The Impacts of Digitalised Daily Life on Climate Change

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Abstract

Digitalisation is reshaping production and consumption practices across society. There is uncertainty around its net energy demand and related greenhouse gas emissions, owing to its complex and varied indirect impacts. This paper focuses on three indirect impacts of digitalisation: 1) efficiency; 2) rebound; and 3) substitution in the context of energy consumption associated with the use of digital innovations in daily life activities. Systemic conditions such as equitable access, trust, and control and agency interact with these domains of activity and determine the ultimate climate impacts of digitalisation in daily life. While digitalisation has the potential to be a game-changing tool in reducing energy consumption, in practice, this will require concerted efforts and policies to steer it in a desirable direction. We outline a research agenda that supports SHAPE (Social Sciences, Humanities and the Arts for People and the Economy) research on the environmental implications of digital engagement, interdisciplinary research bridging SHAPE and STEM (Science, Technology, Engineering, and Mathematics), further research on the indirect and systemic energy impacts of digitalisation, and the importance of factoring in digitalisation as a cross-cutting process within different activity domains. We conclude with policy recommendations focused on enhancing the positive climate impacts of digitalisation in daily life.

***Keywords*:** digital technologies; user behaviour; energy consumption; indirect impacts

Introduction

Digital technologies have seen rapid uptake across industry, the public sector, and all domains of individuals' daily lives. Digitalisation has enabled a vast array of novel consumer innovations, fundamentally shaping new ways of service provision. It centres on information and communication technologies (ICTs) and related applications such as cloud computing, big data analytics, algorithmic optimisation, as well as on-demand platforms and services.[1] In daily life, digitalisation is inextricably linked to smartphones and other internet-enabled devices which act as interfaces to cloud-based services. These 'disruptive innovations' have far-reaching consequences for the ways we live and work.[2]

While the direct energy consumption and carbon emissions of digital technologies' infrastructures, incurred from manufacturing, usage, and final disposal, have gained attention, the indirect impacts on energy and carbon remain largely uncertain, owing to inadequate evidence about how digital technologies are being adopted and integrated into daily life. Digitalisation can reduce energy consumption and emissions and have positive climate impacts, but it can also change behaviours in ways that increase emissions. This discussion paper compares two competing visions of a digital society: a low-carbon digital future that supports meeting the global net zero target and a high-carbon digital future that exacerbates the climate emergency.

Why it matters

With 2023 being the warmest year on record, exceeding the Paris Agreement aim of limiting global warming to 1.5°C above pre-industrial levels for the first time on an annual average,[3] the world is not on track to achieve its climate mitigation goals. Apart from decarbonising the supply side of energy generation, the latest Sixth Assessment Report (AR6) of the International Panel on Climate Change (IPCC) also emphasises the importance of demand-side energy reduction measures, partly through socio-cultural and lifestyle changes.[4] Digitalisation, as a societal and technological key driver of change, will need to align with energy demand reduction goals. However, despite the urgency of tackling climate change, current policy briefs on digitalisation fall short of acknowledging the indirect impacts of digital technologies, primarily focusing on direct impacts. Our paper addresses this shortcoming by synthesising evidence from demand-side activities of daily life consolidated from various SHAPE perspectives.[5]

Conceptual approach

There is much discussion within the literature of the different types of impacts digitalisation has on energy and resource use and thus emissions. We take a commonly accepted taxonomy of direct, indirect, and systemic impacts.[6] Direct

1 B. A. Schuelke-Leech, 'A model for understanding the orders of magnitude of disruptive technologies', *Technological Forecasting and Social Change*, 129 (2018), 261-274.

2 McKinsey, *Disruptive technologies: Advances that will transform life, business, and the global economy.* (San Francisco, McKinsey Global Institute, 2013).

3 Copernicus Climate Change Service, 'Warmest January on Record, 12-Month Average over 1.5°C above Preindustrial,' Monthly Climate Bulletin, February 9, 2024.

4 F. Creutzig et al., 'Demand, Services and Social Aspects of Mitigation', in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. P.R. Shukla et al. (Cambridge, Cambridge University Press, 2022), pp. 503–612.

5 F. Creutzig et al., 'Demand-Side Solutions to Climate Change Mitigation Consistent with High Levels of Well-Being,' *Nature Climate Change* 12, no. 1 (2022), 36–46.

6 N. C. Horner, A. Shehabi, and I. L. Azevedo, 'Known Unknowns: Indirect Energy Effects of Information and Communication Technology', *Environmental Research Letters*, 11, no. 10 (2016), 1–20.

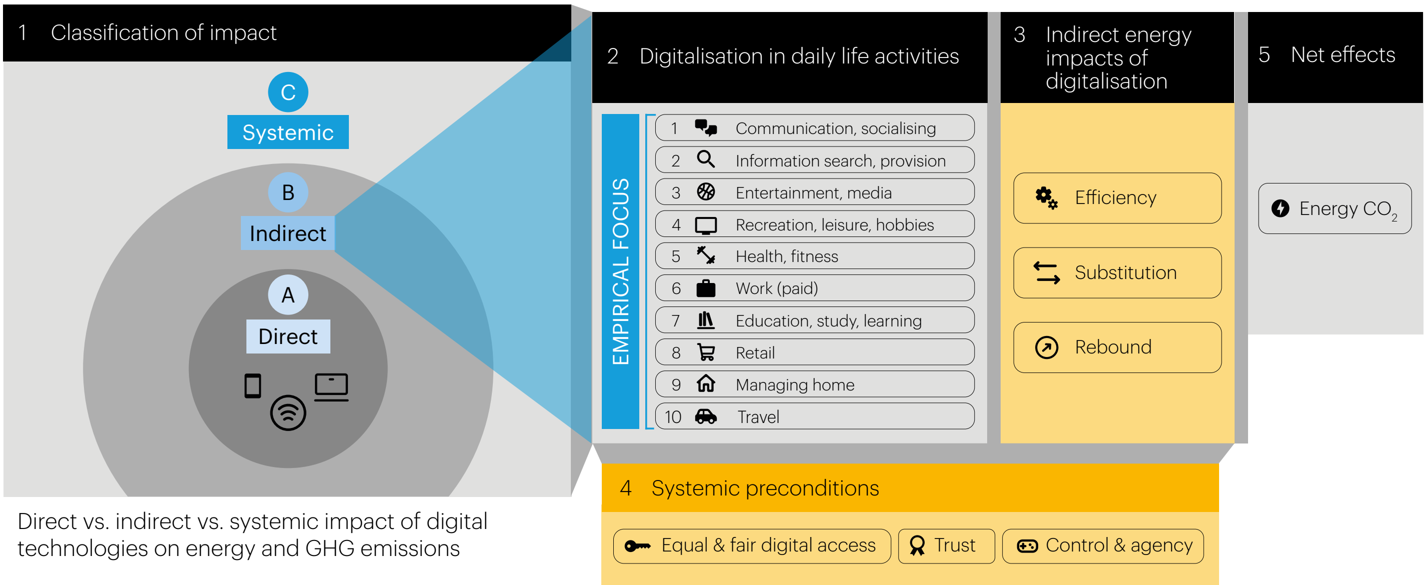
7 C. Freitag et al., 'The Real Climate and Transformative Impact of ICT: A Critique of Estimates, Trends, and Regulations', *Patterns*, 2 (2021).

impacts stemming from the energy used during the operation, manufacture, and disposal of ICTs and infrastructure (data centres, networks) are estimated in the range of 2-4% of global greenhouse gas (GHG) emissions.[7] This is expected to increase as emerging technologies like large language models (LLMs) expand. Interacting with a LLM through generative Artificial Intelligence (AI) is estimated to consume ten times more energy than a standard keyword search, as it requires significant energy for training and deployment.[8]

Although energy intensive, the direct impacts are considered small in magnitude compared to the indirect impacts from how digitalisation is used in daily life.[9] Indirect impacts refer to change of energy consumption from changes in processes, systems, and behaviours. Digitalisation can also have systemic energy impacts from shifts in economic and social institutions caused partly by ICT. For example, the ability to telework can change where people prefer to live as they no longer need to live close to the workplace. As the scope broadens to systemic impacts, uncertainties increase further, with impact pathways being diffuse for areas such as economic activity (e.g., jobs, skills) and on society and governance systems.[10]

This discussion paper focuses on the indirect impacts (see section 'Indirect energy impacts of digitalisation'). We examine how digital innovations are changing daily activities and assess three mechanisms (efficiency, substitution, rebound) by which the innovations can lead to changes in energy consumption and carbon emission, subject to underlying broader systemic conditions. Figure 1 provides a visual overview of the paper.

