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Drivers and effects of digitalisation on energy demand in low carbon scenarios

Noam Bergman, Tim Foxon

Abstract

The world is currently facing two socio-technical transitions: shifting to a low-carbon society, and a digital revolution. Despite some claims to the contrary, evidence suggests that spread and adoption of ICT does not automatically lead to reduction in energy demand, if this stimulates new energy-using practices or wider economic growth. Despite this policy challenge, the two transitions are often considered separately.

This study examines potential drivers of reductions or increases in energy demand due to digitalisation identified in recent leading global and UK net zero transitions scenarios. These include direct effects, indirect and rebound effects relating to home energy use and transport, and effects on economic growth.

The scenarios are first analysed in relation to how they are situated in relation to different framing assumptions: (1) the relative focus on decarbonising energy supply or managing energy demand; (2) a focus on green growth or shifting to a focus on wellbeing (or even degrowth); (3) the extent to which they assume dominant business models led by large ICT firms, or alternative business models which empower communities and users; and (4) the extent to which they envisage key roles for ICT in relation to automation for optimising energy supply and demand or for empowering agency of users.

Specific direct, indirect and economic growth effects of digitalisation on energy demand are then identified, which reflect these and other projections in the scenarios. These imply that the future pathways adopted for digitalisation will have a significant impact on future energy demand and hence on the feasibility and acceptability of achieving net zero goals.

This suggests opportunities for further research and improving policy interactions between these two transitions, and stimulating greater public debate on the different framings for an ICT-driven low carbon transition.

keywords: digital, energy demand, low carbon targets, long-term scenarios

1 Introduction

The world is currently facing two socio-technical transitions: shifting to a low-carbon society, and a digital revolution. Despite some claims to the contrary, evidence suggests that spread and adoption of ICT does not automatically lead to reduction in energy demand, if this stimulates new energy-using practices or wider economic growth [e.g., 1]. Despite this policy challenge, we find that the two transitions are often considered separately.

In this paper, we report from ongoing work investigating a number of climate-focused (and sustainability-focused) transition scenarios, global, Europe and UK-specific, to examine the role of digitalisation in these scenarios. This is part of work under the Digital Society theme of the UK Centre for Research on Energy Demand Solutions (CREDS) examining how the adoption of information and communications technologies (ICTs) and associated business models and user practices could affect energy demand, as part of the transition to a net zero carbon economy.

Our review of key low-carbon transition scenarios starts out by looking at the relations between the two transitions in different scenarios, including their drivers, and how they portray people and technology. We then take a two-pronged approach to linking the two transitions. First, we investigate the extent to which scenarios for a net zero carbon transition incorporate aspects of the digital transformation, in relation to four aspects of framing: *Supply and demand; economic growth and wellbeing; business models and ownership;* and *agency/automation*. Second, we consider the effects of digitalisation on energy demand following three of the four effects listed in Lange et al [1]: direct effects, indirect effects and rebound – in home energy use and transport; and effects on economic growth.

We find that low-carbon transition scenarios vary in their level of engagement with the digital revolution and the level of interaction between the two transitions. The scenarios include many different, and often implicit, assumptions both about technology and about behaviour and social change in relation to technology, energy and climate change. In agreement with other research, we find that the role of energy demand is often understated or overly simplistic in future scenarios.. This suggests opportunities for improving policy interactions between these two transitions, and stimulating greater public debate on the different framings for an ICT-driven low carbon transition, and including more work on demand-side policy in scenarios.

2 Methods and data

The study is an iterative process, attempting to capture the framings and assumptions underlying different studies of low-carbon transition scenarios, and if and how they relate this transition to the 'digital revolution'. In our initial analysis, we consider the drivers of change and the relation between the two transitions in different scenarios, considering the roles of people and technology. Second, we give an interpretive analysis of each study in relation to four framing assumptions, as a demonstrable way of differentiating assumptions in different scenarios and pathways. Third, we use the framework of Lange et al. [1] for investigating effects of digitalization on energy demand, alongside the areas in which digitalisation might impact energy demand, following Lange and Santarius [2].

2.1 *Core framings of scenarios*

We describe four dimensions that assist us in characterising studies and scenarios in terms of their underlying assumptions and relation to the digital revolution. The first two speak to central debates about decarbonising the energy system: focusing on energy supply or demand; and the tensions between economic growth and emissions reduction. The latter two suggest different pathways for digitalisation: domination of large businesses or a shift to other business models; and a focus on user agency or automation. The positioning of each study is interpretive, based on textual analysis of the documents (detail in Appendix 1). It is semi-quantitative, approximating the position of each scenario relative to other scenarios.

2.1.1 **Supply and demand**

Until recently, the focus of much of climate change mitigation research has been on supply-side solutions, primarily technological solutions, and even IPCC assessment reports prior to the 6th "emphasized improved end-use efficiency but provided little insight into the nature, scale, implementation and implications of demand-side solutions, and ignored associated changes in lifestyles, social norms and well-being" [3]. More attention to such demand-side solutions is now becoming more mainstream [4].

