Sustainable digitalization – fostering the twin transformation in a transdisciplinary way
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Can digitalization be designed in such a way that it does not harm the environment or promote unsustainable lifestyles? Can it even promote a green transformation? The authors of this GAIA special issue discuss how stakeholder engagement and transdisciplinary approaches can help address digitalization and sustainability in an integrated way. The special issue deepens insights into the state of knowledge on sustainable digitalization in both scientific and political discourses.

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In recent years, the link between digitalization and sustainability has become an increasingly relevant topic, both in public debate and in scientific research. It has also risen up the political agenda, at least in some countries. As of February 2022, in the European Union the two overarching narratives were sustainability and digitalization, expressed in the *Green Deal* and *Fit for the Digital Age* legislative packages respectively. And while for many years the connections between the two narratives have only been discussed in niches, the debate is now gaining momentum (Kiron and Unruh 2018). The number of public and policy events on this nexus has also increased, including an international symposium hosted by Leuphana University of Lüneburg, the Einstein Centre Digital Future and TU Berlin, and funded by the Robert Bosch Stiftung, in May 2021 entitled *European approaches towards a Sustainable Digitalization*[1]. In this context, the term "twin transition" is increasingly used by high-level policymakers, including the commissioners and their president. And in 2021, two comprehensive reports were published that systematically explore a policy agenda for sustainable digitalization (D4S 2022, Muench et al. 2022).

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While politics and business often unilaterally emphasize the potential of digitalization to increase efficiency and achieve a win-win situation for ecology and economy, the other side of the coin is increasingly coming into focus, namely the challenges posed by digitalization's disruptive character, such as its increasing contribution to power asymmetries and inequalities, its resource consumption, and its rebound effects (Del Río Castro et al. 2021). The more widely digitalization is understood as a process of social change characterized by "the restructuring of domains of social life around and with digital communication and media infrastructures" (Brennen and Kreiss 2016), the clearer the interdependencies between digitalization and the urgently needed sustainability transformation become.

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[1] www.tu.berlin/en/transformation/events/past-events/symposium-european-approaches-towards-a-sustainable-digitalization-mai-2021

Indeed, digitalization impacts the goals and strategies of the sustainability agenda on many levels, and vice versa. While research on the topic of "information and communications technology (ICT) for sustainability" is progressing, many questions on this complex of topics have not yet been sufficiently explored. In particular, transdisciplinary approaches to sustainability strategies at various governance levels – from the EU as a whole, to cities and municipalities, to the individual consumer – are still in their infancy. Given the potentials and risks of digitalization as a complex and dynamic process of economic, social, and cultural change, there is a clear need for sustainability research, and also for sustainability strategies and policies which identify the conditions that put digitalization at the service of sustainable development.

This special issue deepens insights into the state of knowledge and possibilities of knowledge transfer, both in scientific and political discourses. It discusses how stakeholder engagement and transdisciplinary approaches can help address digitalization and sustainability in an integrated way. It also discusses challenges and success factors in how certain digital innovations, for example, artificial intelligence in urban planning processes, can contribute to a green transformation.

The journal edition includes six research articles, two forum articles as well as a short interview with 12 questions providing insights on environmental policy making. We are grateful that *Eckhard Störmer,* a distinguished researcher from the Joint Research Centre of the European Commission who recently published a report on the interface of the green and digital transformation, committed to respond to our questions. In the interview, he sketches out his personal views on urgent environmental challenges and the understanding of the global environment in the light of fast moving technological progress.

12 Questions to ...
pp. 4–5

The six research articles contribute to the overarching questions of this special issue in at least three different ways – 1. by providing an overview of how the discourse on sustainability and digitalization is evolving, 2. by highlighting several topics of high relevance in sustainability science where digitalization is having a significant impact, and 3. by illustrating these impacts through concrete case studies. The six articles fit together seamlessly: the first two provide an overview of "hot topics" as well as shortcomings in current discourses; the following four contribute to the topics.

Discourses surrounding sustainability and digitalization in Europe on Twitter over time
pp. 10–20

Opening this special issue, *Mario Angst and Nadine Strauß* reconstruct the evolving discourse on sustainability and digitalization by analyzing a corpus of relevant tweets from the last decade. Based on a qualitative analysis of these tweets, they identify climate change as a central theme, and were able to capture the discourse around the lifecycle impacts of ICT and the increasing importance of the smart city. They also point out a significant blind spot: the structural impact of digitalization on sustainability is, by and large, overlooked in the discussion.

Digitalization and sustainability: A systematic literature analysis of ICT for Sustainability research
pp. 21–32

With similar intent, *Tilman Santarius and Josephin Wagner* conducted a systematic review of publications from the *ICT for Sustainability (ICT4S)* research community. The authors raise the question of what kind of sustainability implications of ICT are addressed in this research corpus and offer insights into the discourse taking place within an expert community that can help draw conclusions for funding and science policy. Their findings show that the current *ICT4S* discourse focuses heavily on how digitalization enables (energy) efficiency and how to reduce the lifecycle impacts of ICT devices and applications. However, there are few studies that address the potential of digitalization to promote sufficiency- and consistency-oriented practices, or how digital sustainability transformations can be promoted at the structural level, for example, to achieve a circular economy or a post-growth economy. In their conclusions, the authors draw parallels to these foci in current policy debates within the European Union and suggest how science and funding policies could be further developed to address existing gaps.

