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Sustainable Digitalization: At the Intersection of Digital Well-Being, Health, and Environment

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Introduction

Adopted in 2015, the United Nations Sustainable Development Goals (SDGs) aim to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity by 2030. To achieve these goals, an approach of sustainable digitalization that accounts for individual health and well-being as well as minimizes the environmental impact of technology use is important. Referred to as the use of digital technologies in a way that supports environmental, social, and economic sustainability, sustainable digitalization may encompass such action areas as the use of renewable energy sources to power digital infrastructure, the design of digital products and services that reduce waste and conserve resources, and steps to ensure digital technologies are accessible and inclusive for all. Indeed, digital technologies and applications are playing an increasingly important role in our everyday life. For example, it is predicted that in 2023, the number of smartphone users will reach 6.8 billion globally (Statista, 2023b). In a similar vein, the popularity of social media platforms is booming, with the average daily time spent on social media reaching 2 hours and 27 minutes worldwide (Statista, 2023a). Spurred by the pandemic, work practices are getting increasingly digital, with the number of Zoom users reaching 300 million users daily as of 2022 (Zippia, 2023).

So far, this growing trend toward digitalization has brought many benefits, including improved access to information and resources (Dragičević et al., 2022), increased efficiency (Hole et al., 2021), and improved approaches to waste management (Kurniawan et al., 2022). However, some areas still require further attention on our way toward achieving a more sustainable global future. For example, aspects surrounding the environmental impact of digital technologies need to be critically discussed. Indeed, the production and disposal of electronic devices can cause pollution and waste (Notley, 2019; Manisalidis *et al.*, 2020). Further, the energy consumption of digital systems can further contribute to environmental damage. There is also a concern about the effects of electronic waste on human health, as many electronic devices contain toxic materials that can be harmful if not properly disposed of (Saha, 2014). Additionally, in the context of digital use, potential adverse effects of increased screen time on mental and physical health have been debated. For example, studies have shown that excessive use of digital devices is associated with poor sleep (Martin et al., 2021) and being overweight (Fang et al., 2019), as well as may contribute to depression and anxiety (Meier & Reinecke, 2021). At the same time, we can observe positive outcomes of digital technology use, as seen in increases in social capital and support (Meier & Reinecke, 2021) or in the effectiveness of health interventions delivered through social media (e.g., Laranjo et al., 2015; Maher et al., 2014). Altogether, the relationship between users, environment, and digital technology is highly complex. Considering the guiding role of the SDGs, this underlying complexity calls for more attention as to how digitalization influences individual, environmental, and societal aspects. Against this background, this expert opinion touches upon several areas for improvement related to users' well-being and the environment in the context of digital use.

The remainder of this paper is structured as follows. Section 2 focuses on the implications of social media use, harmful communication and interactions in the digital sphere, and issues of healthy child development in the context of digital use. Finally, section 3 is concerned with sustainable digitalization and its role in limiting the impact on the environment.

Sustainable Digital Sphere: Cultivating the Benefits – Mitigating the Risks

Towards a Better Understanding of the Implications of Social Media Use

The growing popularity of social media platforms inevitably raises questions concerning the influence of these platforms on users' well-being, perceptions, and behavior. In this regard, well-being constitutes an umbrella term comprising a variety of outcomes, including risk and resilience factors that contribute to well-being. In the research discourse, subjective (i.e., the balance of positive and negative affect, satisfaction with life; Diener 1984) and psychological well-being (i.e., growth and reaching one's full potential; Ryan & Deci, 2000) but also additional well-being related factors, such as loneliness, stress, self-esteem, and fatigue, just to name a few, have been in the focus of scholarly attention.

So far, research on social media and well-being is still in development. Early (mainly correlational) research has linked social media use to a variety of positive and negative outcomes, ranging from enhancements in social capital (Ellison et al., 2007), improved communication, and feelings of social

connectedness (Koroleva et al., 2011), to exhaustion and fatigue (Bright et al., 2015), and depressive and anxious feelings (Liu et al., 2019).

