Digitalization and sustainability: A systematic literature analysis of *ICT for Sustainability* research

Close scrutiny of the ICT for Sustainability *conference proceedings on digitalization and sustainability reveals a bias on (technological) efficiency solutions. This bias is mirrored in blind spots in the public discourse and the political debate. The sustainable transformation of society calls for more comprehensive research – and research funding – to fill the gaps and integrate efficiency, consistency, and sufficiency strategies on the levels of life-cycle, enabling, and structural effects.*

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Abstract
In order to govern processes of digitalization for the purpose of the common good, it is important to understand the opportunities and risks of information and communications technology (ICT) for a sustainable transformation of society. In this article, we systematically review 215 publications from the *ICT for Sustainability (ICT4S)* conference corpus in order to investigate the state of debate. We analyze to what extent research covers sustainability implications of ICT, 1. regarding different levels of actions and effects, as well as 2. regarding the three different strategies of sustainability – efficiency, consistency, and sufficiency. We find that *ICT4S* research has a one-sided focus on digital efficiency improvements and on life-cycle impacts of ICT devices and applications. There is far less research on digitalization's potential to advance sufficiency-oriented practices, and questions of how to foster digital sustainability transformations at macro- and structural level are only marginally treated. We draw conclusions for funding and science politics.

Keywords
consistency, digitalization for sustainability, efficiency, enabling effects, ICT for sustainability, knowledge transfer, life-cycle effects, literature review, structural effects, sufficiency, sustainability strategies

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The ambiguity of digitalization for sustainability

There is growing recognition within society and academia of the importance to understand the impact information and communications technology (ICT) has on efforts towards a sustainable transformation of society. In this article, we focus on the environmental dimension of necessary sustainability transformations with the main aim to avoid transgression of planetary boundaries, prevent further violation of critical Earth-system processes, and ensure the premises for decent living within humanity's safe operating space (Rockström et al. 2009, Steffen et al. 2015, Fuchs et al. 2021).

The role of ICT in sustainability transformations appears to be ambiguous. One the one hand, digitalization is argued to offer opportunities, for example, by way of resource and energy efficiency improvements, process optimizations, and substitution of physical by virtual consumption. On the other hand, research is concerned with environmental risks that accompany digitalization, for example, the growing volume of resource and energy demands and emissions from the production of ICT hardware and operation of software as well as negative indirect effects such as rebound or reduction effects or malevolent forms of substitution that increase resource and energy intensities (see, e.g., Hilty 2008, Börjesson Rivera et al. 2014, Santarius et al. 2020).

Research on opportunities and risks of ICT for sustainability transformations is conducted in many disciplines and published in various different media and journals (Lange and Santarius 2020). The research community *ICT for Sustainability (ICT4S)* with its recurrent *ICT4S* conferences since 2013, including several hundreds of peer reviewed publications in *ICT4S* proceedings and elsewhere, provides a particular mirror of the wide-ranging state of research on digitalization and sustainability (see, e.g., Hilty and Aebischer 2015, Chitchyan et al. 2020). In this article, we investigate all publications from the *ICT4S* conference corpus between 2013 and 2019 in order to assess the state of debate regarding the role of ICT in sustainability transformations.

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More specifically, we conduct a systematic literature review in order to investigate two overarching questions. First, we analyze whether the conference proceedings cover risks and opportunities of ICT for sustainability on different levels of actions and effects – namely, regarding life-cycle effects of devices, enabling effects, and structural effects. Second, we investigate whether the three basic sustainability strategies – namely, efficiency, consistency, and sufficiency – are treated on equal terms in the *ICT4S* proceedings.

