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Transformation^2: Making software engineering accountable for sustainability

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ABSTRACT

Software engineering, as a central practice of digitalization, needs to become accountable for sustainability. In light of the ecological crises and the tremendous impact of digital systems on reshaping economic and social arrangements - often with negative side-effects - we need a sustainability transformation of the digital transformation. However, this is a complex and long-term task. In this article we combine an analysis of accountability arrangements in software engineering and a model of sustainability transformations to trace how certain dynamics are starting to make software engineering accountable for sustainability in the technological, cultural, economic and governance domains. The article discusses existing approaches for sustainable software engineering and software engineering for sustainability, traces emerging discourses that connect digitalization and sustainability, highlights new digital business models that may support sustainability and shows governance efforts to highlight "green and digital" policy problems. Yet, we argue that these are so far niche dynamics and that a sustainability transformation requires a collective and long-lasting effort to engender systemic changes. The goal should be to create varied accountability arrangements for sustainability in software engineering which is embedded in complex ways in society and economy.

1. Introduction: the need for a transformation^2

Software engineering, as a central practice for digitalization, needs to become accountable for sustainability. Human activities have led to increased greenhouse gas emissions and have stressed Earth's ecosystems. To avoid irreversible ecosystems breakdown, "rapid, far-reaching and unprecedented changes in all aspects of society" are needed ("IPCC, 2018: Summary for Policymakers," 2018). Such changes are necessary within the IT sector as well, and not simply because of ICT systems' high energy consumption (Lange, Pohl & Santarius, 2020). More importantly, ICT systems deployed in our societies re-define our businesses and consumer behaviour (e.g., trade and commerce re-shaped with eBay and Amazon, entertainment with Netflix and Spotify, travel with Lyft and Uber, etc.), our communication behaviour (Messenger Services like Telegram and Whats Up) and possibilities for a democratic public sphere and citizens (e.g. Twitter and Fake News). Because of the pervasive influence of software systems in our society, software engineering practice needs to become accountable for social-ecological goals. This involves seeing that "every line of code represents an ethical or moral decision" (Booch, 2021) and every stakeholder involved in designing IT Products and services should be accountable for the possible impacts of these systems on sustainability.

However, even though sustainability and digitalization are often referred to as big transformations, they run in parallel, not properly connected in practice and often in diametral ways. There is a huge research and action gap, with research still in the early stages of tying sustainability and digitalization together and politics not yet sufficiently addressing these challenges in tandem. This article aims to contribute to closing this gap. Since the 1980s, sustainability as a political project and vision has been shaped by different political bodies, especially the UN and social movements (Caradonna, 2014). At the heart of the idea of sustainability is intergenerational justice, voiced as the normative principle that current generations should not worsen the life chances of generations in the future. The research and literature on sustainability is rich and diverse and it is clear that ecological dimensions are but one aspect of sustainability. Different models and theories of sustainability see the intersection of different social, political, technological, economic and ecological dimensions as being at the heart of sustainability challenges and solutions. The UN names 17 Sustainable Development Goals - from ending poverty to strengthening partnerships for the goals.

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Contrary to these goals, the mainstream model of digitalization and its corresponding software engineering practices centers on high growth and fosters the accelerating consumption of resources and energy (Santarius, Pohl & Lange, 2020). In relation to sustainability, the major industry actors in the ICT sector follow a strategy of ecological modernization where the goal is to achieve efficiency gains but leave the current economic order in place. This results in renewable energy usage for servers or artificial intelligence products for saving energy. However, the main business model of these actors is still to boost consumption and production in other areas, e.g. through online advertising, and thus to exacerbate the sustainability problems of the existing economic model (Lenz, 2021).

To achieve the sustainable development goals, a far reaching transformation of our current social and economic systems is required. Such transformation strategies are by now widely elaborated - even if not yet fully put in practice - in energy, mobility, housing, cities, agriculture and more. However, seeing digital technologies and their development in terms of sustainability is not yet so common. In this paper, we argue that to make software engineering accountable for sustainability a transformative strategy needs to become collectively elaborated and widely debated. A sustainability transformation of the digital transformation, a *transformation*^{2}, is necessary.

