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How To Make Sense of The Complex Relationships Between Multiple Tensions Surrounding Digital Decarbonisation

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According to the Paris agreement in 2015, nations and organisations worldwide set some net zero targets and pledged to decrease their carbon emissions by 2050 or even sooner. Net zero means that the total emissions produced are equal to the total emissions removed from the atmosphere and it is a crucial step towards coping with global warming. To accomplish that goal all sectors should comply with decarbonisation measures, including the progressively expanding, digital sector.

As they spread around every sector and support every activity, making the reliance on technology integral part of people's life, digital technologies should be considered not only as a tool for decarbonisation, but also a potential contributor to carbon emissions production. The increase in the number of digital devices and the extended use of digital services during the past few decades has a negative environmental impact, including landfill pollution, extensive use of water and CO2 emissions, also known as digital carbon footprint. Digital Decarbonisation targets the mitigation of the digital carbon footprint.

This presentation aims to advance the understanding on the factors affecting the mitigation of the carbon emitted from the use of digital technologies. We conducted a literature review, which was analysed thematically to identify the tensions, dilemmas a in nd conflicting goals surrounding the mitigation of the digital carbon footprint, as well as the multiple stakeholder involved and the intricate relationships between them, that we then mapped using a Rich Picture. This presentation will end with highlighting the further need for employing systemic design to understand, analyse and unpack the digital ecosystem surrounding the digital decarbonisation.

KEYWORDS: digital decarbonisation, digital carbon footprint, transition to net-zero, sociotechnical systems, systemic design, rich picture

RSD TOPIC(S): Socioecological Design, Sociotechnical Systems

Presentation Summary

Lately, and especially, during the social distancing period of the pandemic, we experienced an exponential rise in online activities (Haini, 2021). The most popular among them are streaming platforms, video conferencing, social media, and e-commerce, all of them data-centric in nature (Sanchez-Cuadrado & Morato, 2024). The surge in internet users and the emerging technologies, such as AI, contribute additionally to the augmented need for data processing and storing in the data centres globally (Batmunkh, 2022), which in turn leads to an increase in electricity demand and carbon emissions released in the atmosphere (Aslan et al., 2018; Wang & Lee, 2022). As the data production, transition and storage are expected to rise even more over the next few years (Reinsel et al., 2017), there are increasing concerns for the environmental impact caused by that proliferation.

One of the underlying challenges is that it is not straightforward to quantify the environmental cost of every online activity (Batmunkh, 2022) due to the multilayered data-processing chains and the distributed and interrelated infrastructure network that support them (Sanchez-Cuadrado & Morato, 2024). The complexity is magnified by the additional integration of social, economic, and political factors (Borning et al., 2020). This indicates the need to understand the multiple key contributors and their relationships involved in the digital carbon footprint production and mitigation system (Watson et al., 2010).

The purpose of this study is to gain an understanding of the multiple factors influencing the digital carbon emission, production and mitigation by identify the interactions and tensions in the digital ecosystem. The study was conducted during the first period of a doctoral research project and explores ecosystem solutions by gathering insights from the three distinct levels defined as: micro (individuals, groups and teams), meso (organisations, networks and stakeholder groups), and macro (societal norms and beliefs, industry and policy). We conducted a review of the current literature on the overall topic of the digital carbon footprint, where we identified key stakeholders' relationships and the factors that challenge its mitigation. We then used a Rich Picture (Checkland, 1981) to map the key findings and visually represent the constellation of the conflicting relationships occurring between all three levels (micro, meso, macro).

The literature review underpinning this study was conducted through a two-phase process, combining initial database searches with iterative citation tracking. The first phase involved exploratory searches in Scopus, ACM Digital Library and Google Scholar between January and May 2025, using a combination of keywords including "environmental impacts of digital technologies," "digital carbon footprint," "digital sustainability", "digital decarbonisation," and "pro-environmental behaviour." Building on this foundation, the second phase employed a citation-led strategy. Among the thousands of papers identified by the initial broad search, very few served for backward citation tracking- reviewing reference lists, and forward citation tracking- identifying newer studies citing those works. This organic approach provided papers from different scholars and enabled to identify the multiple stakeholders as well as the complex digital processes and infrastructure, shed light on the interplay between the social and technical elements of the digital ecosystem.