Our respective assumptions are, for one, that, from a sustainability perspective, action is needed on all levels in order to truly achieve transformative change in society (Geels 2011, Santarius 2015). For instance, there is little doubt that digitalization can reduce energy and resource demand as well as emissions at the life-cycle level regarding certain products and services. This has been shown in many case studies, for example, by comparing e-books with print books or video streaming with conventional DVD watching (Lüders et al. 2021). However, environmental improvements at the micro-level can be countervailed at the macro-level, for instance, when sales of print books remain at high levels despite additional e-book demand, and people watch more hours on video-streaming and TV altogether than compared to before the advent of streaming.

Secondly, we assume that all three basic sustainability strategies need to be addressed in order to not merely achieve 'ecological modernization' or an optimization of the status, but to achieve deep transformations (Sachs et al. 1998, Geels et al. 2017). For instance, relative efficiency improvements need to be accompanied by absolute reductions as well as by a change in the resource base towards renewable materials and energy carriers. More specifically, sufficiency is needed not only to ensure an absolute decrease in energy or resource consumption, but also to counteract possible rebound effects from efficiency improvements (Herring 2009). Consistency strategies integrate production and consumption processes in natural life cycles and thereby minimize leakage effects or negative spill-over effects between different environmental domains and indicators (Jaeger-Erben et al. 2021). Hence, it is not only important to systematically understand – and develop concurrent strategies – how ICT can advance efficiency improvements, but also how ICT can enable and advance sufficiency and consistency strategies.

A previous study by Mann et al. (2018, p. 222) attests the work of the *ICT4S* research community to be "unfortunately, insufficient to deliver a meaningful change towards a regenerative socioecological transformation". Using the Mann-Bates maturity scale for sustainability, the researchers analyzed the conference corpus to measure how mature the research of the *ICT4S* community is with regard to sustainability. The results of our literature review are more nuanced, but overall, they confirm the critical assessment of the state of debate. We find that the current *ICT4S* discourse has a rather narrow focus on digitalization's opportunities and risks for sustainability transformations. Publications do not cover aspects of sufficiency and consistency as much as aspects of efficiency. And they do not address structural effects as much as life-cycle and enabling effects. Based on the results, our article will formulate main research needs and lessons-learned for policy-making, including funding policies. More specifically, our article will discuss how the particular 'blind spots' of research regarding the transformative potential of ICT in various sectors can be addressed.

A systematic literature review of *ICT4S* research

To assess the state of research on digitalization's opportunities and risks for sustainability transformations, we conduct a systematic literature review of publications from the *ICT4S* conference corpus. We are aware that this selection is neither exhaustive nor representative of all global publications on the issue. However, we consider the publications of the *ICT4S* conferences as a particular mirror of the state of debate. The "ICT4S conferences bring together leading researchers in Information and Communications Technology (ICT) for Sustainability", and *ICT4S* is the only international scientific conference series that claims "to identify and respond to grand challenges in the interplay between sustainability and digital technologies" (Penzenstadler and Easterbrook 2018, preface). Note that it is a highly inter- and transdisciplinary research community, covering disciplines such as informatics, computer sciences, engineering, but also sociology, psychology, economics, as well as future studies, marketing, and other disciplines. Moreover, the *ICT4S* research community integrates members from civil society and business, for example, scholars from Ericson or Telecom who provide trend analyses on energy demand of communication networks from first hand data, for instance (see, e.g., Malmodin 2020, Malmodin and Lunden 2016).

Our literature review covers the proceedings of all six *ICT4S* conferences that took place between 2013 and 2019 (our analysis was finalized by the time the 2021 proceedings were formally published). In total, 215 *ICT4S* conference papers were analyzed.[1] Given the two overarching research questions outlined above, publications were classified along two dimensions. The first dimension is based on the LES model introduced by Hilty and Aebischer (2015). This model conceptualizes the impacts of ICT on society and environment on three connected levels: life-cycle effects, enabling effects and structural effects. Hilty and Aebischer (2015, pp. 27–30) define the potential effects as follows:

1. ***Life-cycle effects*** are "caused by the physical actions needed to produce the raw materials for ICT hardware, to manufacture ICT hardware, to provide the electricity for using ICT systems (including the electricity for non-ICT infrastructures, such as cooling), to recycle ICT hardware, and finally to dispose of non-recycled waste" (Hilty and Aebischer 2015, p. 27).