In this transformation^2 software engineering is a key site for enabling sustainability by design in digital systems. Software engineering practices are of central importance to digitalization. It is here, in the midst of technological development, where values are negotiated and implemented into technical systems and where a central question is what are software engineers accountable for? However, we consider software engineering as embedded within the complex of digitalization of society and as stabilized - and possibly transformed - through systemic changes in culture, technology, the economy, and governance. Therefore, we need multidisciplinary perspectives on sustainability and software engineering. In this spirit this article is an attempt to provide an interdisciplinary perspective, focusing on sociology and informatics. The spirit of the article is furthermore to set the conceptual contours of a larger framework for research on a systemic sustainability transformation in software engineering.

The methodological strategy that we pursue is to tie different strands of literature and research together. This is based on our own involvement in the question of how to make digital systems and their design more responsible and sustainable. We have both been studying the responsible shaping of digital systems from a software engineering and technology assessment perspective, respectively. We have both been teaching software engineering students about responsible and sustainable software engineering. We inhabit similar, yet distinct "knowing spaces" (Law, 2016) – two disciplines, two research institutions and two researcher biographies. To tie these spaces together, the article uses a social scientific sustainability transformation model (Fischedick & Schneidewind, 2020; Schneidewind, 2018) and applies it to the wider software engineering discipline. We use the conceptual architecture of this model to connect the state of research in our fields and to explore accountability arrangements in software engineering. We use empirical examples to support the conceptual argument. However, as we discuss in the conclusion, dedicated and in-depth empirical research needs to follow to operationalise the framework that we present here.

Through this interdisciplinary lens we look at emerging accountability arrangements in software engineering that could possibly support a systemic sustainability transformation. Consequently, this paper sets out to answer the following research questions: How to embed software engineering into a sustainability transition that would make software engineers accountable for sustainability? Which accountability arrangements could support a systemic sustainability transformation of software engineering?

In the first chapter, we discuss accountability theories and possible links to theories of sustainability and argue that accountability arrangements are key to a sustainability transformation. The second chapter discusses possible shifts towards accounting for sustainability in software engineering, starting with a focus on engineering practice. Following on from the sustainability theory that we discussed we analyse possibilities and tensions in culture, the economy and governance related to making software engineering accountable for sustainability, three domains that need to systemically resonate with technological changes to foster a transformation towards sustainability. We end with a discussion on possible next steps and research demands based on this systemic perspective. Together, the article provides a wide perspective on the collective shaping of accountability arrangements that aim to link software engineering and sustainability.

2. Accountability for a sustainability transformation

In line with the growing influence of digital systems on all aspects of social life there is growing insight on and demand for accountability mechanisms in digital systems and their usage contexts (Kroll, 2020; Nissenbaum, 1996). As the power of these systems to monitor, analyse, influence and impact grows so does the need to monitor, analyse, and influence their impacts and effects in responsible ways. Similarly, a sustainability transformation requires new ways of monitoring, analysing and influencing the effects of sociotechnical systems in all spheres of our society, including digital systems. In the following, we argue that these demands can be conceptually interwoven. We link theories of accountability to theories of sustainability transformations and discuss that creating accountability mechanisms for sustainability is a central enabler of a transformation^2.

Accountability is shaped and enabled by accountability arrangements that relate an actor and a forum that can hold the actor to account, i.e. pass judgement and decide on consequences for the actor. These arrangements can differ and change over time, as to who is involved, what the procedures and rules are and where and how they take place and how narrow or loose their focus is (Bovens, 2007). The practices in such accountability arrangements are ways of documenting, analysing and evaluating (past) actions and their aim is to assign responsibility for particular consequences to actors with agency (Cech, 2021; Kroll, 2020). There are many different such arrangements across societal spheres: In law (e.g. a court), in parliament, in business reporting, in project management, in public life and discourse (e.g., a public debate about a political event that holds a government to account based on public values). Thus, we may also ask: What role do such accountability arrangements play in a transformation towards sustainability and how could they look like to reshape responsibilities in software engineering? Or asked differently: Why does a sustainability transformation in digitalization need new ways of seeing and evaluating actions of software engineers?