Why it is challenging to mitigate the digital carbon footprint

One of the main challenges, that was identified in the literature, is the dual role of digital technologies in terms of carbon emissions. The contribution of digital technologies to sustainability are numerous (Haini, 2021; J. Rockström et al., 2017), yet their application may also lead to environmental degradation (Irawan, 2014), by augmented demands on energy and rising amount of carbon emissions (Coroamă & Mattern, 2019; Pohl et al., 2022). A common perception is that digital technologies are a deus ex machina (Nardi, 2019), to combat the climate crisis by reducing energy demands and recourse consumption across various economic sectors (Sui & Rejeski, 2002), leading multiple stakeholders, from intergovernmental organisations (United Nations, 2015) to private sector or even individuals to push towards the usage of digital technologies for achieving sustainability goals (Kunkel & Tyfield, 2021).

On the macro level (Part A of Figure 1), the challenges arise from either the lack or the inefficiencies of environmental policies. Several international efforts that aim to support sustainability has been launched, with most important among them the Paris agreement that promote decarbonisation practices to keep global warming below 1.5 °C (UNFCCC, 2016) as well as the IPCC report, call for the reduction of carbon emissions by 45% by 2030 (IPCC, 2022). Unfortunately, none of them has shown any progress towards the goal of reaching a net zero future anytime soon (Friedman, 2018; W. ; Rockström & Richardson, 2018). Despite the growing concerns about the digital carbon footprint, other sectors like energy and transportation are still considered a priority when it comes to decarbonisation measures (Castro et al., 2024). This could be possibly due to the lack of precise estimations of carbon emissions, but stalling the decarbonisation of the digital industry can jeopardise global net zero goals (Jackson & Hodgkinson, 2024). An additional challenge, to the development and establishment of environmental policies, is the dilemma faced by many countries as well as big corporations worldwide, having to choose between carbon emissions reduction and economic growth, as fast-growing economies are dependent on industrialisation and urbanisation, both significant sources of carbon pollution (Haini, 2021).

In the meso level (Part B, of Figure 1), with the dominant presence of businesses, the emphasis is given into energy gains, with the development of technological innovations, prioritising energy efficiency, to be considered the most successful step towards reducing carbon emissions (Hoffert et al., 2002; Widdicks et al., 2023). Currently, the development of innovations has been intensified, aiming to replace earlier systems that were not designed with energy efficiency in mind (Bekaroo et al., 2016). But efficiencies are not the only system goal, and the efficiency drive can result in counter-productive behavioural and social responses (Widdicks et al., 2023). Jevons' famous observation that increasing efficiency in UK coal use, led to increases in demand (Jevons, 1866), result to the coining of the phrase "Jevons paradox" that is widely used in the literature to describe all the potential indirect effects that the efficiency of any kind of technology can cause.

Finally in the micro level (Part C of Figure 1), while there is an overall awareness of the pitfalls of digitalisation, with most common among them the privacy issues, including data breaches, and lack of transparency (Coroamă & Mattern, 2019), environmental risks seem to be overlooked. People find it challenging to prioritise digital sustainability goals when they contradict with their daily digital practices regardless of their personal belief and commitment to sustainability (Remy et al., 2018). According to previous studies, users do not perceive a negative environmental by using digital practices, and they even find it a necessary trade-off to carbon intensive activities (Elgaaied-Gambier et al., 2020). Video conferencing over daily commuting serves to illustrate this point. Lastly, there is a noticeable lack of motivation among digital users to adjust their personal behaviour (Mattern et al., 2010), and they tend to transfer responsibility to the government and IT companies to provide them with guidelines (Elgaaied-Gambier et al., 2020).

Rich Picture: An Analysis of the Digital Ecosystem

Considering the wide-reaching scope of digital infrastructure and the prevalence of the Internet, it is perhaps unsurprising to see that there are many parties involved (Remy et al., 2018). This complex system is made up of a set of interrelated dynamics between individuals, organisations and policymakers. Effective transition to net zero and beyond requires an understanding of the relationships that form the bigger picture, the ability to zoom between the micro and macro and across silos, as well as to create a new narrative on how to reach a future with regulated carbon emissions (Design Council, 2021b). Figure 1 presents a Rich Picture of the interactions occurring in the digital ecosystem.