Figure 1: Conceptual approach



[8] A. de Vries. 'The growing energy footprint of artificial intelligence', *Joule*, 7 (2023), 2191-2194.

[9] J. G Koomey, H. S. Matthews, and E. Williams, 'Smart Everything: Will Intelligent Systems Reduce Resource Use?', *Annual Review of Environment and Resources*, 38, no. 1 (2013), 311–43.

[10] A. Plepys, 'The Grey Side of ICT', *Environmental Impact Assessment Review*, 22, no. 5 (2002), 509–23.

Indirect energy impacts of digitalisation

Indirect impacts, resulting from changes in processes, systems, and end-users' behaviour, are uncertain. Results from studies are highly sensitive to scoping decisions and assumptions made by researchers due to complex and interconnected effects.[11] Results also vary widely across different digital applications and sectors.[12] There is, however, general agreement that digitalisation has large energy savings potential, but to realise such potential is highly dependent upon the indirect impacts of user behaviour.[13] There are many ways in which user behaviour can have an impact on climate change,[14] but the three key types of indirect impact we focus on here are efficiency, substitution, and rebound.

Efficiency

Efficiency is a keystone of digitalisation's potential to mitigate climate change. By streamlining processes, optimising resource allocation, and reducing waste, the use of digital technologies has the capacity to enhance energy efficiency across various sectors.[15] For instance, digitalisation enables the adoption of smart thermostats, which help optimise energy usage by ensuring that heating and cooling are only provided when necessary, leading to reduced energy consumption without sacrificing comfort.[16] Similarly, for travel, ride-sharing platforms optimise transportation efficiency by matching multiple passengers travelling in the same direction. This real-time flow of information allows for surplus resources to be identified, shared, transacted, or exchanged, reducing the number of individual car trips, lowering fuel consumption and emissions per passenger mile compared to single-occupancy vehicles.[17]

Substitution

Digitalisation also has the potential to drive substitution effects, where traditional products or services are replaced by digital alternatives with different energy implications. Substitution of owning goods with access to services ('usership') and the sharing economy[18] provides greater flexibility of choice to match specific needs and reduce waste.[19] Additionally, the movement of information can avoid the need for movement of people and goods, with 'virtual' being one of the core characteristics of digitalisation.[20] The virtualisation of consumption can facilitate dematerialisation by shifting users from physical to digital or reducing overall demand for products. For example, the streaming of digital entertainment and media reduces the need for physical production and distribution, thereby lowering associated energy and emissions.[21] However, there is no guarantee that the substitution will be less energy intensive than its conventional counterpart. Differing assumptions for user behaviour have a large impact on the estimated savings of digital substitutions.[22]

Rebound

Any energy reduction achieved through efficiency or substitution can lead to rebound effects, in which expected gains (for instance, energy demand reduction) are offset by induced additional consumption or usage of the same good or service, or of others.[23] With digitalisation, rebound effects can occur through various mechanisms.[24] For instance, as energy-efficient appliances and smart home technologies can lower electricity bills, consumers may be inclined to use them more frequently or for longer durations due to perceived cost savings, thus partially offsetting the energy savings achieved through efficiency improvements.[25]

Overall, the indirect impacts of digitalisation on energy consumption and GHG emissions are complex and multifaceted, encompassing a range of interrelated dynamics related to efficiency, substitution, and rebound. While digitalisation holds promise as a tool for reducing environmental impacts, it is imperative to identify and manage these indirect impacts.

11 Horner et al., 'Known Unknowns'.

12 J. C T Bieser and L. M Hilty, 'Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review', *Sustainability*, 10 (2018).

13 Plepys, 'The Grey Side of ICT'; Horner et al., 'Known Unknowns'; Bieser and Hilty, 'Assessing Indirect Environmental Effects'.

14 L. A Reisch, 'The Internet and Sustainable Consumption: Perspectives on a Janus Face', *Journal of Consumer Policy*, 24, no. 3–4 (2001), 251–86.

15 WBGU - German Advisory Council on Global Change, *Towards Our Common Digital Future* (Berlin, WBGU, 2019).

16 B. K. Sovacool and D. D. F. Del Rio, 'Smart Home Technologies in Europe: A Critical Review of Concepts, Benefits, Risks and Policies', *Renewable and Sustainable Energy Reviews*, 120 (2020); Y. Strengers et al., 'Pursuing Pleasance: Interrogating Energy-Intensive Visions for the Smart Home', International Journal of Human-Computer Studies, 136 (2020).

17 Y. Benkler, 'Sharing Nicely: On Shareable Goods and the Emergence of Sharing as a Modality of Economic Production', *The Yale Law Journal*, 114, no. 2 (2004), 273; K. Frenken, 'Political Economies and Environmental Futures for the Sharing Economy', *Philosophical Transactions of the Royal Society A*, 375 (2017).

18 F. Bardhi and G. M. Eckhardt, 'Access-Based Consumption: The Case of Car Sharing', *Journal of Consumer Research*, 39, no. 4 (2012), 881–98; C. P. Lamberton and R. L. Rose, 'When Is Ours Better Than Mine? A Framework for Understanding and Altering Participation in Commercial Sharing Systems', *Journal of Marketing*, 76, no. 4 (2012), 109–25.

19 M. Namazu and H. Dowlatabadi, 'Characterizing the GHG Emission Impacts of Carsharing: A Case of Vancouver', *Environmental Research Letters*, 10, no. 12 (2015); S. Filipović, M. Radovanović, and N. Lior, 'What Does the Sharing Economy Mean for Electric Market Transitions? A Review with Sustainability Perspectives', *Energy Research and Social Science*, 58 (2019).

20 WBGU, *Towards Our Common Digital Future*.

21 V. Court and S. Sorrell, 'Digitalisation of Goods: A Systematic Review of the Determinants and Magnitude of the Impacts on Energy Consumption', *Environmental Research Letters*, 15, no. 4 (2020).

22 Court and Sorrell, 'Digitalisation of Goods'; A. Hook et al., 'A Systematic Review of the Energy and Climate Impacts of Teleworking', *Environmental Research Letters*, 15, no. 9 (2020).

23 S. Sorrell, *The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency* (UK Energy Research Centre, 2007).

24 S. Lange et al., 'The Induction Effect: Why the Rebound Effect Is Only Half the Story of Technology's Failure to Achieve Sustainability', *Frontiers in Sustainability*, 4 (2023).

25 S. Lange et al., 'The Jevons Paradox Unravelled: A Multi-Level Typology of Rebound Effects and Mechanisms', *Energy Research & Social Science*, 74 (2021).

Systemic preconditions

User behaviours that determine the indirect impacts of digitalisation should be contextualised within the broader social system. After all, individual consumer choices are influenced by and situated within social structures, relationships, practices, norms, and culture.[26] Digitalisation is reshaping inequality, community and social capital, political participation, organisations and economic institutions, and cultural participation and diversity.[27] Changes in these social dimensions will influence how individuals engage with digitalisation, consequently affecting the extent to which digitalisation can increase or reduce energy consumption, as shown in Table 1.

Table 1. Examples of interactions between social systems and energy reduction in digital transition

	Supports energy reduction	Undermines energy reduction
Inequality	• Widespread access to energy efficiency tools and green technologies (e.g., smart heating) • Access to information and environmental awareness[28]	• Energy savings only for high income groups, while low and middle income carries burden of cost of legacy network[29] • Digital inequality exacerbating energy justice issues[30]
Community and social capital	• Participation in peer-to-peer sharing economy[31] • Uptake and diffusion of low-carbon digital innovations[32]	• Fragmentation of access and usage of sharing economy, reinforcing structural inequalities[33]
Political participation	• Agency and engagements with climate action[34]	• Misinformation and polarisation undermining decision-making on climate issues[35]
Organisation and economic institution	• Green and digital jobs (e.g., low-emissions or environmental management technologies sector)[36] • Automation resulting in efficiency • Opportunities for low-carbon business models (e.g., circular economy, P2P sharing)	• High unemployment or precarious employment leading to climate vulnerability • Greater wage inequality, hollowing out of middle income, job loss due to automation • Resource-intensive growth-oriented economic activities[37]
Cultural participation and diversity	• Restructuring of production and distribution through dematerialisation[38]	• Hyper-segmentation of culture leading to long-tail niche production • Induced overconsumption[39]

26 A. Warde, 'The Sociology of Consumption: Its Recent Development', *Annual Review of Sociology*, 41 (2015), 117-134.

27 P. Dimaggio et al., 'Social Implications of the Internet', *Annual Review of Sociology*, 207 (2001), 307–336.

28 J., Zhang and X. Gong, 'From Clicks to Change: The Role of Internet Use in Fostering Environmental Sustainability', *Journal of Environmental Management*, 348 (2023).