1 A complete list of all 215 *ICT4S* conference papers analyzed in the systematic literature review is available online at *https://conf.researchr.org/series/ict4s*. *ICT4S* conference papers cited in this article are integrated in the references.

TABLE 1: Number of identified conference papers per level of the LES model and sustainability strategy. Note: Conference papers are double counted if they address more than one level and strategy. If papers treat issues that cannot be assigned to one of the sustainability strategies, they are labelled as "other".

LEVEL	LIFE-CYCLE EFFECTS				ENABLING EFFECTS				STRUCTURAL EFFECTS			
number of papers	66				111				34			
sustainability strategy	efficiency	sufficiency	consistency	other	efficiency	sufficiency	consistency	other	efficiency	sufficiency	consistency	other
number of papers	45	11	8	12	67	33	21	26	18	7	0	12

2. ***Enabling effects*** refer to actions that are enabled by the application of ICT. These actions can be understood as optimizing production, consumption or technical processes, as media substitution (e.g., replacing printed documents with electronic documents) and as externalizing of control over a process or system.
3. ***Structural effects*** refer to actions enabled by ICT that lead to changes in economic structures and institutions. "Institutions, in the wider sense, include anything immaterial that shapes action, that is to say law, policies, social norms, and anything that can be regarded as the 'rules of the game'" (Hilty and Aebischer 2015, p. 30).

For the second dimension of classification, our analysis is guided by the three basic sustainability strategies: efficiency, consistency and sufficiency (Sachs et al. 1998). For the purpose of this paper, we briefly define the three strategies as follows (for more nuanced definitions of these strategies in the context of digitalization, see Santarius et al. 2022):

1. ***Efficiency*** is understood as any strategy aimed at reducing the *relative* energy or material input per unit of production or consumption; that is, the (technical) ratio between inputs and consumption or production level. Note that considerations of rebound effects as a potential effect of efficiency improvements have been assigned to the category of efficiency as well.
2. ***Consistency*** is understood as any strategy aimed at using renewable energies and materials and at closing nutrient cycles. In a broader sense, strategies for consistency are aimed at achieving a circular economy.
3. ***Sufficiency*** is understood as any strategy aimed at decreasing the *absolute* level of resource and energy demand by way of rethinking needs or changing consumption and production habits or patterns (e.g., by way of sharing practices or by changing the modal split in mobility).

Following Mayring (2014), these definitions serve as theoretical deductive root categories for our literature review, and they provide a coding guide to structure our analysis. As a first step, one researcher read abstracts to broadly classify the articles according to levels of effects and sustainability strategies. In the majority of the papers, as a second step, full texts were read to validate the initial classification. As a third step, a second researcher read a random sample of abstracts to double check the classification. Discrepancies in classification were discussed between the two researchers to identify and address any structural differences in classification.

In our analysis, differentiation of the three sustainability strategies was set in relation to the type of effects according to the LES model. Note that we neither treat types of effects nor sustainability strategies as exclusive silos, but that a significant number of conference papers have been found to address more than one type of effect and more than one sustainability strategy. Accordingly, table 1 lists double-counted conference papers that address multiple strategies or effects. Conference papers were numbered and sorted in a table that distinguishes LES levels and sustainability strategies (table 1).

In addition to the classification of conference papers along the two dimensions, structural coding was conducted by one researcher to explore and identify research topics addressed in the conference papers (Saldaña 2013, p. 84). In an iterative process of analytical memo writing and discussing emergent topics with the second researcher who read pre-selected papers, identified research topics were re-categorized and eventually mapped to research clusters, with at least five conference papers qualifying a topic to be considered a research cluster. The research clusters were mapped against the LES levels and sustainability strategies (figure 1, p. 25).