The literature on sustainability transformations is vast, multidisciplinary and different theories of change are being discussed - from more narrow ones with a focus on (technological) efficiency towards more systemic perspectives that tie environmental, social and economic dimensions together and seek to analyse complex and multidimensional changes (Geels, 2011). One of these systemic transformation models has been championed by the The Wuppertal Institute, Germany's leading institute for sustainability research. It argues that a sustainability transformation would need to involve a civilizational turn based on fundamental cultural change that affects institutional, economic, and technological arrangements. A "great mindshift" in this view is central to a necessary great transformation. In this model of sustainability transformations cultural, economic, technological and institutional changes depend on and can also mutually reinforce another, however, cultural change is seen as a driver of the others. Culture designates the meanings associated with certain practices, the ways of seeing, being in and evaluating the world (Fischedick & Schneidewind, 2020; Schneidewind, 2018). This focus on culture is also present in the wider literature on multi-level sustainability transitions, where the roots of change are located in niches that trial innovations based on visions of and expectations for the future (Geels, 2011). The focus on culture as the

crucial factor, however, also points out how important it is to develop new ways of seeing and evaluating the world in light of sustainability. There are different strategies here, from creating consumer awareness to political campaigns. However, shaping accountability arrangements can also contribute to such a cultural "mindshift" as they create obligations and evaluative relationships between actors and forums, which are essentially ways of seeing and evaluating actions. Accountability arrangements can thus provide a particular monitoring and assessment of sustainability transformations. E.g., the complex accountability arrangements stemming from the Paris Agreement on Climate Change in 2015 assess governmental actions in light of a 1.5 °Celsius target and elaborate analytical infrastructures help to identify the carbon budgets of countries for this target.

But how would such seeing and evaluating of software engineering in terms of sustainability take place? Especially given the need for a systemic focus in sustainability thinking? In the following we use the four dimensions of the sustainability transformation model to trace emerging accountability arrangements in software engineering. After looking at software engineering as technological practice we situate it within a systemic transformation perspective and trace (emerging) accountability arrangements in culture, economy and governance related to software development.

3. Transforming technology: sustainability and software engineering

We start the discussion of a possible transformation to make software engineering accountable for sustainability in the "technological" domain of the transformation model. What would accountability for sustainability in software engineering as technological practice require? Software engineers and their ecosystem still generally lack the knowledge, experience, tools and methodological support for accounting for the sustainability effects of software systems they develop. In general, they miss understanding the effects their system might have upon the sustainability of the ecosystem (i.e., the socio-technical system) within which their software systems are embedded. Therefore, Software Engineers need support in new tools, education, science and practice in order to become able to account for sustainability in practice - and to be seen as accountable for sustainability by others, i.e. a forum. Crucially, software engineering, as any other engineering practice, is embedded in sociotechnical arrangements. Discourses, governance structures, business models, organisational cultures, education curricula and more co-define the relevance and the norms in software engineering. In this chapter, however, we start with a focus on methods that can influence software engineering practice during the development phase of new systems. Such methods are so far shaped in research and teaching.

There have been various dynamics, policies and research projects that try to reform engineering by transforming its technical focus into a sociotechnical focus Fisher and Maricle (2015, p. 74). define such socio-technical integration as "any process by which technical experts account for the societal dimensions of their work as an integral part of this work". Such sociotechnical integration has been advanced through "Responsible Research and Innovation", "Anticipatory Governance", "Midstream modulation" or ICT ethics, for example (Erik Fisher et al., 2015). It is typically shaped through inter- and transdisciplinary research and aims to bring together different forms of expertise. The goal of such work is to enhance or transform values and capacities in engineering work to enable taking the sociotechnical context of this work better into account with the goal to foster research and development of technologies that have a closer fit to societal expectations and demands.

Additionally, one can find research work on values and software engineering (Perera et al., 2020). For example there is work on integrating critical systems thinking (CST) for requirements engineering (Duboc, McCord, Becker & Ahmed, 2020; Raza, 2021), as well as work on understanding and measuring values in software engineering (E Whittle, Ferrario, Simm & Hussain, 2021.; Winter, Forshaw, Hunt, & Ferrario, 2019). Following such a perspective we look at methods to integrate sustainability as value and capacity into software engineering.

Software Engineers tend to focus on sustainability's technical dimension, which is concerned with a software system's longevity. But, to understand sustainability and software engineering, one must involve five interconnected dimensions (individual, social, economic, environmental and technical) as defined by Becker et al. (2016):

- "The individual dimension covers individual freedom and agency (the ability to act in an environment), human dignity, and fulfillment. It includes individuals' ability to thrive, exercise their rights, and develop freely.
- The social dimension covers relationships between individuals and groups. For example, it covers the structures of mutual trust and communication in a social system and the balance between conflicting interests.
- The economic dimension covers financial aspects and business value. It includes capital growth and liquidity, investment questions, and financial operations.
- The technical dimension covers the ability to maintain and evolve artificial systems (such as soft-ware) over time. It refers to maintenance and evolution, resilience, and the ease of system transitions.
- The environmental dimension covers the use and stewardship of natural resources. It includes questions ranging from immediate waste production and energy consumption to the balance of local ecosystems and climate change concerns. Complex software-intensive systems can affect sustainability in any of these dimensions."