29 P. Vaishnav, 'Implications of Green Technologies for Environmental Justice', *Annual Review of Environment and Resources*, 48 (2023), 505–30.

30 B.K. Sovacool et al., 'Decarbonization and Its Discontents: A Critical Energy Justice Perspective on Four Low-Carbon Transitions', *Climatic Change*, 155 (2019), 581-619.

31 F. Celata, C. Y. Hendrickson, and V. S. Sanna, 'The Sharing Economy as Community Marketplace? Trust, Reciprocity and Belonging in Peer-to-Peer Accommodation Platforms', *Cambridge Journal of Regions, Economy and Society*, 10, 2 (2017), 349-63.

32 E. Vrain et al., 'Social Influence in the Adoption of Digital Consumer Innovations for Climate Change', *Energy Policy*, 162 (2022).

33 C. J. Martin, 'The Sharing Economy: A Pathway to Sustainability or a Nightmarish Form of Neoliberal Capitalism?', *Ecological Economics*, 121 (2016), 149-59; T. Eichhorn, S. Jürss, and C. P. Hoffmann, 'Dimensions of Digital Inequality in the Sharing Economy', *Information, Communication & Society*, 25, 3 (2022), 395-412.

34 C. Wamsler et al., 'Meaning-Making in a Context of Climate Change: Supporting Agency and Political Engagement', *Climate Policy*, 23, 7 (2023), 829-44.

35 M. Judge et al., 'Environmental Decision-Making in Times of Polarization', *Annual Review of Environment and Resources*, 48 (2023), 477–503.

36 World Economic Forum, *Future of Jobs Report 2023* (Geneva, World Economic Forum, 2023).

37 L. M. Meier, *Consumer Society and Ecological Crisis* (London, Routledge, 2023).

38 Court and Sorrell, 'Digitalisation of Goods'.

39 V. Frick and E. Matthies, 'Everything Is Just a Click Away. Online Shopping Efficiency and Consumption Levels in Three Consumption Domains', *Sustainable Production and Consumption*, 23 (2020), 212-23.

Given the interplay between social well-being and energy reduction, both must be primary objectives of digitalisation. The ideal digital future should uphold social well-being dimensions that empower individuals and enhance their capabilities to reduce energy consumption.[40] Social well-being dimensions are measured through subjective personal well-being; quality of relationships; health; participation in work, leisure, and volunteering; quality of local area and community; personal finance; education and skills; economy; governance; and environment.[41] Achieving these dimensions requires several systemic preconditions.

Equal and fair digital access

The digital divide remains a significant issue in the UK and globally. In 2023, seven per cent of all UK adults and eighteen per cent of those aged 65 and above lacked internet access at home.[42] While lack of interest is the primary reason, cost is also cited as a barrier especially for those from lower socioeconomic backgrounds. This digital exclusion may create a vicious cycle of digital poverty amplifying material poverty.[43] In addition to material access, accessing digital innovations require knowledge, skills, and competencies.[44] Further, people's financial, time, and social resources determine their level of usage. These physical, cognitive, and social barriers to digital access will shape people's participation in a low-carbon digital future.

Trust

Trust fosters social participation, enhances social resources, and improves social well-being.[45] Trust also facilitates the uptake and diffusion of low-carbon digital innovations and lifestyles, such as participation in the sharing economy.[46] There is a growing risk of erosion of trust due to breaches of privacy, misuse of data, and spread of misinformation exacerbated by new technologies like generative AI. The UK sees particularly low levels of trust in tech businesses and on how governments are managing innovations. The latest Edelman Trust Barometer survey found almost half of respondents in the UK saying innovation is poorly managed. This perception is associated with higher rejection of emerging innovations.[47] Further, research shows perceived information overload on the internet is inversely related to interpersonal trust.[48] An ideal low-carbon digital future must uphold people's trust in technology and in each other, which raises the importance of trustworthy institutions, data and privacy protection, cybersecurity, as well as content moderation approaches.

Control and agency

Digitalisation is increasingly taking over human control in many ways, from automation of tasks to decision-making, with little to no input from users, which creates tension between human agency and machine automation.[49] Further, the prevalence of "surveillance capitalism" through the misuse of data for surveillance and behaviour manipulation is also raising concerns.[50] This erosion of control and agency will influence people's acceptance of innovations.[51] Ensuring users' informed control over how they can use technologies and how their data is being used by the innovations will be an essential first step to strengthening agency.[52]

The three systemic preconditions discussed here, equal and fair digital access, trust, and control and agency, inform how individuals interact with digital innovations in their daily activities, and the implications of these interactions on the indirect energy impacts of their behaviours.

Indirect energy impact of digitalisation in daily life activities

An examination of the potential positive and negative energy impacts arising from the indirect impacts of digitalisation in daily life requires an understanding of the ways in which digitalisation interfaces with day-to-day activities. To this end, we compiled classifications of household activities from the literature with relevance to sociological, digital, economic, and other analytical perspectives and mapped the ways in which these activities are being transformed through digitalisation (Appendix 1). We then consolidated these into ten categories that we believe constitute a comprehensive picture of daily activities. Table 2 provides examples of relevant digital applications and potential indirect energy impacts for each activity category based on existing literature from across the SHAPE fields.

40 F. Creutzig et al., 'Digitalization and the Anthropocene', *Annual Review of Environment and Resources*, 47 (2022), 479–509.
41 Office for National Statistics, *Review of the UK Measures of National Well-being, October 2022 to March 2023* (Office for National Statistics, 2023).
42 Ofcom, *Online Nation 2023* (Ofcom, 2023).
43 B. Faith, K. Hernandez, and J. Beecher, *Digital poverty in the UK* (Institute of Development Studies, 2022).
44 J. A. G. M. Van Dijk, 'Digital Divide: Impact of Access', *The International Encyclopedia of Media Effects* (John Wiley & Sons, Inc., 2017).
45 A. Adedeji et al., 'Examining the Pathways from General Trust Through Social Connectedness to Subjective Wellbeing', *Applied Research in Quality of Life*, 18 (2023); H. S. Kim and A. Shin, 'Examining the Multilevel Associations between Psychological Wellbeing and Social Trust: A Primary Analysis of Survey Data', *Journal of Community Psychology*, 49, no. 7 (2021), 2383–2402.
46 Vrain et al., 'Social Influence in the Adoption of Digital Consumer Innovations'
47 Edelman Trust Institute, *2024 Edelman Trust Barometer Global Report*.
48 C. E. Beaudoin, 'Explaining the Relationship between Internet Use and Interpersonal Trust: Taking into Account Motivation and Information Overload', *Journal of Computer-Mediated Communication*, 13 (2008), 550-568.
49 J. Heer, 'Agency plus Automation: Designing Artificial Intelligence into Interactive Systems', *Proceedings of the National Academy of Sciences*, 116, no. 6 (2019), 1844-1850; B. Wagner, 'Liable, but Not in Control? Ensuring Meaningful Human Agency in Automated Decision-Making Systems', *Policy & Internet*, 11, no. 1 (2019).
50 S. Zuboff, *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power* (Profile Books, 2019).
51 Edelman Trust Institute, *2024 Edelman Trust Barometer*, p. 57
52 H. Kennedy, T. Poell, and J. van Dijck, 'Data and Agency', *Big Data and Society*, 2, no. 2 (2015).

