [9, 15]—is one of the most pressing challenges modern society faces. Our socio-technical systems have become unsustainable, most notably in the environmental sense, adversely impacting the ecosphere, potentially beyond repair.

In this context, assessing the sustainability of systems is key, and this need has been recognized before in academic and political circles [18, 21]. Unfortunately, current sustainability assessment methods are often restricted to the assessment of the system itself, and overlook the lifecycle phases before and after the effective operation phase of the system. This is a severe shortcoming as development processes that lead from goal setting through system design and implementation to system deployment exhibit increasingly higher environmental impacts. For example, information and Communications Technology (ICT) currently contributes to about 4% of global CO_2 emissions, comparable to the carbon emissions of the avionics sector. This number is projected to increase to about 14% by 2040 [6] without intervention, forcing ICT to cut CO_2 emissions by 72% by 2040 [16]. This environmental pressure is enough to threaten the net end-to-end sustainability of systems—i.e., to incur sustainability debt during the design and development phases of the system, which the eventual system can never make up for.

Unfortunately, the rapid expansion of digital technology gave rise to an unhealthy level of techno-optimism: a deceptive idea that digitalization—with pertinent examples of artificial intelligence (AI) and big data technologies—will inevitably help reduce the pressure society puts on the environment, without *fundamentally* rethinking the structure or goals of our growth-based economies [1]. The most common argument is that digital technology helps understand and optimize engineered systems by identifying intricate patterns beyond human comprehension. Alas, the sustainability of systems can be quickly overshadowed by the unsustainability of misused methods, especially those of digital kind [8].

The message of this article is twofold. First, when evaluating the sustainability of systems, the sustainability of methods must be consider too. Second, when evaluating the sustainability of methods, one must consider the bigger context in which methods are used.

2 Conceptual Framework

Figure 1 visualizes the conceptual framework for developing sustainable systems by sustainable methods. In this framework, sustainable development goals (SDGs) serve as the motivation to develop systems along a process of development methods. To consider a system sustainable, we mandate that the total debt accumulated by the methods throughout its development *and* the system's lifespan ($\sum CO_2$) must be less than an appropriately formulated budget ($\sum CO_2$). In terms of environmental sustainability, for example, we can rely on CO_2 emissions as the top-level KPI.

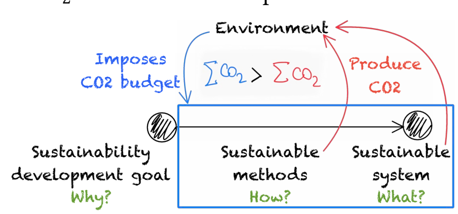

Figure 1: Conceptual framework for the development of sustainable systems by sustainable methods

2.1 Required capabilities: what to assess?

There are two major requirements to the framework, associated with its two scopes: system and method sustainability assessment.

2.1.1 System scope: end-to-send lifecycle understanding. In the systems scope, we need to understand the macro-level end-to-end systems lifecycle that starts with setting the goals and reaches as far as the operation and maintenance of the system, and preferably beyond: into the retirement phase of the system [12]. Such a view can enable finding trade-offs between the sustainability of methods and systems. Assessing end-to-end sustainability is hindered by the often informal notion of engineering processes [3], and while isolated efforts exist [2, 22], true end-to-end approaches are lacking.

2.1.2 Method scope: localized understanding. Complementing end-to-end understanding, there is a need for a more localized understanding of sustainability. With the reduced scope, detailed domain-specific modeling [14] and simulation become feasible and can support decision-making in the local scope.

2.2 Choosing KPIs: by what to assess?

A key performance indicator (KPI) captures a performance aspect that is the most critical for the success of an organization [24]. Choosing the right KPIs is paramount to properly assess sustainability. We suggest separating KPIs by the scopes of the framework.

2.2.1 System scope: carbon savings. Carbon-based KPIs work well in the system scope for two reasons. First, carbon-based KPIs are well established for measuring environmental impact. Following the strong notion of sustainability [4], environmental sustainability subsumes the rest of sustainability dimensions, suggesting that its KPIs are appropriate to measure overall sustainability impact. Second, there are, in fact, carbon budgeting mechanisms in place that work at the ecospherical scale [26] and could serve as the budgeting mechanism for computing-at-scale.