As stated, these dimensions are interconnected. Thus, if in one system something changes then this can have an impact in one or more dimensions in one or more systems. Consider for example carbon offsets to incentivize environmentally sustainable behaviour through trade-offs with the economic dimension. Next to thinking about different dimensions and their interconnections, one must also consider that many impacts of sociotechnical systems play only out over time. Thus, three orders of effects can be differentiated (Hilty & Aebischer, 2015):

- *Immediate effects* are the direct impacts of the production, use, and disposal of IT products and services. This includes the immediate impact of system features (e.g. that one can now format a document) and the full life-cycle impacts (e.g. the resource consumption during development and usage).
- *Enabling effects* are the indirect effects of a system's application over time. This includes not only opportunities to consume less or more resources (e.g. HD streaming) but also other changes induced by system use (e.g. new business models).
- *Structural effects* are systemic impacts of a system's application over a longer time. They emerge from the ongoing use of software systems and manifest as persistent changes at the macro level (e.g. new social norms or laws).

As shown, due to the inherently multidisciplinary nature of sustainability an integrated view including concepts and methods from a range of disciplines is crucial for sustainable IT product and services design.

The current research landscape in software engineering and sustainability can be roughly classified as follows. The main differentiation exists between Sustainable software engineering and software engineering for sustainability. Sustainable software engineering is concerned with the longevity of systems. Thus, it covers concepts, principles, and methods that contribute to software endurance (e.g. technical sustainability). Software engineering for Sustainability is concerned with one or more dimensions of sustainability covering the socio-technical context of the software system (Penzenstadler, 2013; Venters et al., 2018). Software engineering for Sustainability can be further subdivided into Green IT, sustainability *in* software engineering, and sustainability *by* software engineering. Green IT is concerned with the environmental impacts of software-intensive systems. The in and by differentiation can be seen as follows (Hilty & Aebischer, 2015):

- *Sustainability in software engineering*: Designing IT products and services covering the five dimensions and three orders of effect. Thus, this covers any system that takes sustainability impacts into account when designing it
- *Sustainability by software engineering*: Creating, enabling, and supporting sustainable development by means of Software Systems. Thus, this covers systems explicitly supporting an SDG and sustainable development

In the following table (Table 1) we provide an overview about how "sustainability", "software engineering", and accountability are connected.

We differentiate between "classical software engineering" and "software engineering for sustainability" to show that there is a different use and understanding of the term sustainability. In addition, we would like to point out that there has been a shift taking place towards a more holistic view of sustainability and software engineering, which in turn also influences the accountability arrangements presented in the table. However, we are aware that our classification is only a rough classification and can be discussed. Moreover, the differentiation between "Mainstream software engineering" and "Sustainable software engineering" might be misleading as "Classical software engineering" includes "Sustainable software engineering". As stated we want to show how sustainability is used and understood in connection with software engineering thus we used this classification.

With regard to "software engineering for sustainability" we not only differentiated between the sustainability in and by software engineering as discussed above but also added software engineering for Green IT as this is a term that is also often used with regard to sustainability and software engineering (Hilty & Aebischer, 2015) and we wanted to show the difference between a green approach and a sustainable approach.

To summarise, the columns represent the classification of sustainability and software engineering. The rows represent the "sustainability dimensions" focused on as well as the "general focus" and "concrete examples" used. These rows are added to make the different classification more accessible. Finally, we added the row "accountability arrangement" to connect sustainability, software engineering and accountability.