Hot spots and blind spots in the *ICT4S* conference papers

Our systematic literature review delivers deep insight into thematic hot spots but also the blind spots of literature on ICT for sustainability. Table 1 shows the number of conference papers identified per level and sustainability strategy. Note that research endeavours can be multidimensional and thus address more than one level and strategy. In fact, out of the 215 analyzed conference papers, 51 address two or more strategies or levels and 27 could not be assigned to any of them. Accordingly, conference papers have been double counted when addressing more than one level or strategy. The following subsections give an overview of key topics identified per level, starting with the level including the most conference papers and closing with the level including the least.

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Level of enabling ICT effects

As table 1 shows, the *majority of conference papers (n=111) investigate enabling effects of ICT.* Taking into account the three sustainability strategies, 67 of those conference papers focus on efficiency. 33 conference papers focus on sufficiency, and 21 focus on consistency. 27 conference papers bound to the level of enabling effects address more than one sustainability strategy.

Further analysis shows that the focus on *efficiency* in the majority of the conference papers refers to the provision or use of energy. For instance, research looks at various ICT solutions for optimizing energy supply in electricity grids (Uslar and Masurkewitz 2015, Hinrichs et al. 2015) or digital infrastructures for the grid-wide balance between energy demand and supply. Examined infrastructures are, for example, (renewable) energy trading platforms (Wagner vom Berg et al. 2016, Murkin et al. 2016) or a blockchain technology for efficient trading of renewables (Mihaylov et al. 2016). Balancing energy demand and supply per household (Brito et al. 2016, Schien et al. 2019) or site via demand shifting is another approach researchers examine in terms of efficiency, such as how to optimize the workload placement of a multi-site cloud provider by migrating its energy consumption to countries with the lowest carbon intensity of electricity (James and Schien 2019).

On the user side, research explores ICT-supported energy efficiency strategies in data centres (Procaccianti and Routsis 2016), households and buildings (Schien et al. 2019, Shafqat et al. 2019, Denward et al. 2015, Tabatabaei 2016, Georgievski and Bouman 2016, Beucker and Hinterholzer 2019, Li et al. 2013), cities and neighbourhoods (Svane 2013, Blöchle et al. 2013, Kramers et al. 2013, Al-Anbuky 2014), and offices (Lou et al. 2019). A recurrent theme is feedback from ICT devices and applications to users regarding their energy consumption with the potential result of fostering energy efficient behaviour (Weeks et al. 2014, Jakobi and Stevens 2015a, b, Kamilaris et al. 2015, Shafqat et al. 2019, Lou et al. 2019, Schien et al. 2019, Price et al. 2013, Tabatabaei 2016, Knoll et al. 2016b, Johnson et al. 2013). Other conference papers focus on ICT-based feedback for the efficient use of water (Anda et al. 2013) or the efficient handling of waste (Nyström et al. 2018). Another topic frequently discussed is whether and to what extent ICT can support retrofitting of houses in order to increase energy and resource efficiency (Massung et al. 2014, Weeks et al. 2015, Sabet and Easterbrook 2016). Some conference papers deal with ICT-based efficiency solutions and related greenhouse gas savings (Williams et al. 2013, Malmodin and Bergmark 2015, Coroama and Höjer 2016) and with ICT applications that support efficient process designs in different contexts such as e-waste recycling (Franquesa et al. 2015), waste collection (Shahrokni et al. 2014), environmental information systems (Thies and Stanoevska-Slabeva 2013) and reporting (Mora-Rodriguez and Preist 2016), as well as food sharing (Katzeff et al. 2019).