2.2.2 Method scope: domain-specific KPIs. In support of the requirement of localized understanding, KPIs in the method scope must be domain-specific and appropriate to the specific problem at hand. These KPIs may or may not be carbon-related. Often, they are of economic or technical nature. This is fine as long as these simplified KPIs are connected to the right system-scope KPI [10].

2.3 Enablers: how to assess?

The following are key enablers in support of the outlined principles. One part of these enablers are technical methods (Section 2.3.1) that help deal with sustainability goals; another part are sustainability methods (Section 2.3.2) that help technical methods become more sustainable, aligning them with the overall message of this article to foster sustainable methods in the design of sustainable systems.

2.3.1 Technical methods.

Modeling and simulation. Sustainability is stratified (has different interpretations at different levels of abstraction) and multisystemic (is an artifact of interactions among multiple socio-technical systems) [5]. These traits challenge the understanding of sustainability. Modeling, through the power of abstraction [8] allows for the gradual refinement and understanding of complex problems. Simulation makes use of models and allows for virtual experimentation with the future system when numerical analysis is not feasible.

Digital twins are real-time, live representations of systems and processes with the ability to control them [17]. Digital twins make modeling and simulation actionable in the operative phase of systems and processes, often used for purposes, such as adaptive control and predictive maintenance [25] for sustainability.

Artificial intelligence can be of high utility when modeled systems and phenomena are too complex for human modelers, e.g., due to the intricate non-linear and a-casual relationships in modern cyber-physical systems [11]. AI has been employed in an array of problems to augment manual modeling, e.g., simulator construction [13] and co-simulation [19], and remains a key enabler.

Recent progress in AI simulation [20] recognizes the synergies among the three techniques above and situates modeling, simulation, digital twins, and AI within a coherent technical stack.

2.3.2 Sustainability methods.

Approximate computing is a paradigm for trading off computing precision for performance, energy-efficiency, and reduced environmental impact [23]. In many cases, precision of software (e.g., AI) can be tuned back safely to still guarantee the satisfaction of functional and extra-functional properties of the system.

Frugal computing is the paradigm of “achieving our aims with less energy and material” [27]. Similar in its goals to approximate computing, frugal computing extends the frame of sustainability to society as it advocates society to “start treating computational resources as finite and precious” and “to be utilised only when necessary, and as frugally as possible” [27].

This work is an open call to introduce approximate and frugal computing to modeling, simualtion, digital twins, and AI.

2.4 Operationalization: twin transition

Twin transition is a prime candidate to serve as the operationalization of the framework. Twin transition is a joint digital and sustainability transformation approach that recognizes the visceral links between digitalization and sustainability [7]. Twin transition advocates sustainable growth by co-evolving the digital and sustainability maturity of organizations. As digitalization and sustainability maturity reinforce each other, organizations advance toward more sustainable systems and methods.

2.4.1 End-to-end understanding: by sustainable digitalization. At the macro level, in the context of end-to-end understanding, twin transition helps improve the digital capabilities of organizations while also keeping their usage sustainable. This helps avoid using advanced but unsustainable digital methods and using methods in support of incorrect sustainability goals.

2.4.2 Localized understanding: by atomic transitions. At the micro level, atomic transitions help localize goal-setting and decision-making. A sufficiently infinitesimal atomic transition can very well focus on either digitalization or sustainability improvements without having to focus on the trade-offs between the two, rendering these atomic transitions manageable and easier to assess.

3 Conclusion

The magnitude of environmental problems necessitates rethinking our systems engineering practices. While advanced digital technology—such as AI and big data—offers unprecedented opportunities to improve the sustainability of systems, they are major contributors to adverse environmental pressure. As the environmental impact of digital technology is on an accelerating course, we must shed techno-optimism and rethink the ways of developing systems. We argue that the sustainability of systems and methods are inextricably linked and we must foster more holistic practices of developing sustainable systems *by* sustainable methods.

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