Table 2. Digitalisation's indirect impacts on energy and climate

Activity categories	Digital applications	Supports energy reduction	Undermines energy reduction
Communication, socialising	Social media, online forums, email, messaging apps, personal websites	Pro-environmental behaviours;[53] engagement with climate action and low-carbon lifestyles, reduce travels to meet people;[54] substitute physical mail delivery; encourage online climate activism	Polarisation and misinformation on climate; increase travel to meet online connections;[55] rebound effect on increasing communication intensity[56]
Information search, provision	Search engine, generative AI, Wikipedia	Substitute encyclopedia (dematerialisation)	Increased energy to train and operate AI models (direct energy)
Entertainment, media	E-book, e-movie, e-games, e-news, e-magazines	Substitute physical entertainment and media formats (dematerialisation)[57]	Multiple screen viewings[58]
Recreation, leisure, hobbies	Ticket bookings, digital camera, photo editing apps, virtual volunteering	Substitute paper, substitute camera and films	
Health, fitness	Wearable, health and fitness apps, telehealth, online pharmacy	Encourage active travel, substituting travel to pharmacy/ surgery	Induce demand for new care devices[59]
Work (paid)	Teleworking	Teleworking - reduce commuting and office energy use[60]	Induce traveling (working from further, additional shopping trips);[61] increase domestic energy use[62]
Education, study, learning	Google classroom, massive online open course	Reduce commuting and educational institution energy use	
Retail (all categories inc. food & drink)	Meal delivery kits, online grocery, grocery subscription, e-retail, P2P sharing, food delivery apps, food waste app	Substitute personal travel to shops, optimise logistics;[63] reduce food and material waste	Add logistics on top of personal travel, increase returns, increase packaging;[64] targeted advertisements inducing consumption;[65] sharing retail platforms reducing waste
Managing home (all categories inc. energy)	Smart heating, smart energy, smart lighting, smart appliances, task platforms, robot vacuum, digital voice assistants	Increase efficiency of energy-intensive domestic activities; reduce or shifting energy demand	Induce demand for smart home techs for pleasure and comfort instead of energy management[66]
Travel	Shared mobility, ride-hailing, shared ride-hailing, mobility-as-a-service, navigation apps	Efficient route, reduced vehicle ownership[67]	Deadheading (ride-hailing cars driving without passengers), induced demand, reducing public transit ridership[68]

From the examples in Table 2, common themes emerge on how digital applications might support or undermine energy reduction efforts in all activity categories. Using digital innovations (e.g., smart heating or smart energy devices, navigation apps) or substituting energy- and material-intensive analogues (e.g., digital entertainment and media) can increase efficiency and result in energy demand reduction. Both mechanisms fundamentally require access to digital devices and infrastructure, trust in digital applications, and knowledge and skills to optimally use a technology. A study on people's perception of smart energy technologies in the UK found that support for these energy-efficiency technologies in residential contexts is constrained by lack of knowledge, health and safety concerns, privacy concerns, and concerns about losing control and autonomy.[69] Addressing these concerns can encourage uptake of low-carbon technologies and engaging in low-carbon behaviours.

Further, digitalisation can have indirect energy reduction benefits through facilitating low-carbon lifestyle changes. In many ways, digitalisation can support low-carbon opportunities such as increasing avenues to engage in climate action and reducing commuting, vehicle ownership, food or shopping waste. Participation in low-carbon lifestyles is also influenced by trust, social capital, and issues of digital inequality, as exemplified in the case of the sharing economy, constraining who gets to participate and receive the benefits of such lifestyles.[70]

At the same time, in any activity, digitalisation can undermine energy and GHG reduction efforts through rebound effects and induced consumption. These negative consequences arise when access to digital technologies and innovations is not complemented with sustainability considerations, and inadvertently increases consumption. For instance, online marketing uses algorithm-based targeting to promote consumption and exert control over content availability.

Table 3 provides estimates for digitalisation's potential impacts on energy demand for the most energy-relevant of the ten categories in Table 2. Of these, home energy management, mobility, and retail have relatively obvious energy implications, whereas other categories such as information and communication play a supporting role in determining digitalisation's energy impacts by enabling or inhibiting other energy-intensive activities.

53 Z. Shah, L. Wei, and U. Ghani, 'The Use of Social Networking Sites and Pro-Environmental Behaviors: A Mediation and Moderation Model', *Int. J. Environ. Res. Public Health*, 18 (2021).
54 I. Røpke and T. H. Christensen, 'Energy Impacts of ICT - Insights from an Everyday Life Perspective', *Telematics and Informatics*, 29, 4 (2012), 348–61.
55 Røpke and Christensen, 'Energy Impacts of ICT'.
56 R. Fouquet and R. Hippe, 'Twin Transitions of Decarbonisation and Digitalisation: A Historical Perspective on Energy and Information in European Economies', *Energy Research & Social Science*, 91 (2022).
57 Court and Sorrell, 'Digitalisation of Goods'.'
58 Y. Strengers et al., *Digital Energy Futures: Future Home Life* (Melbourne, Monash University, 2021).
59 Strengers et al., *Digital Energy Futures*, p. 8.
60 A. Hook et al., 'A Systematic Review of the Energy and Climate Impacts of Teleworking', *Environmental Research Letters*, 15 (2020).
61 Hook et al., 'Energy and Climate Impacts of Teleworking'.
62 Y. Shi, S. Sorrell, and T. Foxon, 'The Impact of Teleworking on Domestic Energy Use and Carbon Emissions: An Assessment for England', *Energy & Buildings*, 287 (2023).
63 H. B. Rai, S. Touami, and L. Dablanc, 'Not All E-Commerce Emits Equally: Systematic Quantitative Review of Online and Store Purchases' Carbon Footprint', *Environmental Science & Technology*, 57 (2023), 708–18.
64 Rai et al., 'Not All E-Commerce Emits Equally'.
65 Lange et al., 'The Induction Effect'.
66 Lange et al., 'The Induction Effect'; Strengers et al., *Digital Energy Futures*, p. 128.
67 Tirachini, 'Ride-Hailing, Travel Behaviour and Sustainable Mobility: An International Review', *Transportation*, 47 (2020); ITF, *ITF Transport Outlook 2019* (OECD Publishing, 2019).
68 Tirachini, 'Ride-Hailing, Travel Behaviour and Sustainable Mobility'; ITF, *ITF Transp. Outlook 2019*.
69 A. Spence et al., 'Dumber Energy at Home Please: Perceptions of Smart Energy Technologies are Dependent on Home, Workplace, or Policy Context in the United Kingdom', *Energy research & social science*, 75 (2021).
70 M. Z. Ferrari, 'Beyond Uncertainties in the Sharing Economy: Opportunities for Social Capital', *European Journal of Risk Regulation* 7, no. 4 (2016), 664–74; T. Eichhorn, S. Jürss, and C. P. Hoffmann. 'Dimensions of Digital Inequality in the Sharing Economy', *Information, Communication & Society*, 25 (2022).

Table 3. Quantitative estimates of digitalisation's indirect impacts on energy or carbon

Activity categories	Digital application	Impact ranges (ΔEnergy or ΔCarbon)	Sources
Entertainment, media	E-publications	ΔE -90% to +3000%	1
	E-news	ΔE -1400% to +550%	
	E-music	ΔE -87% to +235%	
Work	Teleworking	ΔE -15% to -0.01%	2
Travel	Ride-hailing	ΔE +41% to +90%	3
	Shared ride-hailing	ΔC -62% to -12.6%	4
	Mobility-as-a-Service	ΔE -50% to +20% ΔC -50% to +20%	5
	Autonomous vehicles	ΔE -45% to +60% ΔC -94% to +48%	6
Retail	E-retail	ΔC -94% to +140%	7
	P2P goods	ΔC -89% to +55%	8
Managing home	Home energy management systems	ΔEimp -91% to +9.1% ΔC -79%	9
	Smart heating (residential)	ΔE -36% to +2%	10
	Smart cooling (residential)	ΔE -7.7% to -7.6%	
	Smart lighting	ΔE -73.2% to -13.4%	11
	Smart home appliances and Internet of Things	ΔE -10% to -2.63%	12

Note: ΔE = % change in energy use; ΔC = % change in CO2 or CO2e; ΔEimp = % change in energy imported from the grid.
Sources are available in Appendix 2.