Out of the 111 conference papers that investigate enabling effects, 33 conference papers address *sufficiency*. The most prominent issue (11 conference papers) refers to energy consumption in households and ICT solutions that support sufficient behaviour of occupants, for example, by spurring reflection and discussion on energy consumption using an "ambient information display" to visualize indoor temperature (Hedin et al. 2018). Denward et al. (2015) look at how offers from energy suppliers to manage energy efficiency in apartment buildings with the help of ICT also lead to discussions on comfort expectations and social practices related to the concept of comfort – and often also to the lowering of indoor temperature levels. In the context of sufficient energy consumption, another focus is on the extent to which ICT-supported feedback on energy use and energy supply helps users adapt their household routines to the availability of renewable energy (also in the context of prosuming: Price et al. 2013, Ferrario et al. 2014, Barreto et al. 2019 and via pricing Brito et al. 2016). Sufficiency strategies possibly supported by ICT are, for example, shifting activities over time (Bourgeois et al. 2014), sharing oversupply of self-generated energy within the community, or carrying out alternative, less energy-intensive activities (Ferrario et al. 2014).

The second most prominent topic (6 conference papers) is ICT-supported sufficiency in mobility. These conference papers deal with how ICT provides users with information enabling them to use more sustainable transportation modes, such as public transport, ridesharing, or rental bikes (Viktorsson 2013, Gieselmann et al. 2013, Nyblom and Eriksson 2014). One conference paper deals with information from ICT applications to decision makers in rural municipalities so that they can consider specific mobility needs and lifestyles of different socio-demographic groups in their mobility planning process with the goal of enabling all groups to access sustainable transportation modes (Knoll et al. 2016a). Kramers et al. (2015) look at how emerging ICT tools can reduce travelling altogether by decentralizing workplaces into work hubs, while Weiser et al. (2015) investigate the circumstances for components such as ICT-based feedback and game elements to afford user motivation toward changes in personal mobility behaviour. A third topic (4 conference papers) deals with ICT that supports self-organizing processes, with the focus more generally on community-level effects (Lukács 2013, Gui and Nardi 2015) or on sufficient practices within communities, such as food sharing (Katzeff et al. 2019) and mapping for urban farming (Walker and Becker 2016).

Of the 111 conference papers investigating enabling effects, 21 conference papers address aspects of the *consistency* strategy. The majority examine ICT-supported transition from fossil fuels to the use of renewable energy (which in itself can be understood as consistency strategy) and thereby also address efficiency and sufficiency strategies described above in relation to energy use and supply. Only two conference papers deal with consistency alone. They examine the role of ICT-based solutions in supporting sustainable agriculture (Grunfeld and Houghton 2013, Batchelor et al. 2014), for example, by scaling up the use of organic input with the help of digital platforms to exchange knowledge on organic input production as well as trade those inputs (Grunfeld and Houghton 2013). Hence, research on how ICT can enable a circular economy regarding other resources than energy is scarce.