In the meantime, building on the accumulated research evidence, meta-studies have started to emerge. So far, their findings remain inconclusive. Whereas some meta-reviews indicate a small negative effect (e.g., Meier & Reinecke, 2021; Yoon et al., 2019), others report inconsistent results (e.g., Valkenburg et al., 2021) and stress the importance of person-specific effects (Beyens et al., 2020, 2021) (e.g., Beyens et al. 2020; Beyens et al. 2021). For example, a recent study by Beyens et al. (2020) suggests that effects of social media use may vary from person-to-person: whereas 10% of adolescents in their sample felt worse, 46% felt better, and 44% did not experience changes in their affective well-being as a consequence of social media use. Results of experimental interventions mainly targeted at the reduction of social media use provide further relevant evidence: In these studies, abstinence from social media has been linked to small improvements in subjective well-being (Allcott et al., 2020; Tromholt, 2016), decreases in loneliness (Hunt et al., 2018), depression (Mosquera et al., 2020) and stress (Vanman et al., 2018). At the same time, two experimental studies in this domain have shown either mixed results (Vanman et al., 2018) or no effect (Hall et al., 2021).

As such, the outcome of social media exposure may depend on a variety of factors, including users' demographics, personality predispositions, and psychological states, the nature and extent of activities they engage in, the underlying motives of use, the parties they communicate with on these platforms, and the specifics of content they are exposed to (Yang et al., 2021). For example, exposure to images of people with idealized body types can trigger unfavorable social comparisons leading to undesirable internalization of such ideals (Holland & Tiggemann, 2016). In this context, a recent meta-study into the role of users' exposure to appearance-ideal images on social media reports a moderate negative effect on respondents' body image (de Valle et al., 2021).

At the same time, excessive usage of social media platforms by itself is a cause of concern. For example, a recent meta-analysis by Huang (2022) reports moderate correlations between problematic social media use and such markers of users' well-being as depression and loneliness. At the same time, a large-scale survey among adolescents found that 4.5 percent are at least susceptible to problematic usage tendencies (Bányai et al., 2017). Importantly, such undesirable behavioral tendencies get amplified by specific social media design characteristics that hook individuals to the respective platform. For example, the constant reloading of a news feed may tap into users' urge to complete a specific unit of something ("unit bias"), potentially keeping users on the platform longer than intended. In light of these effects, user-friendly platform designs preventing such undesirable developments are essential.

Next to well-being, social media participation and, thereby, exposure to information shared on those platforms may exert influence on individual perceptions and behaviors. For example, exposure to (often one-sided and thereby biased) social media content may influence individuals' perceptions of themselves and others. For example, led to believe that others have it better (Chou & Edge, 2012), users have been shown to engage in conspicuous consumption (and thereby overspending) (Krause et al., 2019a) and negative communication (Krause & Baumann, 2021). Little-by-little, minute changes in perceptions on the individual level may cause opinion shifts affecting the society at large. Already now, ongoing research and media coverage portrays Social Media platforms as a breeding ground for polarization (Allcott & Gentzkow, 2017) and hate speech (Mondal et al., 2017). These issues can be aggravated by the proliferation of algorithmically designed "echo chambers", in which people may become increasingly isolated from different viewpoints and opinions (Allcott & Gentzkow, 2017). In this context, increasing social media literacy and awareness of users as to the biased nature of social media content may be an effective measure in counteracting these undesirable developments (Saiphoo & Vahedi, 2019).

At the same time, social media platforms offer an untapped potential to do good. Meta-studies indicate social media's potential to facilitate bridging and bonding social capital (D. Liu et al., 2016), including being a resource of informational and social support (D. Liu et al., 2018). Further, extant meta-reviews report on the effectiveness of social media interventions on healthcare-related behavioral outcomes (e.g., Laranjo et al., 2015; Maher et al., 2014). For example, access to social media communities (e.g., Facebook groups) providing information as well as interaction and exchange possibilities with others has been shown to have a positive effect on fitness aspirations (Foster et al., 2010) and weight loss (Ma et al., 2010). In this context, however, the spread of fake news via social media cannot be ignored and

needs to be closely monitored. Hence, improving the quality of health information on social media platforms should be a priority for both policy-makers and platform providers (Melchior & Oliveira, 2022).