The extent to which people integrate digital applications into daily life depends partly on systemic preconditions and other enabling factors. Willingness to adopt applications that appear to require access to personal information depends on trust levels, both in the service providers and in governance structures. Fairness and accessibility determine who benefits from digitalised services and how wide the digital divide is. Control and agency play a part in determining to what degree people choose to integrate digital applications into their daily lives. These preconditions also shape usage patterns, which in turn determine the extent of digitalisation's beneficial or detrimental indirect impacts. The ranges in Table 3 represent a summary of the best available literature on the positive and negative indirect impacts of digitalisation in these domains. While some of these are from different geographies and at different scales and the net impact for the UK will depend upon patterns of deployment and the local energy mix and systemic conditions, these estimates still provide a useful heuristic to understand the ways in which digitalisation could play out.

In 2022, around 48% of the UK's net greenhouse gas (GHG) emissions (including from the use of fuels) were estimated to be from domestic transport and buildings and product uses.[71] This provides an idea of the scale of impact, positive or negative, that digitalisation could have in these areas.

In a scenario with high levels of digitalisation across these domains, facilitated by high levels of trust, control and agency, and fair access, and strong policy steering, there could be significant energy demand reductions stemming from digitalisation of daily life. This would also imply low levels of rebound behaviour, with material and energy consumption continuing at business as usual (or lower) levels rather than increasing substantially. Households might adopt a variety of energy management applications in the home, such as home energy management systems (HEMS) and smart heating, which could lower carbon emissions by 91% and 36% respectively. In such a scenario, households would increasingly rely on e-retail (grocery and other retail), which could optimise travel for shopping and consumption behaviour and lower emissions by 94% and 89% respectively. Mobility patterns would change, aided by shared ride-hailing services (62% reduction in carbon emissions) and a transition to a mobility-as-a-service system (50% reduction in carbon and energy). The proliferation of autonomous vehicles could facilitate transport decarbonisation (45% reduction in energy demand).

[71] UK Department for Energy Security & Net Zero, *2022 UK Greenhouse Gas Emissions, Final Figures*.

In a contrasting scenario that is detrimental for climate goals, the negative indirect impacts associated with digitalisation could outweigh the positive ones. Perceptions of being efficient with energy use could result in rebound behaviours, increasing energy demand in buildings (9% and 2% increases from the use of HEMS and smart heating). Overconsumption of goods stemming from the increased convenience of using e-retail could result in a 140% increase in carbon emissions. In the mobility domain, individual ride-hailing could overtake shared ride-hailing and result in a 41 – 90% increase in energy consumption. The proliferation of autonomous vehicles in such a scenario could lead to a 48% increase in carbon emissions compared to a business-as-usual case.

The net impacts of these digital applications deployed in tandem in these activity domains is yet to be determined. Some applications could work synergistically with one another, whereas others could have unintended trade-offs. This is a key research agenda point for future research.

In conclusion, digitalisation can either help or hinder energy reduction efforts depending on user behaviour and systemic preconditions of access, trust, and control and agency. Digitalisation could be a key enabler for driving demand-side decarbonisation, supporting consumers to adopt low-carbon lifestyles across mobility, retail and home management activities. Conversely, digital technologies, if not steered adequately, could equally result in overconsumption and induced new demand, hindering progress on emissions reductions. A good digital future needs to be low-carbon and energy-efficient, while not compromising on social wellbeing. To achieve this, the interaction effects of targeted climate policies and novel business models need to be harnessed through concerted efforts.[72]

Research and policy implications

This review has explored the good and bad scenarios of digitalisation for climate. The future of digitalisation will depend on how society engages with new technologies and innovations, yet a significant knowledge gap in this issue remains. This challenge calls for the following research agenda:

1. **Support and embed SHAPE research insights to understand environmental implications of digital engagements in various contexts, cultures, and communities.** SHAPE insights are fundamental to fully understanding how digitalisation interacts with different socio-cultural contexts and communities. The breadth of SHAPE perspectives, such as but not limited to psychology, sociology, anthropology, geography, ethics, energy sociology, and humanities, can bring to the forefront a transition to a sustainable and digitalised society that considers equity, fairness, justice, trust, and agency.
2. **Include indirect and systemic energy impacts of digitalisation in environmental assessment studies.** While digitalisation's direct energy impact is significant, its indirect and systemic energy impacts are likely larger in scale and magnitude, yet inadequately explored. SHAPE research insights can help tease out the mechanisms of indirect and systemic changes resulting from digitalisation and find ways to measure them through indicators of activity changes, consumption changes, or time use changes. SHAPE can also improve understanding on the relationships between societal preconditions and specific digital applications.
3. **Foster interdisciplinary research and collaboration within and between SHAPE and STEM.** A sociotechnical approach acknowledges the complex multidirectional interactions between technology and society. SHAPE and STEM bring unique expertise that can explore the interactions between technological affordances, technical algorithms, individual characteristics, and social dynamics.
4. **Build research on digitalisation as a cross-cutting transformation beyond application- or domain-specific studies.** Digitalisation is a sweeping transformation of practices and norms across all aspects of life, but a research gap remains on how changes in one activity may spill over to changes in another activity. Research should try to explore cross-cutting phenomena or synthesise growing research on specific applications or domains to identify interactions and comparisons.
5. **Encourage action- and policy-oriented research.** Research on the environmental impacts of digitalisation should consider practical implications that are relevant for digital practitioners and policymakers. Research findings from SHAPE can be translated into actionable recommendations to then shape digital policies.

In conjunction with developing research on the issue, there are proactive strategies that can be considered to steer digitalisation's future:

1. **Develop a standard measurement and reporting of energy consumption and GHG emissions from digitalisation's entire lifecycle.** Policymakers should work with researchers, businesses, and civil society to develop a measurement standard and reporting framework that captures energy consumption and GHG emissions of a technology or application's lifecycle (manufacturing, operating, use, disposal), including indirect and systemic effects from the use of the technology or application.[73] The government should also encourage businesses to report their environmental impacts.

[72] Sugiyama et al., 'High with Low: Harnessing the Power of Demand-Side Solutions for High Wellbeing with Low Energy and Material Demand', *Joule* 8, no. 1 (2024), 1–6.

[73] OECD, *Measuring the Environmental Impacts of AI Compute and Applications: The AI Footprint* (Paris, OECD, 2022); ITU, *Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors* (ITU, 2022).

2. **Embed environmental sustainability as a goal and principle in digital strategy.** A clear vision for a digital transition that upholds environmental sustainability principles is required. In alignment with OECD recommendations, climate change must be a central consideration in policies around technology development as well as innovation's lifecycle, including during the use phase.[74] This means emphasising sufficiency, repairability, circularity, and efficiency in the development and use of digital technologies and applications.

3. **Develop cross-sectoral digital transformation policy approach and coordination.** While much of the regulations for digital transformation will be under each sectoral regulator (e.g., transport, business and trade, buildings), development of an overarching policy and monitoring process helps address cross-sectoral risks and supports coherence across sectors.

4. **Manage rebound effects by promoting sustainable business models for consumers.** Innovative business models that serve climate goals should be prioritised. At the same time, the government can also take a more proactive role in limiting digital applications that operate counter to the common good, such as misusing data for surveillance and inducing consumption. Policymakers can introduce best practices that guide responsible business practices.

72 Global Partnership on AI, Climate Change AI, and The Centre for AI & Climate, *Climate Change and AI: Recommendations for Government Action* (GPAI, 2021).

References

Adedeji, Adekunle et al., 'Examining the Pathways from General Trust Through Social Connectedness to Subjective Wellbeing', *Applied Research in Quality of Life*, 18 (2023).

Bardhi, Fleura and Giana M. Eckhardt, 'Access-Based Consumption: The Case of Car Sharing', *Journal of Consumer Research*, 39, no. 4 (2012), 881–98.

Beaudoin, Christopher. 'Explaining the Relationship between Internet Use and Interpersonal Trust: Taking into Account Motivation and Information Overload', *Journal of Computer-Mediated Communication*, 13 (2008), 550-568.

Benkler, Yochai, 'Sharing Nicely: On Shareable Goods and the Emergence of Sharing as a Modality of Economic Production', *The Yale Law Journal*, 114, no. 2 (2004), 273.

Bieser, Jan C. T. and Lorenz M. Hilty, 'Assessing Indirect Environmental Effects of Information and Communication Technology (ICT): A Systematic Literature Review', *Sustainability*, 10 (2018).