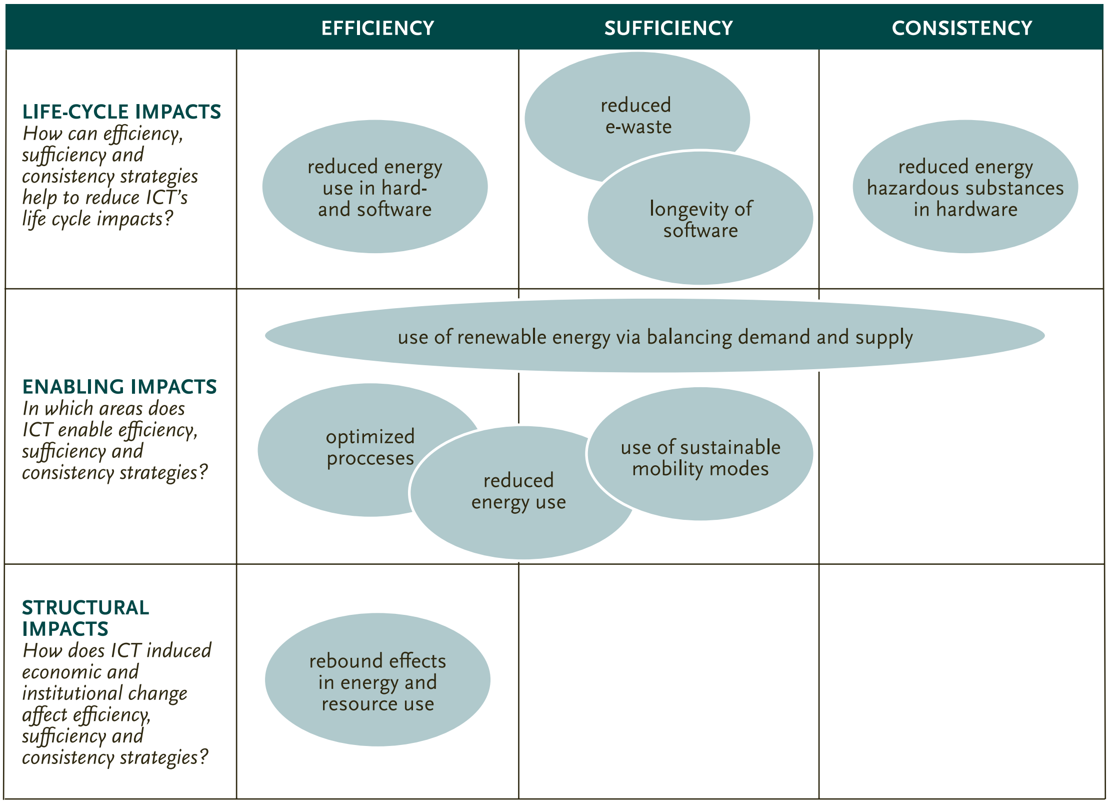

FIGURE 1: Research clusters within *ICT4S* proceedings of the years 2013 to 2019.

Level of ICT's life-cycle effects

Significantly fewer conference papers address the level of *life-cycle effects of ICT (n = 66)*. For 45 conference papers, the focus is again clearly on efficiency aspects, mostly *energy efficiency* (37 conference papers). In several conference papers the energy consumption of software and hardware is considered as a prerequisite to improve energy efficiency. Van Bokhoven and Bloem (2013) and Hintemann and Hinterholzer (2019) for example, deal with the energy consumption of software in data centres, while Philippot et al. (2014) deal with the energy consumption of websites. Hintemann and Fichter (2015), Hintemann and Clausen (2016) and Hintemann and Hinterholzer (2019) address the energy consumption of hardware, with a focus on hardware in data centres.

Several conference papers deal with the carbon footprint related to the energy consumption of the ICT and the entertainment and media sectors (Malmodin et al. 2013, Malmodin and Lundén 2016, Malmodin and Lundén 2018). Other conference papers focus on energy efficiency measures in data centres (Vandromme et al. 2014, Gysel et al. 2013, Romero et al. 2014), on software level (Koçak et al. 2013, Grosskop and Visser 2013, Chinenyeze et al. 2014, Kalaitzoglou et al. 2014) as well as on chip level (Rexha and Lafond 2019). Five conference papers examining the application of insights of ICT life-cycle assessments in practice also address aspects of resource and energy efficiency (Kramers et al. 2015, Schmidt 2016, Lautenschutz et al. 2018, Oyedeji et al. 2019, Condori Fernandez et al. 2019).