Finally, it is worth mentioning that inconsistencies in the reported findings and the lack of conclusive evidence in this domain can be linked to the measurement issues research encounters. So far, an overwhelming majority of studies that link social media use to indicators of users' well-being has relied on self-reported measures of social media use. However, recent advancements have questioned the validity of this approach, providing evidence for the discrepancy between self-reported and the actual media use (Parry et al., 2021). In this context, the ability to collect objective data as to the specifics of social media use (e.g., time on site, frequency of use, engagement in certain actions, communication with specific social ties) holds major potential for gaining more clarity in this research domain.

Against this background, the following recommendations might be useful:

Enhancing Social Media Literacy: As social media is a tool that is here to stay and considering that research also continuously observes positive facets of using those platforms in dependence on, amongst others, individual- and context-dependent factors, it is crucial to educate the broader public on how to leverage the individual and social value of these platforms while minimizing their potential for detrimental outcomes. In this context, promoting social media literacy will support users in critically evaluating online content. Thereby, it may help debias users' distorted perceptions, safeguard users' privacy, allow users to recognize when they are being manipulated or deceived, and thereby protect them against the harmful impact of misinformation. Against this background, further research is also needed to better understand the effectiveness of such interventions (including their different forms and formats) across different population segments.

Avoiding Dark Design Features: The time users spend on social media platforms should not be the direct function of specific design features (e.g., endless scrolling). Instead, it should be determined by the value of the content users receive. Therefore, individuals should be given more control in this area (e.g., via an easily accessible non-algorithmically curated news feed option). By requesting platforms to offer their users a news feed option not based on profiling, the Digital Service Act makes a positive step towards greater user empowerment. Furthermore, as social media represents an important source of information for various demographics, extending efforts to verify and link to curated and research-supported information for sensitive topics (e.g., healthcare) is advisable.

More Research Using Objective Measures: So far, the majority of studies that link social media use to metrics of users' well-being has relied on self-reported measures of social media use. At the same time, retrospective self-reports may suffer from recall bias and measure the "perceived use", instead of an actual one. For example, Sewall et al. (2020) found that correlations between estimated use and well-being outcomes were consistently stronger than in the case of actual use. Considering the evident discrepancies between self-reported and objective measures of media use (Parry et al., 2021), more studies are needed that utilize objective measures (Madigan et al., 2020). In this context, it is important to facilitate access to objective data for research purposes. Further, initiatives on (social media) data donations to support research in this important area need to be further developed and facilitated.

Living Lab and Collaborations with Social Media Providers: Linked to the previous recommendation, we call for more research collaboration between platform providers and research community. Those can include researcher-in-residence programs or take the form of living labs. In this context, the Digital Service Act taps into a meaningful direction by regulating data access options for research. However, further opportunities for data access and collaborative research need to be made available to facilitate progress in this area to the benefit of platform users and society at large.

Preventing and Combating Harmful Interactions Online

The dissemination of digital technologies such as online forums, social media platforms and smartphones has heavily impacted interpersonal communication. Whereas early studies have celebrated these new emerging spaces for giving users the ability to effortlessly share content, exchange ideas, and give and receive social support (Koroleva et al., 2011), recent reports increasingly stress the risks of communication online. Compared to offline interactions, communication within the digital sphere is subject to certain particularities that may facilitate antisocial tendencies among users. First, the changing

nature of communication offers large-scale and easy access to potential targets for antisocial activities (P. K. Smith, 2011). Second, the interconnectedness and sharing affordances of digital technologies facilitate content to spread widely throughout a network (P. K. Smith, 2011). Indeed, numerous users of digital technologies report incidents of cyberbullying, cyberharassment, and other antisocial behaviors to which they have been exposed to. For example, among German adolescents, around one-quarter report being the victim of cyberbullying sometime in the past (Sergentanis et al., 2021). While exposure to these destructive behaviors often affects minors, adults are also not immune to the risks of becoming the victims or bystanders of digitally-enabled antisocial behavior.