Celata, Filippo, Cary Y. Hendrickson, and Venere S. Sanna, 'The Sharing Economy as Community Marketplace? Trust, Reciprocity and Belonging in Peer-to-Peer Accommodation Platforms', *Cambridge Journal of Regions, Economy and Society*, 10, 2 (2017), 349-63.

Copernicus Climate Change Service, 'Warmest January on Record, 12-Month Average over 1.5°C above Preindustrial', *Monthly Climate Bulletin*, February 9, 2024.

Court, Victor and Steven Sorrell, 'Digitalisation of Goods: A Systematic Review of the Determinants and Magnitude of the Impacts on Energy Consumption', *Environmental Research Letters*, 15, no. 4 (2020).

Creutzig, Felix et al., 'Demand-Side Solutions to Climate Change Mitigation Consistent with High Levels of Well-Being,' *Nature Climate Change* 12, no. 1 (2022), 36–46.

Creutzig, Felix et al., 'Demand, Services and Social Aspects of Mitigation', in *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. P.R. Shukla et al. (Cambridge, Cambridge University Press, 2022), 503–612.

Creutzig, Felix et al., 'Digitalization and the Anthropocene', *Annual Review of Environment and Resources*, 47 (2022), 479–509.

de Vries, Alex. 'The growing energy footprint of artificial intelligence', *Joule*, 7 (2023), 2191-2194.

Dimaggio, Paul et al., 'Social Implications of the Internet', *Annual Review of Sociology*, 207 (2001), 307–336.

Edelman Trust Institute, *2024 Edelman Trust Barometer Global Report*. (Edelman, 2024).

Eichhorn, Thomas, Sebastian Jürss, and Christian P. Hoffmann, ‘Dimensions of Digital Inequality in the Sharing Economy’, *Information, Communication & Society*, 25, no. 3, (2022), 395-412.

Faith, Becky, Kevin Hernandez, and James Beecher, *Digital poverty in the UK* (Institute of Development Studies, 2022).

Ferrari, Marianna Z, ‘Beyond Uncertainties in the Sharing Economy: Opportunities for Social Capital’, *European Journal of Risk Regulation*, 7, no. 4 (2016), 664–74.

Filipović, Sanja, Mirjana Radovanović, and Noam Lior, ‘What Does the Sharing Economy Mean for Electric Market Transitions? A Review with Sustainability Perspectives’, *Energy Research & Social Science*, 58 (2019).

Fouquet, Roger and Ralph Hippe, ‘Twin Transitions of Decarbonisation and Digitalisation: A Historical Perspective on Energy and Information in European Economies’, *Energy Research & Social Science*, 91 (2022).

Freitag, Charlotte et al., ‘The Real Climate and Transformative Impact of ICT: A Critique of Estimates, Trends, and Regulations’, *Patterns*, 2 (2021).

Frenken, Koen, ‘Political Economies and Environmental Futures for the Sharing Economy’, *Philosophical Transactions of the Royal Society* A, 375 (2017).

Frick, Vivian and Ellen Matthies, ‘Everything Is Just a Click Away. Online Shopping Efficiency and Consumption Levels in Three Consumption Domains’, *Sustainable Production and Consumption*, 23 (2020), 212-23.

Global Partnership on AI, Climate Change AI, and The Centre for AI & Climate, *Climate Change and AI: Recommendations for Government Action* (GPAI, 2021).

Heer, Jeffrey, ‘Agency plus Automation: Designing Artificial Intelligence into Interactive Systems’, *Proceedings of the National Academy of Sciences*, 116, no. 6 (2019), 1844-1850.

Hook, Andrew et al., ‘A Systematic Review of the Energy and Climate Impacts of Teleworking’, *Environmental Research Letters*, 15, no. 9 (2020).

Horner, Nathaniel C., Arman Shehabi, and Inês L. Azevedo, ‘Known Unknowns: Indirect Energy Effects of Information and Communication Technology’, *Environmental Research Letters*, 11, no. 10 (2016), 1–20.

International Telecommunication Union, *Enabling the Net Zero transition: Assessing how the use of information and communication technology solutions impact greenhouse gas emissions of other sectors* (ITU, 2022).

International Transport Forum, *ITF Transport Outlook 2019* (OECD Publishing, 2019).

Judge, Madeline et al., ‘Environmental Decision-Making in Times of Polarization’, *Annual Review of Environment and Resources*, 48 (2023), 477–503.

Kennedy, Helen, Thomas Poell, and Jose van Dijck, ‘Data and Agency’, *Big Data and Society*, 2, no. 2 (2015).

Kim, Harris Hyun Soo and Areum Shin, ‘Examining the Multilevel Associations between Psychological Wellbeing and Social Trust: A Primary Analysis of Survey Data’, *Journal of Community Psychology*, 49, no. 7 (2021), 2383–2402.

Koomey, Jonathan G., H. Scott Matthews, and Eric Williams, ‘Smart Everything: Will Intelligent Systems Reduce Resource Use?’, *Annual Review of Environment and Resources*, 38, no. 1 (2013), 311–43.

Lamberton, Cait Poynor and Randall L. Rose, ‘When Is Ours Better Than Mine? A Framework for Understanding and Altering Participation in Commercial Sharing Systems’, *Journal of Marketing*, 76, no. 4 (2012), 109–25.

Lange, Steffen et al., ‘The Induction Effect: Why the Rebound Effect Is Only Half the Story of Technology’s Failure to Achieve Sustainability’, *Frontiers in Sustainability*, 4 (2023).

Lange, Steffen et al., ‘The Jevons Paradox Unravelled: A Multi-Level Typology of Rebound Effects and Mechanisms’, *Energy Research & Social Science*, 74 (2021).

Martin, Chris J. ‘The Sharing Economy: A Pathway to Sustainability or a Nightmarish Form of Neoliberal Capitalism?’, *Ecological Economics*, 121 (2016), 149-59

McKinsey, *Disruptive technologies: Advances that will transform life, business, and the global economy*. (San Francisco, McKinsey Global Institute, 2013).

Meier, Leslie M. *Consumer Society and Ecological Crisis* (London, Routledge, 2023).

Namazu, Michiko and Hadi Dowlatabadi, ‘Characterizing the GHG Emission Impacts of Carsharing: A Case of Vancouver’, *Environmental Research Letters*, 10, no. 12 (2015).

OECD, *Measuring the Environmental Impacts of AI Compute and Applications: The AI Footprint* (Paris, OECD, 2022).

Ofcom, *Online Nation 2023* (Ofcom, 2023).

Office for National Statistics, *Review of the UK Measures of National Well-being*, October 2022 to March 2023 (Office for National Statistics, 2023).

Plepys, Andrius, ‘The Grey Side of ICT’, *Environmental Impact Assessment Review*, 22, no. 5 (2002), 509–23.

Rai, Heleen B., Sabrina Touami, and Laetitia Dablanc, ‘Not All E-Commerce Emits Equally: Systematic Quantitative Review of Online and Store Purchases’ Carbon Footprint’, *Environmental Science & Technology*, 57 (2023), 708–18.

Reisch, Lucia A, 'The Internet and Sustainable Consumption: Perspectives on a Janus Face', *Journal of Consumer Policy*, 24, no. 3–4 (2001), 251–86.

Røpke, Inge and Toke Haunstrup Christensen, 'Energy Impacts of ICT - Insights from an Everyday Life Perspective', *Telematics and Informatics*, 29, 4 (2012), 348–61.

Schuelke-Leech, Beth-Anne, 'A model for understanding the orders of magnitude of disruptive technologies', *Technological Forecasting and Social Change*, 129 (2018), 261-274.

Shah, Zakir, Lu Wei, and Usman Ghani, 'The Use of Social Networking Sites and Pro-Environmental Behaviors: A Mediation and Moderation Model', *Int. J. Environ. Res. Public Health*, 18 (2021).

Shi, Yao, Steve Sorrell, and Timothy Foxon, 'The Impact of Teleworking on Domestic Energy Use and Carbon Emissions: An Assessment for England', *Energy & Buildings*, 287 (2023).

Sorrell, Steven, *The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency* (UK Energy Research Centre, 2007).