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The next two articles provide contributions that address the discursive deficits identified by Tilman Santarius and Josephin Wagner, namely how ICTs can be used to structurally impact sustainability transformation and policies for a circular economy. *Matthias Gotsch and his co-authors* analyze the role of environmental data science applications and shed light on their potential to support the transition to a green economy. Their study not only highlights numerous examples of green economy applications, but can also be used to formulate policy recommendations to better integrate digital technologies into green economy policies. Finally, the authors propose six measures that can help overcome the identified barriers to greater use of data science for green transformation. These range from aspects of data availability and quality to concrete ways to address regulatory hurdles.

Dominik Piétron and his co-authors argue that strategic governance of product data is key to designing circular ecosystems with low carbon emissions and minimal consumption of natural resources. Exploring the technical and policy framework required for data-based policy tools, the authors analyze five empirical cases along the product life cycle. Their results show how strategic governance of product-related data can link material and product flows and shape new collaborative circular ecosystems. Applying this data governance perspective to the EU's Digital Product Passport proposal, they believe that the unclear technical specifications for data collection and data standards, as well as the lack of comprehensive material tracking, could create high coordination costs and thus hinder circular ecosystems. Therefore, they propose the creation of publicly coordinated Product Data Platforms that complement the Digital Product Passport by making data more accessible.

The next two research articles follow up on the first by Mario Angst and Nadine Strauß by providing contributions to the "hot topics" identified in their Twitter analysis: urban planning and the concept of smart cities for sustainability. *Florian Koch and his co-authors* connect the concept of the smart city to sustainability research. They critically reflect on the potential of data from smart city approaches and raise the question of what opportunities new data offer for urban *Sustainable Development Goals* monitoring systems. Using the example of the Berlin district of Treptow-Köpenick, they highlight the potential but also the many pitfalls of implementation, such as technical barriers, difficulties in assessing data quality, and lack of time resources for data maintenance. In conclusion, they argue that the monitoring of smart cities should be understood as both a social and a technological process.

The contribution of data science applications to a green economy
pp. 33 – 39

Digital circular ecosystems: A data governance approach
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Monitoring the Sustainable *Development Goals* in cities: Potentials and pitfalls of using smart city data*
pp. 47 – 53

Using augmented reality in urban planning processes. Sustainable urban transitions through innovative participation
pp. 54 – 63

More sustainable artificial intelligence systems through stakeholder involvement?
pp. 64 – 70

Frank Othengrafen and his co-authors explore how augmented reality can help to both increase motivation for participation and present planning concepts more realistically through various forms of visualization. Using two case studies on sustainable urban development in Vienna and Lucerne, they show how the use of augmented reality not only increases the motivation of the population to participate in planning processes, but also enhances the quality of participation processes and can thus trigger the sustainable transformation of cities.

In addition to the six research articles, this special issue includes two articles in the *Forum* section. In the first article, *Stefanie Kunkel and her co-authors* look at the impact of the use of artificial intelligence systems (AI) on the environment. They raise the question of whether and how stakeholder engagement, as a key characteristic of transdisciplinary research, can help us better understand and manage the environmental impacts of AI. In their article, they analyze sustainability frameworks for software and AI, asking to what extent these frameworks consider both the direct and indirect environmental impacts of software and AI, and whether and how stakeholders are involved to identify these impacts. The authors propose ways in which greater stakeholder involvement can benefit the development of sustainable AI.

In the second article of the *Forum* section, *Maike Gossen and Otmar Lell* question the prevailing understanding of the interplay between digitalization, sustainability, and consumption. They base their contribution on the diagnosis that the positive trends of digitalization for sustainability are outweighed by the unsustainable consumption patterns of digital business models. The authors discuss how it is possible and necessary to shape digitalization in a way that promotes sustainable consumption. To do so, they illustrate examples of current policy approaches shaping the impacts of digitalization on sustainable consumption, and propose approaches for a systemic policy framework to promote sustainable consumption in digital environments. By introducing a "positive accountability" approach, they offer an alternative to current approaches of "isolated" regulation and suggest an integrated regulatory approach that can lead to a comprehensive assessment of digital business models.

Sustainable consumption in the digital age. A plea for a systemic policy approach to turn risks into opportunities
pp. 71–76

We hope that the articles in this special issue will help advance the discourse on linking digital and sustainability transformation, and that some of the concrete suggestions for decision- and policy-making will resonate beyond the academic community. The articles highlight the complexity of the issue and the particular challenge of acting quickly in the face of the current sustainability crisis, while keeping in mind the risk of unintended side effects. They also show that focusing on shallow leverage points (see Abson et al. 2017), such as increasing the efficiency of technologies and processes, is not enough to truly address these crises and realize the full potential of digitalization. Instead, deeper leverage points, such as system paradigms and structures, must also be considered if current socio-technical-political and ecological systems are to be transformed both digitally and sustainably. Since purely descriptive-analytical research alone – as important as it is – is not enough to promote truly transformative change, we would like to thank all the authors of this special issue for not only providing thorough analyzes, but also making concrete recommendations for action.

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