Additionally, there exist several ethical frameworks for developing IT Systems e.g. the ACM Code of ethics or the "Forum computer scientists for peace and social responsibility".[1] The first ethics for programmers have been developed already 35 years ago. Currently, in the area of AI alone there exist about a hundred already, yet sustainability is a niche topic in these (Jobin, Ienca & Vayena, 2019; Morley, Floridi, Kinsey & Elhalal, 2020). The frameworks are developed by private companies, research institutions and public sector organizations. However, despite these massive numbers, several issues arise, first who is developing these frameworks? Are they democratically legitimated? When looking for example at the EU AI High Level Expert Group (EU AI HLEG)[2] this paper has been developed by 52 experts, of which 26 are from large industrial companies, four are ethicists and the remaining 22 are from Consumer Protection and civil rights movements. The paper itself is quite vague and short sighted and in doubt one does not need to follow the guidelines (Selke, 2018). Second, some of these frameworks seem to function like ethical washing, a marketing narrative for the customers (Classical software engineering). And third, the developers themselves do argue that Software Systems are unbiased. Simply "doing your job" for "value-neutral technologies" is still a common perspective (Daniels, Nkonde & Mir, 2019). Additionally, a study in Europe about the current perceptions and practices of sustainability and software engineering revealed that they think there is no connection between software engineering and sustainability, thus there is a lack of awareness and a narrow understanding of sustainability. Moreover, the ethical frameworks in the discipline are not conducive to sustainability impacts (Chitchyan et al., 2016).

What we traced here are accountability arrangements in software engineering as a profession. Becoming a software engineering professional means being socialised and trained within communities of software engineering practice, e.g. in the classroom or in industry settings. Individual software engineers are being held to account by other software engineering practitioners (the forum) and judged by the norms, capacities and values that are passed on and transformed by the wider software engineering community. However, accounting for sustainability is an emerging topic in this profession - with academic discussions and forms of teaching on sustainability still being niche issues. Here, wider changes are needed, such as influential guidelines by software engineering associations, industry norms or sustainability becoming a required topic in studies of computer science.

Such changes, however, are unlikely to happen solely from within the profession. Based on the above discussed transformation model this is not surprising as accountability for sustainability needs to be shaped in a complex and distributed manner across technological, cultural, economic and governance domains. In the following chapter we trace emerging accountability arrangements in these domains that may complement and influence professional software engineering.

3.1. Transforming digital culture, economy and governance towards sustainability

As we've discussed above, engineering practices are embedded in cultural, economic and governance dynamics and structures. Sustainability transformations require that mutually reinforcing changes happen in each of these domains. In this chapter we trace emerging dynamics in culture, governance and the economy that could further enable accountability for sustainability in software engineering. We thus move towards the contexts and environments that co-define software engineering practices. In a mix of theory and examples we discuss how software engineering is being made accountable for sustainability in these domains. And we point towards further changes that may need to be necessary.

3.2. Culture: envisioning a transformation[2]

Research in science and technology studies and technology assessment has shown that discourses, future imaginaries and visions are of central importance in shaping innovation and transformation processes (Jasanoff & Kim, 2015; Konrad, van Lente, Groves & Selin, 2016). The ways in which technologies are imagined and talked about, how they are contested and legitimated are central in shaping innovations and technological practices. In the cultural domain struggles over the question "what is digital technology good for?" take place and here, goals and responsibilities in innovation processes are shaped (Lösch, Heil & Schneider, 2017). The wider meanings assigned to digital technologies thus also influence the meaning of software engineering and its responsibilities in shaping these technologies. Such wider discourses therefore define the public norms and expectations towards technologies and their designers.

Culturally, it is significant how the digital transformation and the sustainability transformations have run in parallel for a long time with often diverging ideas about the future, different actors shaping them and little cultural intersections. The "immaterial" digital "new economy" seemed to be not of much interest in sustainability cultures with their focus on the wasteful industries and technologies of the "old economy", e.g., cars, fossil energy and industrialised agriculture. And possibly, the digital utopianism of the new economy (Turner, 2010) has impregnated digital innovations with an idea of radical novelty and improvement for too long. However, this seems to change somewhat, not least by the increased critical scrutiny that digital system and businesses have

[1] www.fiff.de

[2] https://ec.europa.eu/futurium/en/european-ai-alliance/ai-hleg-steering-group-european-ai-alliance.html

Table 1
Accountabilities for sustainability in different forms of software engineering.