Sovacool, Benjamin K. and Dylan D. Furszyfer Del Rio, 'Smart Home Technologies in Europe: A Critical Review of Concepts, Benefits, Risks and Policies', *Renewable and Sustainable Energy Reviews*, 120 (2020).

Sovacool, Benjamin K. et al., 'Decarbonization and Its Discontents: A Critical Energy Justice Perspective on Four Low-Carbon Transitions', *Climatic Change*, 155 (2019), 581-619.

Spence, Alexa et al., 'Dumber Energy at Home Please: Perceptions of Smart Energy Technologies are Dependent on Home, Workplace, or Policy Context in the United Kingdom', *Energy Research & Social Science*, 75 (2021).

Strengers, Yolanda et al., 'Pursuing Pleasance: Interrogating Energy-Intensive Visions for the Smart Home', *International Journal of Human-Computer Studies*, 136 (2020).

Strengers, Yolanda et al., *Digital Energy Futures: Future Home Life* (Melbourne, Monash University, 2021).

Sugiyama, Masahiro et al., 'High with Low: Harnessing the Power of Demand-Side Solutions for High Wellbeing with Low Energy and Material Demand', *Joule 8*, no. 1 (2024), 1–6.

Tirachini, Alejandro, 'Ride-Hailing, Travel Behaviour and Sustainable Mobility: An International Review', *Transportation,* 47 (2020).

UK Department for Energy Security & Net Zero, *2022 UK Greenhouse Gas Emissions, Final Figures*. (Department of Energy Security & Net Zero, 2024).

Vaishnav, Parth 'Implications of Green Technologies for Environmental Justice', *Annual Review of Environment and Resources*, 48 (2023), 505–30.

Van Dijk, Jan A. G. M, 'Digital Divide: Impact of Access', *The International Encyclopedia of Media Effects* (John Wiley & Sons, Inc., 2017).

Vrain, Emilie et al., 'Social Influence in the Adoption of Digital Consumer Innovations for Climate Change', *Energy Policy*, 162 (2022).

Wagner, Ben, 'Liable, but Not in Control? Ensuring Meaningful Human Agency in Automated Decision-Making Systems', *Policy & Internet*, 11, no. 1 (2019).

Wamsler, Christine et al., 'Meaning-Making in a Context of Climate Change: Supporting Agency and Political Engagement', *Climate Policy*, 23, 7 (2023), 829-44.

Warde, Alan, 'The Sociology of Consumption: Its Recent Development', *Annual Review of Sociology*, 41 (2015), 117-134.

WBGU - *German Advisory Council on Global Change, Towards Our Common Digital Future* (Berlin, WBGU, 2019).

World Economic Forum, *Future of Jobs Report 2023* (Geneva, World Economic Forum, 2023).

Zhang, Jiaping and Xiaomei Gong, 'From Clicks to Change: The Role of Internet Use in Fostering Environmental Sustainability', *Journal of Environmental Management*, 348 (2023).

Zuboff, Shoshana, *The Age of Surveillance Capitalism: The Fight for a Human Future at the New Frontier of Power* (Profile Books, 2019).

Appendix 1. Detailed activity categorisation

Activity categories – social science perspectives		
Energy Sociology (Ropke & Christensen, 2012)	Office of National Statistics - expenditure	Office of National Statistics - time use
Communication; Entertainment; Information; Purchase and sale; Work at home; Education; Hobbies and volunteer work; Administration and finances; Domestic work and management of the dwelling; Health	Food & non-alcoholic drinks; Alcoholic drinks, tobacco, & narcotics; Clothing & footwear; Housing (net), fuel & power; Household goods & services; Health; Transport; Communication; Recreation & culture; Education; Restaurants & hotels; Miscellaneous goods & services	Travelling and transport; Working not from home; Working from home; Study Keep fit; Unpaid childcare; Gardening and DIY; Unpaid household work (excluding travel and childcare); Sleep and rest; Personal care (including eating and drinking); Entertainment, socialising, and other free time; Other
Activity categories – digital perspectives		
ICT service by end-use (Court & Sorrell, 2020)	App store	Internet use (Blank & Groselj, 2014)
E-learning; E-retail; E-government; E-health E-sharing; E-press/books E-music/movies; E-games; Teleworking; Video conferencing; Smart production; Smart transport and logistics; Smart energy; Smart buildings; Cybersecurity	Games; Business; Education; Utilities; Lifestyle; Food & Drink; Shopping; Health & Fitness; Productivity; Finance; Entertainment; Travel; Medical; Sports; Social Networking; Music; News; Photo & Video; Reference; Navigation; Books; Weather; Magazines & Newspapers; Developer Tools; Graphics & Design; Kids + Stickers	Entertainment; Commerce; Information seeking; Socialising; Email; Blogging; Production (creating content); Classic mass media; School/work; Vice

Activity categories – energy perspective
Energy end-uses and efficiency indicators (International Energy Agency, 2023)
Residential (cooking, lighting, residential appliances, space cooling, space heating, water heating); passenger transport; services; industry; freight transport;

Appendix 2. Sources for quantitative estimate of digitalisation's indirect impacts on energy or carbon

1 **Entertainment and media:** Court et al., 'Dematerialisation and Sharing of Goods'.

2 **Work:** Hook et al., 'Energy and Climate Impacts of Teleworking'.

3 **Ride-hailing:** Tirachini, 'Ride-hailing, travel behaviour, and sustainable mobility'; G. D. Erhardt et al., 'Do transportation network companies decrease or increase congestion?' *Science Advances*, 5, no. 5 (2019); J. W. Ward et al., 'Effects of on-demand ride sourcing on vehicle ownership, fuel consumption, vehicle miles traveled, and emissions per capita in U.S. states', *Transportation Research Part C: Emerging Technologies*, 108 (2019), 289–301; A. Henao and W. E. Marshall, "'The impact of ride-hailing on vehicle miles traveled', *Transportation*, 46, no. 6 (2019), 2173–2194; Y. Crozet, G. Santos, and J. Coldefy, *Shared mobility and MaaS: The regulatory challenges of urban mobility* (Centre on Regulation in Europe CERRE, 2019).

4 **Shared ride-hailing:** ITF, *Transport outlook 2019; ITF, Transition to shared mobility: How large cities can deliver inclusive transport services* (ITF, 2017); ITF, *Shared mobility: Innovation for liveable cities* (ITF, 2016); C. Wilson, L. Kerr, F. Sprei, E. Vrain, and M. Wilson, 'Potential climate benefits of digital consumer innovations', *Annual Review of Environment and Resources*, 45 (2022), 113–144.

5 **Mobility-as-a-Service:** M. Karlsson et al., *MaaSiFiE: Impact Assessment* (Conference of European Directors of Road, 2017); R. Ceccato et al., 'MaaS Adoption and Sustainability for Systematic Trips: Estimation of Environmental Impacts in a Medium-Sized City', *Sustainability*, 15, no. 11 (2023); P. Labee, S. Rasouli, and F. Liao, 'The implications of Mobility as a Service for urban emissions', *Transportation Research Part D: Transport and Environment*, 102 (2022); X. Zhao, C. Andruetto, B. Vaddadi, and A. Pernestål, "Potential values of maas impacts in future scenarios," Journal of Urban Mobility, 1 (2021); D. A. Hensher, C. Q. Ho, and D. J. Reck, 'Mobility as a service and private car use: Evidence from the Sydney MaaS trial', *Transportation Research Part A: Policy and Practice*, 145 (2021), 17-33; M. Noussan and S. Tagliapietra, 'The effect of digitalization in the energy consumption of passenger transport: An analysis of future scenarios for Europe', *Journal of Cleaner Production*, 258 (2020).