At the same time, falling prey to antisocial behavior is highly detrimental to individual and collective well-being. For example, being a victim of cyberbullying may intensify depression, increase substance abuse inclination, cause suicidal ideation, and significantly decrease prosocial acting toward others (Kowalski et al., 2014). In this regard, instead of being an environment that enables social cohesion, digital technology-enabled communication may undermine the very fabric of social well-being. Importantly, the detrimental effects of cyberbullying are not limited to victims per se. Also, bystanders may suffer the negative consequences from these exposures. For example, recent studies establish a link between being the witness to cyberbullying and depressive symptoms and social anxiety (Doumas & Midgett, 2021; Wright et al., 2018). However, despite the far-reaching effects of these detrimental effects, the implications of toxic exposures on bystanders have received limited scholarly attention.

In addition, the progressive development of AI-based technologies may amplify the risks in this area. For example, technological advances in artificial intelligence in the area of image generation and natural language models provide users access to powerful tools. Next to educational, playful, and value-driven encounters, such tools can, unfortunately, be also misused to harm others, especially as their artificially created content is often hard to distinguish from an authentic one. Already now, image filters commonly used across social media platforms may cause body image issues for its viewers as they propagate unrealistic appearance standards (Kleemans et al., 2018). Also, a rising volume of artificially created pornographic content (Ajder et al., 2019) showcases the dangers of these easily accessible AI tools.

Against this background, the following recommendations might be useful:

Preventing and Combating Antisocial Behavior: Educational campaigns highlighting the characteristics and dangers of cyberharassment, especially in school settings, constitute an important tool to fight cyberbullying, and other forms of antisocial behavior in the digital space. In this regard, instructing children and adolescents on the steps they should take if they experience bullying online is crucial. As cyberbullying happens online, the perpetrator often does not see the reaction of the victim (P. K. Smith, 2011) causing a dissociation between the harmful action and its resulting consequence. Furthermore, we emphasize the importance of creating healthy communication patterns in the digital world. In this context, content moderation constitutes an essential part of platform health and, next to harmful content deletion, should focus on working against antisocial tendencies while promoting prosocial activities.

More Research into the Spillover Effects: Events experienced on digital platforms may have far-reaching implications beyond the digital space. For example, the coping strategies of victims and bystanders may range from confronting the perpetrator, deleting one's social media account, to even victimizing others in response. Importantly, resultant effects may further spill over into the offline sphere. For example, a relationship between online victimization and getting victimized in the offline context has been revealed (Kowalski et al., 2012). However, studies into the spillover effects of harmful online interactions still remain limited. Therefore, more research into the implications of exposure to online antisocial behavior for victims and bystanders is vital.

Understanding and Managing the Risks of New AI Applications: Considering current and advancing capabilities of AI applications, it is essential to continuously inform the broader public across all demographics concerning the risks these tools may hold. In addition to enhancing digital technology literacy as to the potential uses but also dangers of such tools among the broader public, continuous efforts should be invested into labeling content as to its artificial origin and into hindering its harmful exploitation by design.

Placing Special Focus on Healthy Child Development[1]

The sustainability of our society depends on the resilience and well-being of our younger generations. At the same time, children and adolescents are a special group of IT users. Due to their ongoing physical, behavioral, social, and emotional development, they may be more vulnerable to the adverse effects of technology (over)use (Bergert et al., 2020; Krasnova et al., 2021). More children and adolescents have access to screen-based devices (e.g., smartphone, tablet, computer, and television) than ever before (Madigan et al., 2022). For example, whereas only 20% of 6- to 7-year-olds used smartphones from time to time in 2014, the current level reaches 64% (Bitkom e.V., 2022). Importantly, the time spent on digital activities has also risen, especially during the pandemic (e.g., Francisco et al., 2020; López-Gil et al., 2021): Specifically, the screen time of children and adolescents increased by 52% (on average 82 minutes), reaching an alarming level of 4.1 hours per day on average during the pandemic (Madigan et al., 2022), while, at the same time, children's engagement in physical activity decreased by 20% (Neville et al., 2022). The combination of higher screen time and lower physical activity levels can be particularly detrimental (Oswald et al., 2020; Page et al., 2010). Especially children from low socioeconomic backgrounds appear to be vulnerable to these trends: They have been found to spend more time with screen-based devices (Oswald et al., 2020; Rideout, & Robb, 2019) and play apps with more manipulative designs (Radesky et al. 2022).