	"Classical software engineering"		"Software engineering for sustainability"		
	Mainstream software engineering is seen as accountable for	"Sustainable software engineering" is seen as accountable for Venters et al., (2018)	Software engineering for "Green IT" is seen as accountable for Hilty & Aebischer, (2015)	"Sustainability by software engineering (Hilty & Aebischer, 2015; Penzenstadler, 2013)	"Sustainability in software engineering" (Hilty & Aebischer, 2015; Penzenstadler, 2013)
Sustainability dimensions (focused on)	None	Technical	Environmental	One selected SDG	Technical, Social, Individual, Economic, Environmental
General Focus and possible Methods	Cost benefit analysis of the company	Technical Debt management	Clean energy and resource efficiency	Starting from SDGs to frame technical products	Integrated and systemic analysis of sociotechnical dimensions and effects of sustainability
Concrete Approaches (examples)	Agile Approaches such as Scrum	Refactoring	Energy Saving Algorithms, Smart energy grid systems	AI for Good, The app Codecheck	The Sustainability Awareness Framework (SusAF) (https://zenodo.org/record/3676514)
Included in the accountability arrangement	Client, employer	Future clients	Environmentalists	Indirect stakeholders, wider public	General public, society

received in the past decade. The most popular sustainability controversy in the past years has been the digital currency "bitcoin" with its enormous energy consumption - by design - consuming more than smaller industrialised countries for the sake of financial speculation (Schinckus, 2020). The strong climate movement from 2018 onwards has also led some tech commentators to link climate change and ongoing digitalization (Software engineering for "Green IT") (Tarnoff, 2019).

A key example to culturally link digitalization and sustainability are the "AI for Good" conferences[3] (Sustainability by software engineering) which from 2017 onwards have been organised by a UN organisation with a focus on using AI technologies to achieve SDGs. Interestingly, the Xprize foundation[4] is co-organiser of this series. This is an organization led by rich Silicon Valley entrepreneurs that explicitly wants to foster research and innovation that could lead to a future of "abundance" through technology. Thus we see the collaboration of two actors who are at the heart of dominant visions of sustainability (UN) and "disruptive" digitalization (XPrize). Mixing the missions of these organizations one could read the conference as an effort to enable a vision of digital-sustainable abundance - a vision that is in tension with a regionalised "degrowth" or "post-growth" economy envisioned by many in sustainability circles (Adloff & Neckel, 2019). A conference and movement building exercise that tried to foster such perspectives of a social-ecological transformation with digital technologies has taken place in Germany since 2018: The "bits and bäume" conference has brought researchers and civil society actors from sustainability movements and digital politics movements together to foster exchanges and synergies, also explicitly trying to seek common ground in these transformative agendas (Höfner et al., 2019).

We might say that culturally the past years may be a turning point in public discourses and efforts of transformation actors when it comes to sustainability and digitalization. It remains to be seen, however, whether these new dynamics can challenge dominant hegemonies of technological change. Most probably much will depend on the further cultural struggles fought for sustainability, i.e., will this become a central goal for societies or not? Furthermore, both sustainability and digitalization are very broad and contested concepts with different actors, meanings and strategies (Lenz, 2021).

Yet, such contestations in discourse and public debates about digital technologies have an indirect effect on shaping software engineering by reframing the challenges and purposes of the technologies and thus demanding a certain accountability of software engineers based on public values and norms. Theorists of accountability arrangements describe that some such arrangements are diffuse and vague such as holding actors to account for moral or political ideals in public discourse (Bovens, 2007; Kroll, 2020). However, such meaning creation in public can have significant effects on an actors public image (e.g. Facebook after the political communication scandals) and especially for companies these images are important aspects of brand value. The next section will look more closely at the company level and its effects on accountability for sustainability.

3.3. *Economy: business models for sustainability*

In most circumstances software engineering takes place in companies where it is embedded in organisational goals and business models. The company can be considered an accountability arrangement in which employees are monitored and assessed in light of the company values and its business model. Of course, these business models are also shaped by governance and regulation, which we address in the next section. Here our focus is on tendencies that are visible for digital business models that could include sustainability as a core aim of companies.

First, however, we need to note how the dominant business models in the IT industry are strongly supportive of unsustainable effects. The list of current critiques is long. The concentration of power, the data extraction and surveillance, the addictive services (e.g. social media), the huge power consumption of vast data centers, the electronic waste produced, the extreme competition, the culture of disruption and exponential scaling as goals and more (Sadowski, 2020; Santarius et al., 2020).

These business models, however, are contested by various actors by now and the search for alternatives is on (Scholz & Schneider, 2017). Interestingly, the past years have also seen software engineers and others organising to effect changes in big IT companies, e.g. to prevent military research or to demand climate action (Nedzhvetskaya & Tan, 2019). Furthermore, many big IT companies have certain initiatives for "green IT", with renewable energy contracts for servers or AI products to optimize energy use in certain sectors. This, however, draws on a narrow understanding of sustainability as other aspects and systemic consequences are left untouched (Lenz, 2021), e.g. facebook is running many of its servers with renewable energy, yet still contributing to spreading hate online.