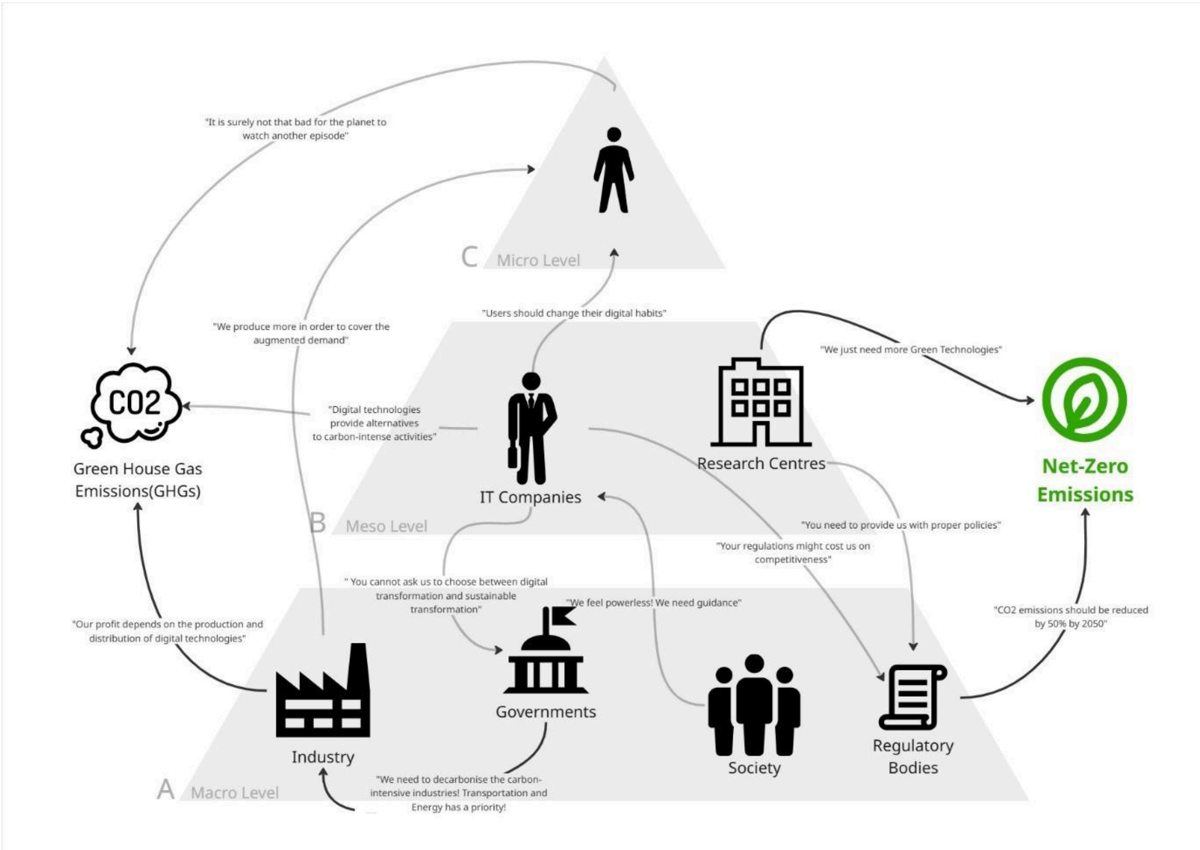

Figure 1 A rich picture illustrating the complex, inter-related factors involved in mitigating digital carbon footprint

Rich pictures originated in the Soft Systems Methodology (SSM) developed by Peter Checkland (Checkland, 1981, Checkland & Scholes, 1990). The rich picture works as a representation that can be used at the beginning of the process of understanding a problem and move towards developing actionable insights (Monk & Howard, 1998). The rich picture identifies the primary stakeholders, their interrelationships, and their insights (Monk & Howard, 1998). The three most important components of a rich picture are structure, processes, and concerns:

- Structure refers to aspects of the context that are resisted to change such as hierarchies, geographical locations and physical equipment, among others. It mainly though includes all the people who affect or could conceivably be affected by the system (Monk & Howard, 1998). In Figure 1, that could be the three levels (macro-meso-micro) and the stakeholders involved.