Only few conference papers (n = 11) address *sufficiency* on the level of ICT's life-cycle effects. Bookhagen et al. (2013), Picha Edwardsson (2014), Remy and Huang (2014), Joshi and Pargmann (2015), Thomas et al. (2015) and Schneider et al. (2018) address the problem of e-waste. For example, Bookhagen et al. (2013) deal with how to improve the acceptance for recycling programs. Others examine measures to extend the life span of digital devices, such as reducing the number of owned devices (Thomas et al. 2015) and reusing them or designing for modularity (Joshi and Pargmann 2015, Thomas et al. 2015) and attachment (Schneider et al. 2018) as well as longevity (Joshi and Pargmann 2015, Thomas et al. 2015, Remy and Huang 2014). Three conference papers address problems like unnecessary software configurations (Kern et al. 2015), unneeded software parts (Schmidt 2016) or unnecessary stored data (Romero et al. 2014). Kern et al. (2015), for example, propose sufficiency promoting default configurations, such as a reduced image size for mobile versions of websites. Two conference papers also address sufficiency aspects such as design for reusability, maintainability, modifiability (Oyedeji et al. 2019, Condori Fernandez et al. 2019), or user education on sustainability and awareness raising on resource use in relation to sustainable software system design (Oyedeji et al. 2019).

Even fewer conference papers (n = 8) deal with *consistency* on the level of life-cycle effects. Five of them address the problem of hazardous substances (Joshi and Pargmann 2015, Ercan et al. 2016, Schluep et al. 2013, Wendschlag et al. 2014, Picha Edwardsson 2014).

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Level of structural effects of ICT

Only 34 conference papers could be assigned to the *level of structural effect.* 18 were classified to deal with efficiency, only seven address sufficiency, and none address consistency.

Conference papers dealing with *efficiency* aspects are mainly concerned with ICT-induced energy and resource efficiency and related rebound effects (8 out of 18). Pihkola et al. (2018), for example, examine trends related to energy consumption of mobile data transfer and mobile networks in Finland. The findings include that, although the energy efficiency of mobile access networks has significantly improved, the total energy consumption continues to grow due to increasing data usage and new functionalities. Bieser et al. (2019) examine ICT-induced time-rebound effects by looking at how ICT usage changed lifestyles and time use patterns. A further efficiency related topic identified on the structural effect level is an ICT-supported change in economic structures. Two conference papers deal with structural changes induced in the energy sector by implementing a decentralized digital currency (Mihaylov et al. 2016) or a peer-to-peer trading platform (Murkin et al. 2016). Another addresses the problem of increasing unemployment due to automation, the potential of internalizing external costs with the help of cryptocurrency, and the potential positive impact of ICT-based knowledge sharing infrastructures on people's cooperative behaviour (Penzenstadler et al. 2014).

Regarding *sufficiency,* two conference papers address the problem of users' increasing dependency on ICT devices and applications. Bates et al. (2015, p. 300) examine "how digital technologies have been, and continue to be, adopted in domestic practices – and how the growth of interactions with various ecologies of digital technologies can lead to growth in use and energy consumption". One study explores how "Internet disconnection affects our everyday lives and whether such disconnection is even possible in today's society" (Widdicks et al. 2018, p. 384).

Mapping these findings to research clusters – with at least five conference papers qualifying a topic to be considered a cluster – highlights the *ICT4S* research emphasis on enabling and life-cycle effects, and efficiency.

In need of transformative digitalization research

It is our finding that research published in the *ICT4S* conference corpus to a large extent examines how digitalization enables (energy) efficiency as well as how life-cycle impacts of ICT devices and applications can be reduced. At the same time, much less research examines digitalization's potential to advance sufficiency-oriented practices, and questions of how to foster digital sustainability transformations at structural level are only marginally treated.[2]

Based on these findings, we can draw two major conclusions: first, our findings can be used to better understand current public and political discourses on digitalization and sustainability – and the role science in general and the *ICT4S* discourse in particular might be playing in it. And second, our findings suggest changes in science and funding policy in order to address blind spots in existing research.