On the other hand, within the digital transformation certain niches exist that can support an integrated and systemic sustainability transformation. In particular digital commons have received much attention as possible game changers: in open source projects, shared and open knowledge (e.g. Wikipedia) or data commons. Here the focus is not so much on efficiency gains through technology but on social, economic and cultural innovations enabled by digital technologies that could lead

[3] https://aiforgood.itu.int/
[4] https://www.xprize.org/

to more robust forms of sustainability (Höfner et al., 2019; Lenz, 2021).

Yet, within the European innovation landscape, that we are familiar with, more sustainable business model alternatives are coming into being (Kutzschenbach & Daub, 2021; Pfotenhauer & Frahm, 2019) and pioneers such as "fairphone" are trying to create sustainable IT products. The past years have seen many initiatives for "digital-social innovation" explicitly focusing digital innovation on societal challenges, e.g. as contributing to the SDGs. The platform DSI4EU[5] lists around 1500 projects across the EU that use digital technologies to tackle social challenges, many of them being for profit projects (Sustainability by software engineering). Similarly, the movement for "platform cooperatives" which champions democratic, cooperative business structures for digital companies has been growing. Here the goal is to involve workers, customers and other stakeholders as co-owners of the company with a democratic voice in the company's governance (Scholz & Schneider, 2017). Rethinking the goals and organisation of companies would also necessitate to rethink software engineering practises as they are a central aspect of digital business models. Businesses that focus on solving SDGs or with an inclusive and democratic structure could strongly affect the values and valuing processes that are necessary in software development projects and thus transform how software engineering is being done. In short, business models and structures are themselves accountability arrangements for software engineering and they need to be changed to foster sustainability.

3.4. Governance: digital and green politics

Governance is a key area in sustainability transformations. Here the regulatory frameworks are set within which companies produce and consumers consume. In this section we trace dynamics in governance with a focus on Europe and Germany that seem to open up pathways for sustainability governance in the IT sector. Regulations form central accountability arrangements in society with actors being made liable for upholding certain rules and state agencies and courts being forums that hold actors to account. Regulations thus can be highly relevant in shaping change and that's why they are typically highly contested.

Fostering innovation and digitalization have been central to politics and policy in the past years as western societies see themselves as technologised societies (Maasen, Dickel & Schneider, 2020; Pfotenhauer & Frahm, 2019). Similarly, sustainability has been on political agendas for a long time, if however, it was considered a niche topic for long. The wave of climate protests from 2018 onwards has changed that and sustainability (with a focus on climate protection) has become a central topic in public discourse and governance discourses. Yet, digitalization and sustainability are rarely seen as interrelated in policy with digital policies's recent focus on data protection rights, e.g. the EU's General Data Protection Regulation, and anti-monopoly measures (Wagner, Ferro & Stiftung, 2020) and the focus of sustainability policies on energy, mobility and agriculture (Schneidewind, 2018).

On a European level, the EU "Green Deal" is the latest policy strategy that aims to enhance sustainbility across the continent and sets the goals of climate neutrality in 2050. In the recent past the EU's digital policies started to refer to the green deal as well. The EU's "digital compass" strategy for example writes that a "digital decade" should also lead to a more sustainable Europe and that "digital technologies help to reduce environmental impact significantly"[6]. Whether these rhetorical efforts enable more profound sustainability measures for IT industries remains to be seen with most of the EU's digital strategy focusing on other issues besides sustainability.

Certain nation states are also starting to put a policy focus on sustainability and digitalization. In Germany[7] we can observe a growth in policy advice with a focus on connecting digitalization and sustainability. The main expert committee for policy advice on sustainability has published the report "Our shared digital future" in 2019 which explores the strategic intersection of digitalization and a sustainability transformation. It points out that connecting these transformations in practice and policy is a key challenge, yet also envisions possibilities for sustainable-digital futures (WBGU – Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen, 2019). The project CODINA launched by the ministry for the environment aims at creating knowledge and actor networks for creating policies for sustainable forms of digitalization (https://codina-transformation.de/). Here researchers and policy-makers discuss digitalization and sustainability with regards to the state, supply chains, the design of digital systems, digital-sovereignty and more.