In this light, numerous studies have aimed to investigate the potential effects of screen time on child development and well-being. In these studies, high screen use is associated with an array of adversarial implications (Madigan et al., 2019; Radesky & Christakis, 2016). For example, studies have linked screen time to reduced well-being and depression (Liu et al., 2016; Trott et al., 2022), physical harms, such as poor sleep (Calamaro et al., 2012; Martin et al., 2021), and weight problems (Fang et al., 2019; Wijga et al., 2010), socio-emotional harms (Page et al., 2010), and cognitive impairments, such as ADHD symptoms (attention problems, hyperactivity, and impulsivity) (Nikkelen et al., 2014) and lower language skills (Madigan et al., 2020). In addition, recent studies find that already children as young as ten years old may show addictive behavior with digital devices (Schulz van Endert, 2021), which has been linked to psychological and behavioral problems (Cho & Lee, 2017; Sahu et al., 2019). In response, concerns about the adverse effects of screen-based activities on children have spiked, leading to the proliferation of guidelines for professionals and families to manage and limit children and adolescents' screen time. For example, the most prominent recommendation by WHO (2020) is to have no more than 2 hours of total screen time (including all screens, such as television, smartphone, etc.) per day during leisure time. In a similar vein, researchers call for fostering healthy device habits, which include moderating use, monitoring content, using screens for creative purposes or social connection, and prioritizing device-free time and physical activity (Krasnova et al., 2021; Madigan et al., 2022). For example, preliminary evidence shows that so called "green time" can buffer negative effects of screen time (Oswald et al., 2020).

Importantly, the usage of digital devices by children and adolescents is not only limited to leisure time. In the course of the pandemic, we have witnessed a rapid acceptance of online education formats by students, teachers, and parents. Indeed, there are many advantages to digital education. On the one hand, the increased use of education apps and other e-learning solutions allows students to learn and acquire information more independently (Pan & Zhang, 2020). In addition, digital tools offer teachers opportunities to create a motivating and interactive learning environment. However, fully online learning during the lockdown has been problematic and challenging for families (Liu et al., 2018) and resulted in lower educational progress, in particular for younger children (Andresen et al., 2021). Beyond the effects specific to the pandemic, there is a concern that increased integration of digital devices into children's daily life may further fuel screen time and problematic digital device use (Krasnova et al., 2021) — especially as they are particularly vulnerable to developing addictive behaviors (Köster et al., 2022). Among others, this is because educational apps often include entertainment elements, rewarding children with extra gaming time (Morris & Hobbs, 2019; Radesky et al., 2022). Thus, even a well-intended educational app may potentially train children's brains to crave more screen time (Dunckley, 2015). Hence, leveraging the beneficial potential of digital education while mitigating potential risks is an important task for policy-makers, educators, and parents.

[1] Ideas presented in this section have been initially formulated in Krasnova et al. (2021)

Against this background, the following recommendations might be useful:

More Research into the Long-term Risks to Child Development: Children's use of digital devices is a relatively new phenomenon. Therefore, the long-term risks of this phenomenon still remain unclear, especially in view of the decreasing age of technology exposure and adoption (Gottschalk, 2019). For example, 15 studies studying the effect of screen time on myopia provide mixed evidence, with more recent studies exposing a trend of association between hours spent by children using screens and myopia (Lanca & Saw, 2020). Furthermore, the influence of (excessive) digital use by family members on children needs to be further understood. Against this background, we call for more research initiatives to explore these effects.