In the current public and political discourses on digitalization and sustainability, there is substantial hope in the potential contribution of digitalization to advance efficiency improvements in various sectors (mobility, agriculture, energy, etc.) and industries (BMU 2020, see, e.g., CODES 2022, Digitaleurope 2021, EESC 2020, GeSI and Deloitte 2019). The potential impact of digitalization on advancing sufficiency or consistency is much less considered (see, e.g., Ellen Macarthur Foundation 2019). Without overstressing the role for public discourses of science in general and of the specific *ICT4S* conference proceedings in particular, there appears to be a correlation between the key issues in research and the key issues in politics. Is the scientific community partly responsible for the public discourse's one-sided focus on efficiency? Or is it just much simpler to come up with technology solutions than to change social systems and challenge values?

Accordingly, conclusions for funding and science politics can be drawn. There is a deep need to foster research on how digital innovations are embedded in political, economic, and regulatory systems.

While improving efficiencies is a worthwhile strategy, a more balanced approach that covers efficiency, consistency, and sufficiency would be desirable. This holds true, for one, in general, because important sustainability goals such as steep greenhouse gas emissions reductions can best – or even only – be achieved by a smart combination of all three strategies (BUND et al. 2008, chapter 8). And, more particular, because efficiency improvements generate rebound effects that intensify production and induce a more intensive application of digital technologies – which in turn countervails the digital savings potential (Herring 2009, Santarius et al. 2016). Even the most recent IPCC report devotes special attention to sufficiency policies (IPCC 2022). If policy makers are advised to carefully balance efficiency strategies with consistency and sufficiency strategies in a comprehensive policy mix (for a concept for digital sufficiency, see Santarius et al. forthcoming), this should be claimed for research as well: rela-

2 For similar findings in public discourses see Angst and Strauß (2023, in this issue).

tively more research is needed that investigates digitalization's potential for a circular economy and for sufficiency, and more research should pursue a holistic view considering combinations of all three sustainability strategies.

In a similar vein, current policy making regarding digitalization for environmental sustainability has a strong focus on both unleashing enabling effects and reducing life-cycle effects. Take, for instance, the 2021 EU Council decision *Digitalization for the Benefit of the Environment:*[3] most of the policy initiatives suggested focus on digitalization as a leverage for environmental protection, while in the final part initiatives are suggested to make ICT themselves, particularly data centres, more environmentally sound (i.e., green IT). The same holds true for the few policy prescriptions at national level, for example, in Germany and Finland, which also focus on green IT and digital enabling factors (BMU 2020, LVM 2021). Again, this focus of the political and public debate appears to correlate with the state of the scientific debate in the *ICT4S* conference corpus.

While it is important that politics addresses challenges of green IT, it is probably even more important to address the indirect and structural environmental impacts of digitalization on overall production and consumption patterns (Lange and Santarius 2020). If sustainable development requires not only technological and incremental changes but profound social changes, including changes in values, institutions, and practices (see WBGU 2011), then "making digitalization work for sustainability" is far more complex than greening technologies and leveraging optimizations. The big question for both research and politics is how to make digitalization a driving force for deep and society-wide sustainability transformations. Research, at least in the *ICT4S* conference corpus, is so far not well equipped to provide solutions – and maybe research is part of the reason why the political debate is not focused on this question.

Accordingly, conclusions for funding and science politics can be drawn. There is a deep need to foster research on how digital innovations are embedded in political, economic, and regulatory systems. Simply changing technologies to become more efficient might be possible without such insights, but the implementation of comprehensive strategies that combine efficiency, consistency, and sufficiency requires a profound understanding of technology's role and embeddedness in existing socio-economic contexts. In particular, if a change in consumption and production patterns for greater sufficiency is desired, research is needed to more comprehensively understand how to foster technology adoption, use, and acceptability *outside of* and *beyond* existing power structures in order to support new practices. In particular, research is necessary on how certain digital solutions can help disrupt present path dependencies and break up lock-in modes of unsustainable production and consumption. In short, science politics and funding – at EU level, but also at a national level and within the private sector and civil society – should favour research on digitalization that rests on a coherent and transformative combination of all three sustainability strategies.

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