Most probably strongly related to the shift in culture and public discourse we can observe policy activities that try to bring sustainability and digitalization together. It remains to be seen whether these efforts have lasting and transformative impact or will simply "green wash" digital policy. However, governance and policy are key domains for shaping accountability arrangements in research and industry. Certain regulations to reduce greenhouse gas emissions in the IT sector, for example, would have a strong impact on the requirements of software development.

Concluding this chapter we might say that there are dynamics in technology, culture, economy and governance that try to foster the mutual integration of digitalization and sustainability and could support a systemic transformation. However, so far these are niche trends that we observe and systemic efforts of engendering a transformation towards sustainability are not yet particularly strong. In the conclusion we therefore discuss possible outlooks from here and research gaps that need to be addressed.

4. Conclusion

To summarize, in this paper we have presented a conceptual link between software engineering, sustainability and accountability. We argue that with the rising influence of digital systems on all aspects of human life we need accountability arrangements for designing and using digital systems. As the power of these systems rises we (software engineers as well as users, citizens, states and societies) need to elicit, analyse, and influence their effects in responsible ways. Accordingly, a sustainability transformation requires new ways to elicit, analyse, and influence the effects of sociotechnical systems in all spheres of our society, including digital systems. Thus, we argue that these demands can and should be conceptually interwoven as creating accountability arrangements for sustainability is a central enabler of a transformation[2].

Such accountability is created through distributed accountability arrangements that are based on the embedding sustainability as value and capacity for software engineering in technological practice, culture, economy and governance. While this is still far from mainstream we identified several niches where this is enabled. In software engineering research and teaching, part of technological practice, there are efforts to transform values and capacities of engineers to address sustainability. In culture and public discourse, digitalization and sustainability are increasingly woven together, resulting in the transformation of the framing of digital technologies and their purposes. Such cultural frames are ways of seeing and evaluating and they can transform normative orders and public values. In the economy we could identify several trends for alternative business models for digital companies that focus

[5] https://digitalsocial.eu/

[6] https://digital-strategy.ec.europa.eu/en/policies/digital-compass

[7] We focus on Germany because we are most familiar with developments here. However, similar trends can also be seen in countries such as the Netherlands and Sweden.

on inclusion, public purpose and sustainability. Lastly, we discussed transformations in governance as a key site where regulations and incentives for innovation are set. While there are efforts at building policy discourses of a "green and digital future", high-level policies that address digitalization and sustainability together are still lacking in the European context.

Thus, although there are efforts at creating accountability in software engineering for sustainability this is not yet widely established or even the norm. However, that was the case in other technological domains as well where by now sustainability transformations are far more advanced across technology, culture, economy and governance. Such transitions establish "mind shifts" and they typically take a long time. The energy transformation, for example, has been collectively in the making for decades. With its cultural and political roots in the anti-nuclear protests of the 1970s, various actors have for decades collectively shaped this transformation by researching renewable energy production, arguing for decentralization, creating new businesses and lobbying politics (Aykut, 2015). Such collective making of a transformation could also take place for software engineering: Technological strategies of reducing waste may be necessary in software engineering to reduce software and hardware waste and reduce obsolescent IT products; a culture of sufficiency that focuses on needs and not on desires may reshape the use of digital products; a public discourse leading to consumers who widely request sustainable IT products may stabilise more sustainable business models and a sectoral sustainability policy framework for the IT sector may engender structural change in the digital economy.

Several issues for further research emerge from such a perspective. First, future research needs to look at the systemic relationships across technology, culture, economy and governance. E.g. how do changing public discourses (culture) shape software engineering practice in firms (technology, economy), or how do regulations (governance) shape business models (economy) and software engineering practices (technology). Second, if more robust accountability arrangements for sustainability in software engineering are to emerge there needs to be more work that operationalises values and capacities to address the future impacts of digital systems, i.e. to take a sustainable future into account. This is necessarily a multi-disciplinary and social task, that transgresses research and academia, but by the systemic nature of sustainability transformation needs to involve different actors in shaping these values and capacities. Therefore, a third issue is how to redesign software engineering institutions, e.g. study programmes, software engineering processes, software companies, to be able to include various stakeholders and a perspective on a sustainable future. This would then also need to involve assessments of how digital systems designed for sustainability influence wider society. The task thus is huge and needs to be transformative. However, the complex and collective nature of transformations could also create new possibilities that make what seems impossible now more feasible – this is the nature of collective mind shifts for sustainability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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