More Research into Individual Differences: While studies often look at the quantity (e.g., the overall screen time), effects may depend on individual characteristics (e.g., age, family environment, engagement in physical activity, and recreational time spent in nature), the characteristics of use and related content (e.g., watching videos, playing games, listening to music, reading, doing homework, co-viewing), as well as device and screen type (e.g., TV, tablet, laptop, stationary PC, smartphone). More research is needed to better understand the intricacies of these effects on child and adolescent development. Additionally, identifying characteristics of children who are particularly at great risk for problematic outcomes should be a priority in future studies (Madigan et al., 2022; Oswald et al., 2020).

More Research and Regulatory Oversight in the Context of Apps Used by Children: Recent statistics show that about half of all 2- to 4-year-olds have their own mobile device and more than two-thirds of 5- to 8-year-olds (Common Sense Media, 2020). However, these apps often include persuasive design features, that may extend children's screen time. A recent study of mobile apps played by 3-5-year-old children estimated that up to 80% of these apps included manipulative and persuasive design elements (e.g., simulated time pressure, gifts, and attractive enticements to encourage extended playtime), which can affect children's use behavior (Radesky et al., 2022). These findings underscore the importance of pursuing child-centered design policies that focus on considering children's needs in app development.

Finding the Right Balance in Digital Education: The increasing use of digital tools at school may hold significant potential for better learning outcomes. Nevertheless, these applications should be examined in terms of their child-friendly design (see recommendation above). It is also important to ensure that children's total screen time does not exceed recommended levels and that physical activity and "green time" are promoted as well. Finding the right balance in this area, considering the benefits but also accounting for potential risks, is an important challenge for policy-makers, educators, and parents that needs to be addressed as we move forwards toward a more digital future.

Limiting the Impact on the Environment through Responsible and Sustainable Digitalization

To achieve the SDGs, an approach of sustainable digitalization that accounts for individual health and well-being and, simultaneously, minimizes the environmental impact of technology use while leveraging the potential of digital solutions is needed. At the same time, whereas digital technologies can offer solutions for environmental issues, they also hold risks of environmental damage.

Indeed, a number of environmental risks can be identified along the product lifecycle. The mere manufacturing of digital devices involves toxic substances that may pose threats to human health (Matthews and Matthews, 2003). Moreover, their production process often involves the shipment of individual technological components that traverse the earth several times before a finished product can finally be delivered to its end-consumer such as a wafer in the semiconductor industry (Plank *et al.*, 2017, pp. 179–80). After technological components have reached the end of their lifespan, they may end up in landfills as e-waste, polluting the earth and contaminating the water (Saha, 2014). Indeed, the vast amount of e-waste and the non-appropriate re- or upcycling can cause environmental pollution and pose danger to human health (Accenture, 2020).

However, not just the stages of the product lifecycle but also the provision of digital services may hold risks for sustainability. For example, the infrastructure necessary for the provision of digital services can account for up to 85% of the whole environmental impact (Schien *et al.*, 2013; Achachlouei and Moberg, 2015) that can take the form of air, water, and noise pollution (Maisonneuve *et al.*, 2009;

Zhong, 2021; Dwivedi *et al.*, 2022). Indeed, the energy demands attributed to the technological infrastructures (e.g., for running complex AI models or blockchain solutions) has been increasingly growing over the last years. For example, with 107.65 terawatt hour, the energy consumption of Bitcoin has reached its all-time-high in 2022 (CCAF, 2023), which is believed to be higher than the power consumption of Finland (Statista, 2022). In a similar vein, computational resources needed to train AI models have been doubling every 3.4 month from 2012-2018 (OpenAI, 2018). At the same time, the required energy to enable these operations still does not come from eco-friendly renewable energy sources to a sufficient extent (Khan *et al.*, 2022). This would be mandatory since fossil fuels and energy consumption contribute to carbon emission.