- Processes refer to the transformations and the flows (Monk & Howard, 1998). In Figure 1, process is indicated by the arrows suggesting the relationships between the different stakeholders.
- Concerns, or issues (Checkland, 1981) referring to the different motivations and perspectives arising from the people involved in the system (Monk & Howard, 1998). In Figure 1, the concerns are presented through the quoted arguments of one stakeholder to the other.

Needs for more systemic design approaches

A way forward is only by understanding the problem through its environmental, economic and social aspects and consequently working towards a solution in a same systematic approach (Borning et al., 2020). Digital decarbonisation requires an understanding of the relationship between digital technologies and their environmental impact, that could only be achieved through an interdisciplinary approach, where stakeholders and sectors would collaborate, rather than work in silos (Santarius et al., 2023). Effective transition to net zero and beyond requires the ability to zoom between the micro and macro and across silos, as well as to shape effective narratives to help picture a future with regulated carbon emissions (Design Council, 2021a). On that note, there is an ever-growing call in the literature for systems thinking approaches (Easterbrook, 2014; Pargman & Raghavan, 2014), intersectional collaboration (Knowles et al., 2018; Silberman et al., 2014) and new narratives (Bloomfield & Manktelow, 2021; Hák et al., 2018).

Systems thinking, that has already been applied widely in the field of sustainability (Garrity, 2018; Hofman-Bergholm, 2018; Voulvoulis et al., 2022), can similarly support digital sustainability (Widdicks et al., 2023). Systems thinking promote the building of relationships and collaborations, among different stakeholders and sectors, as well as the critical dialogue, by bringing together multiple perspectives (Kjøde, 2022). Effective transition to net zero requires a mindset shift from the one of competition to one of collaboration (Battistoni & Barbero, 2019). In that shift narratives could play a crucial role. Stories can provide a new lens towards understanding the dynamic processes and the multiple relationships in a complex system (Tsoukas & Hatch, 2001), like the one surrounding the mitigation of the digital carbon footprint. Narratives might contribute to communicating sociotechnical ecosystems but could also be employed for analysing and mapping (Wilkins et al., 2024) the multiple tensions involved. Storytelling could be used in all different phases from exploring the problem, engage with stakeholders, mapping, identify leverage points and eventually lead to develop actionable insights (Talgorn & Hendriks, 2021).

Lastly, affiliated with systems thinking is design thinking, which provides a user-oriented problem-solving approach and has also been identified as a possible approach to tackle complex socio-ecological problems (Buhl et al., 2019). Design has many of the elements needed to tackle systemic challenges, providing methods for dealing with complex, open-ended questions, framing opportunities and embracing uncertainty (Design Council, 2021b). Specifically, systemic design is in the intersection of systems thinking and system tools, research methods, and design practices like sketching and visualization practices, provides a human-centred practice to understand and reconstruct complex services and systems consisting of multiple-stakeholders (Jones, 2014). Systemic design intent to modify the given theoretical, methodological and practical design tools to provide new ways of approaching social and environmental complexity (Smith & Kalantidou, 2023), making it a promising practice for the challenges of digital decarbonisation.

Conclusion

As digital transformation continues to accelerate, a deeper understanding of its digital carbon footprint is essential, for digital technologies to potentially become part of the solution, not a multiplier of the problem of global warming. A range of stakeholders, along with the infrastructure network and data processes constitute the digital ecosystem, making the mitigation of the digital carbon footprint a rather challenging task. The literature review revealed that a constellation of interdependent factors arising from individual behaviours, professional practices, and broader policies, affect the digital carbon footprint. By mapping these dynamics across micro, meso, and macro levels using a Rich Picture methodology, the study offers a systems-oriented perspective on the tensions and interactions that challenge the effective mitigation.

While the challenges presented regarding the mitigation of the digital carbon footprint do not represent a complete of exhaustive list, and further research required on this topic, the current study aims to highlight the complexity of the mitigation task and the importance of adopting novel approaches to make sense and overcome the uncertainties surrounding the digital decarbonisation. The findings lay the groundwork for future studies integrating systemic design, to map the digital ecosystem and identify the leverage points where interventions could occur, collaborations between stakeholders and sectors, and storytelling, to investigate ways of collectively reduce the environmental burden of digital technologies, promoting more sustainable digital practices and reach net-zero by 2050.

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