6 **Autonomous vehicles:** O. Silva, R. Cordera, E. González-González, and S. Nogués, 'Environmental impacts of autonomous vehicles: A review of the scientific literature', *Science of The Total Environment*, 830 (2022; P. Kopelias, E. Demiridi, K. Vogiatzis, A. Skabardonis, and V. Zafiropoulou, 'Connected & autonomous vehicles – Environmental impacts – A review', *Science of The Total Environment*, 712 (2020); Z. Wadud, D. MacKenzie, and P. Leiby, 'Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles', *Transportation Research Part A: Policy and Practice*, 86 (2016), 1–18; Y.Chen, S.Young, X. Qi, and J. Gonder, 'Estimate of fuel consumption and GHG emission impact from an automated mobility district', in 2015 International Conference on Connected Vehicles and Expo (ICCVE) (Shenzhen, China, IEEE, 2015) , pp. 271–278; Y. Chen, J. Gonder, S. Young, and E. Wood, 'Quantifying autonomous vehicles national fuel consumption impacts: A data-rich approach', *Transportation Research Part A: Policy and Practice,* 122 (2019), 134– 145; J. H. Gawron, G. A. Keoleian, R. D. De Kleine, T. J. Wallington, and H. C. Kim, 'Life Cycle Assessment of Connected and Automated Vehicles: Sensing and Computing Subsystem and Vehicle Level Effects', *Environmental Science & Technology*, 52, no. 5 (2018), 3249–3256; C. Stogios, D. Kasraian, M. J. Roorda, and M. Hatzopoulou, 'Simulating impacts of automated driving behavior and traffic conditions on vehicle emissions', *Transportation Research Part D: Transport and Environment*, 76 (2019), 176–192.

7 **E-retail:** Rai et al., 'Not all e-commerce emits equally'.

8 **P2P goods:** A. Fremstad, 'Does Craigslist Reduce Waste? Evidence from California and Florida', *Ecological Economics*, 132 (2017), 135–143; R. Koide, S. Murakami, and K. Nansai, 'Prioritising low-risk and high-potential circular economy strategies for decarbonisation: A meta-analysis on consumer-oriented product-service systems', *Renewable and Sustainable Energy Reviews*, 155 (2022); E. Johnson and A. Plepys, 'Product-service systems and sustainability: Analysing the environmental impacts of rental clothing', *Sustainability*, 13, no. 4 (2021), 1–30; F. H. Abanda and L. Byers, 'An investigation of the impact of building orientation on energy consumption in a domestic building using emerging BIM (Building Information Modelling)', Energy, 97 (2016), 517–527; M. Martin, D. Lazarevic, and C. Gullström, 'Assessing the environmental potential of collaborative consumption: Peer-to-peer product sharing in Hammarby Sjöstad, Sweden," *Sustainability*, 11, no. 1 (2019).

9 **Home energy management systems:** C.O. Adika and L. Wang, 'Smart charging and appliance scheduling approaches to demand side management', *International Journal of Electrical Power and Energy Systems*, 57 (2014) 232-240; F. Al Faris, A. Juaidi, and F. Manzano-Agugliaro, 'Intelligent homes' technologies to optimize the energy performance for the net zero energy home', *Energy and Buildings* (2017), 262-274; S. Barja-Martinez et al., 'A Novel Hybrid Home Energy Management System Considering Electricity Cost and Greenhouse Gas Emissions Minimization', *IEEE Transactions on Industry Applications*, 57, 3 (2021), 2782-2790; M. Beaudin and H. Zareipour, 'Home energy management systems: A review of modelling and complexity', *Renewable and Sustainable Energy Reviews* (2015) 318-335; M.C. Bozchalui

et al., 'Optimal operation of residential energy hubs in smart grids', *IEEE Transactions on Smart Grid*, 3, 4 (2012), 1755-1766; A. C. Duman et al., 'A home energy management system with an integrated smart thermostat for demand response in smart grids', *Sustainable Cities and Society*, 65 (2021); M. Ilic, J. W. Black, and J. L. Watz, 'Potential Benefits of Implementing Load Control', *IEEE Power Engineering Society Winter Meeting Conference Proceedings*, 1 (2002), 177-182; X. Jin et al., 'Foresee: A user-centric home energy management system for energy efficiency and demand response', *Applied Energy*, 205 (2017), 1583-1595; N. Li, L. Chen, and S. H. Low, 'Optimal Demand Response Based on Utility Maximization in Power Networks', *2011 IEEE Power and Energy Society General Meeting* (2011); J. N. Louis, A. Caló, and E. Pongrácz, 'Smart Houses for Energy Efficiency and Carbon Dioxide Emission Reduction', ENERGY 2014 (2014); A. Majdi et al., 'A smart building with integrated energy management: Steps toward the creation of a smart city', *Sustainable Energy Technologies and Assessments*, 53 (2022); P. Munankarmi et al., 'Community-scale interaction of energy efficiency and demand flexibility in residential buildings', *Applied Energy*, 298 (2021); A. Nilsson et al., 'Smart homes, home energy management systems and real-time feedback: Lessons for influencing household energy consumption from a Swedish field study', *Energy and Buildings*, 179 (2018), 15-25; J. V. Paatero and P. D. Lund, 'A model for generating household electricity load profiles', *International Journal of Energy Research*, 30, 5 (2006), 273-290; Z. Rahimpour, G. Verbič, and A.C. Chapman, 'Can phase change materials in building insulation improve self-consumption of residential rooftop solar? An Australian case study', *Renewable Energy*, 192 (2022), 24-34.

10 **Smart heating and cooling:** I. Khajenasiri et al,. 'A Review on Internet of Things Solutions for Intelligent Energy Control in Buildings for Smart City Applications', *Energy Procedia* (2017); X. J. Lin et al., 'A review of the transformation from urban centralized heating system to integrated energy system in smart city', *Applied Thermal Engineering*, 240 (2024); F. Lu et al., 'Cooling system energy flexibility of a nearly zero-energy office building using building thermal mass: Potential evaluation and parametric analysis', *Energy and Buildings*, 236 (2021); T. Park et al., *Evaluating the Nest Learning Thermostat* (The Behavioural Insights Team, 2017); J. Pohl et al., 'Environmental saving potentials of a smart home system from a life cycle perspective: How green is the smart home?', *Journal of Cleaner Production*, 312 (2021); J. Pohl et al., 'Assessing the environmental performance of ICT-based services: Does user behaviour make all the difference?', *Sustainable Production and Consumption*, 31 (2022), 828-838; M. Ringel, R. Laidi, and D. Djenouri, 'Multiple benefits through smart home energy management solutions—a simulation-based case study of a single-family-house in Algeria and Germany', *Energies*, 12, 8 (2019); M. L. Rodríguez-Pertuz et al., 'Feasibility of zonal space heating controls in residential buildings in temperate climates: Energy and economic potentials in Spain', *Energy & Buildings*, 218 (2020); Y. Zhou, 'Demand response flexibility with synergies on passive PCM walls, BIPVs, and active air-conditioning system in a subtropical climate', *Renewable Energy*, 199 (2022), 204-225.

11 **Smart lighting:** J. Byun et al., 'Intelligent Household LED Lighting System Considering Energy Efficiency and User Satisfaction', *IEEE Transactions on Consumer Electronics* (2013); I. Chew et al., 'Smart lighting: The way forward? Reviewing the past to shape the future', *Energy and Buildings*, 149 (2017), 180-191; S. P. Galindo, D. Borge-Diez, and D. Icaza, 'Novel control system applied in the modernization of public lighting systems in heritage cities: Case study of the City of Cuenca', *Energy Reports*, 8 (2022); J. Higuera et al., 'Smart lighting system ISO/IEC/IEEE 21451 compatible', *IEEE Sensors Journal*, 15, 5 (2015), 2595-2602; R. Laidi, D. Djenouri, and M. Ringel, 'Commercial Technologies for Advanced Light Control in Smart Building Energy Management Systems: A Comparative Study', *Energy and Power Engineering*, 11, 8 (2019), 283-302; N. H. Moadab et al., 'Smart versus conventional lighting in apartments-Electric lighting energy consumption simulation for three different households', *Energy and Buildings*, 244 (2021); Z. Nagy et al., 'Occupant centered lighting control for comfort and energy efficient building operation', *Energy and Buildings*, 94 (2015), 100-108; K. R. Wagiman et al., 'Lighting system control techniques in commercial buildings: Current trends and future directions', *Journal of Building Engineering*, 31, (2020).

12 **Smart home appliances and Internet of Things:** B. Fong et al., 'Optimization of Power Usage in a Smart Nursing Home Environment', *IEEE Transactions on Industry Applications*, 59, 1 (2023), 38-46; H. Ismail, I. Jahwar, and B. Hammoud, 'Internet-of-Things-Based Smart-Home Time-Priority-Cost (TPC)-Aware Energy Management System for Energy Cost Reduction', *IEEE Sensors Letters*, 7, 9 (2023).

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