On the other hand, digitalization holds potential to provide for a more sustainable future (see Feroz et al., 2021). Among others, digital technologies can offer solutions for better pollution control (Ye *et al.*, 2020) and waste management (Lu *et al.*, 2016), provide means for corporate environmental management (Beier, Kiefer and Knopf, 2022), and enable to rise of smart and sustainable cities (Singh *et al.*, 2020). Particularly concerning the latter, they can support zero-waste generation mechanisms (Awasthi *et al.*, 2021), usage of clean energy (Razmjoo *et al.*, 2022), and sustainable consumption practices (Coderoni and Perito, 2020), thereby fostering urban sustainability. Furthermore, reusable digital technology leads to increased sustainability of core infrastructures (Hustad & Olsen, 2021). Tech enterprises in the area of digital transformation are already active in mitigating climate change, but more efforts are needed to combat environmental threats (Jones and Wynn, 2021).

Additionally, finding technological solutions to reduce emissions is an important goal. While more than 2 million tons of carbon dioxide are currently removed from the atmosphere yearly, it will not be enough to meet the Paris Agreement goal of limiting global warming (Naddaf, 2023). This results in an emission reduction gap and the need to emphasize urgency in emission reduction and removal (Smith *et al.*, 2023). To achieve this goal, leveraging technology's bespoken potential will be of utmost importance.

Considering the risks and the potential of digitalization outlined above, the question of how sustainable digitalization can be achieved is important. So far, with some exceptions (Kühn, 2018; Lange and Santarius, 2018; WBGU 2019; Wallimann-Helmer *et al.*, 2021), digital transformation and sustainability transformation of business and society have been considered separately. However, both transformations are interdependent and can be mutually beneficial. Thus, an integrated perspective is necessary to steer these critical developments meaningfully. In this context, latest advances on the characteristics of sustainable digitalization are particularly of interest (cf. Herlo, Ullrich and Vladova, 2022). In the following, two recent frameworks on sustainable digitalization will be briefly discussed.

Specifically, Fritzsche et al. (2022) derive three core aspects of sustainable digitalization. Those include (1) the sustainable design of digital technologies, (2) the use of digital technologies to achieve sustainability, and (3) the realization of sustainable systemic change. In this case, (1) the *sustainable design of digital technologies* refers to developing and using climate-neutral CPU models and server centers on the hardware side (Cao *et al.*, 2022) and developing application systems that reduce energy consumption on the software side (Kern *et al.*, 2018). In addition, adequate reparability of digital technologies and a certain degree of accessibility must be ensured (Gossen, Rohde and Santarius, 2021). Further, (2) the focus on *sustainability through digital technologies* is primarily on achieving ecological and social sustainability goals. For example, at the level of industry and society, resource management can be fostered by digital technologies. In private households, digital solutions can be used to manage energy consumption in line with demand. In addition, digital spaces and capabilities can provide information and participation opportunities for individuals, thereby contributing to a higher degree of social inclusion (Hamm *et al.*, 2021). Finally, (3) the *realization of sustainable systemic change* comprises social innovations and sustainable business models (Michelini, 2012; Boons and Lüdeke-Freund, 2013) that gradually substitute the conventional approach of steady growth by an economic sustainable approach, based on needs and sufficiency practices of the affected parties.

Further, based on the need for fundamental change, Lange and Santarius (2020) elaborate three guiding principles of sustainable digitalization: (a) digital sufficiency, (b) consistent data protection, and (c) common good orientation in the distribution of the gains of digitalization. The principle of (a) *digital sufficiency* demands a conscious conceptualization of digital solutions in terms of their longevity and multiple uses (technology sufficiency) and the economical use of data (data sufficiency) (Santarius *et al.*, 2022). Additionally, the sufficiency of use prescribes the emphasis on repairing (instead of buying

new) or reusing already used devices (Lange and Santarius, 2020). Next, the principle of (b) *consistent data protection* is focused on ensuring the maximum level of privacy protection through both devices and applications (Willis, 2014). In this context, applying the principle of data sufficiency is an important pre-condition that serves data protection as it stipulates the transmission of less data in the first place (Lange and Santarius, 2020). Finally, it is crucial (c) *to increase the common good orientation* when distributing the benefits of digitization. To this end, the Internet should be understood as a common good that its users develop (Lange and Santarius, 2020). In this context, the openness of source code and collaborative platform design are characteristics that contribute to the common good orientation (Curto-Millet and Corsín Jiménez, 2022).

Notably, whereas the characteristics outlined by these frameworks aim at ensuring the achievement of a sustainable digitalization, there are interrelationships between them. Thus, they can also either reinforce or hamper each other, if not implemented correctly. For example, whereas digital technologies can help to generate more ecological sustainability, their use can lead to considerable resource consumption if these tools are not designed sustainably. For example, the rapid explosion of AI and big data has introduced opportunities for society to reduce its energy, water, or land use intensities and facilitate environmental governance (Nishant, Kennedy and Corbett, 2020). At the same time, operations involving AI and big data are energy-intensive. Sizable data volumes involved in big data operations require facilities for storage that require maintenance and accessibility, placing demands on natural resources such as water and non-renewable energy (Lucivero, 2020). In a similar vein, whereas aggregated healthcare data can automate diagnosis (Keane and Topol, 2018) and improve precision in treatment (Shaban-Nejad, Michalowski and Buckeridge, 2018), it is also linked to concerns regarding ownership, responsibility, privacy, and, importantly, availability of sufficient competencies to use such approaches (Panch, Mattie and Celi, 2019). Subsumed under the umbrella of rebound effects, the detrimental sides of such interrelationships must be identified and addressed, for example, by increasing efficiency through digital technologies and their sustainable design (Tretter, Reichel and Gaugler, 2020).

Taken together, whereas digitalization offers significant potential on our path to a more sustainable and healthier future, it simultaneously creates risks that need to be addressed. The responsible application of technological advancements requires education regarding environmentally aware behavior and particularly understanding of the rebound effects on both sides: consumer and producer. Due to their normative character, the above-introduced characteristics of sustainable digitalization already point to numerous needs for action to master the ongoing sustainability transformation. Furthermore, in the view of the increasing amount of technology waste and climate risks that threaten both humans and the environment, the following recommendations are meaningful:

Solving the Technology Waste Problem: The increasing production and usage of digital devices in combination with increasing demands for computing capacity, data storage, and bandwidth, as well as the tendency towards shorter product life cycles, lead to vast amounts of decommissioned information technology hardware and end user devices. To meet these challenges, appropriate concepts for disassembly, reuse, and upcycling must be developed to utilize the available resources.

Mitigating Climate Threats with Technology: Currently, almost all carbon dioxide removal results from conventional methods of managing land, and only a tiny proportion can be attributed to new technologies (Smith *et al.*, 2023). Here, efforts in developing technologies that remove greenhouse gas emissions at a large scale need to be intensified. In this context, policy-makers, industry leaders, and researchers need to act together to achieve this ambitious goal.

Incentivizing Sustainable Behavior: Incentivizing individual and collective efforts to reduce emissions and engage in environmentally friendly actions should receive more attention. On the individual level, approaches to sustainable and sufficient consumption of resources need to be publicly promoted. For example, regulating and increasing consumer awareness about the issue of parcel returns, specifically problematic in the fashion industry, seems urgent since it constitutes a burden for the environment (Asdecker, 2021). Furthermore, creating greater awareness among consumers as to the implications of their behavior on the environment in general is necessary. In this context, one suitable measure could be to foster competencies in sustainability and digitalization while pointing out the rebound effects of individual behavior.

Aligning (Technological) Developments Ecologically and Sustainably: Finally, enabling digital sufficiency at the individual and societal levels through knowledge transfer is crucial for fostering environmental health. At the regulatory level, such measures may include recycling obligations for electronic devices or binding eco-friendly standards for the digital core infrastructure, technologies, and devices. Creating awareness via education, trustworthy certifications, and standards that measure direct and indirect resource consumption can further strengthen trends towards more sustainable consumption, including demand for durable products and environmentally friendly services.

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