Supply side narratives focus on decarbonising supply, most commonly through renewable energy and electrification. Demand side narratives consider energy efficiency measures and low-carbon technology, but also changes to behaviour, culture, planning and infrastructure, which enable lower energy and emissions lifestyles.

2.1.2 Economic growth and wellbeing

Green growth has a range of definitions, but it is firmly based in the ecological modernisation paradigm, which asserts that economic growth and environmental sustainability are not mutually exclusive (e.g., see discussion in [5]). Greenhouse gas emissions are often seen as a proxy for (environmental) sustainability, and so green growth narratives focus on economic growth that is accompanied by reduced emissions, ignoring broader issues of environmental and social sustainability. In these narratives, the tension between growth and emissions reduction is not addressed or considered easily resolvable, with growth presumed to provide quality of life and well-being. Other narratives consider human (and natural) wellbeing alongside economic growth, and some, such as degrowth, question the possibility of decoupling economic growth from resource in general, and specifically a decoupling from greenhouse gas emissions rapid enough to meet climate change targets [e.g., 6]. They argue that economic growth does not deliver societal benefit beyond a certain point, questioning whether it is the right model for developed economies [7]. A recent paper [8] critiques the IPCC's lack of degrowth scenarios, "where economic output declines due to stringent climate mitigation" (p 1), suggesting a growing acceptance of this perspective.

2.1.3 Business models and ownership

This draws on work such as Lange & Santarius [2], who discuss how benefits from digitalisation are distributed in a highly inequitable manner. Kawalek [9] describes the power of the digital world as the ICT industry and its involvement are in every sector, going from backroom service to a powerful source of social spectacle – the most valuable brands – 'superstar firms' and culture of billionaires, increasing inequality in wealth distribution. Kawalek describes how we are looking at a winner-takes-all oligopolistic future as ICT expands to healthcare, the automotive sector and more.

Lange & Santarius argue there is a need to shift to ensure digitalisation aligns with the common good as a guiding principal. A policy framework would be required "to ensure equitable distribution of employment, income and power" (p 116). This includes suggestions to strengthen platform cooperatives, ensure access to critical digital education, and more. Similarly, Kawalek offers the 'left' solution of public ownership of digital infrastructure: "Digital technology and renewables should be used to make life cheaper e.g. lower costs of transport through autonomous vehicles, lower energy costs through solar etc. Public ownership of technology ensures benefits are distributed and hours at work are reduced."

Hence, we distinguish between narratives in which a dominant business model sees large ICT firms, making technology-based changes, profiting from user data sales and other benefits as digitalisation and ICT penetrate more sectors of the economy, and narratives which feature more localised ICT, a digital commons, and social and environmental aspects in addition to the technology.

2.1.4 Automation or Agency

This reasoning for this axis draws partly on the smart homes literature, which finds two opposing narratives regarding control [10]: in one, informing and empowering consumers helps them make better 'energy choices', e.g., government documents suggest smart technologies offer consumers more control over energy use, in turn helping to lower bills [11,12]. In the other, smart technologies to act with minimum consumer participation, as they would work better by 'circumventing' users to optimise energy use. This dichotomous representation has been criticised in the context of domestic smart homes technologies (SHTs): the first presents an informed consumer as an unrealistic automaton [13], while trials suggest users limit themselves to the more basic functions of SHTs [10,14]; the second implies an indifferent consumer, leaving no room for an engaged citizen; this approach could miss opportunities for domestic energy savings through demand side management [13]. Unlike this dichotomy, the *agency* end of our access is the engaged citizen. The Grubler et al. [4] narrative of user-led change through new functionalities of digital technologies and services is an example of an agency-led narrative.

So, we distinguish between narratives in which automation circumvents users by algorithm and technical efficiency, minimising user interaction or behaviour change beyond 'uptake' of new technologies and systems, and narratives in which technology is an enabler, giving users more information and control, combining behaviour change with best use of technology and giving agency to users / prosumers.

2.2 *Digitalisation and energy demand*

In constructing our analytical framework to consider digitalisation and energy demand, we start with Lange and Santarius [2], who identify five areas where digitalisation could contribute to reducing energy demand and/or carbon emissions:

1. E-materialisation: replacing physical products with electronic / digital delivery of services

2. Enabling a stable, decentralised, renewable energy supply

3. Promoting more sustainable consumption patterns, e.g., giving access to information about products and services, enabling prosuming and sharing economy models

4. Reducing transport needs through teleworking and optimisation through digitalisation of shared mobility, public transport and logistics networks

5. 'Industry 4.0': digitalisation of production processes boosting material and energy efficiency.

However, they note, that in each of these areas, direct and indirect (rebound effects) drivers of increases in levels of end-use consumption could reduce or negate the potential energy savings. In this project, we will focus particularly on demand-side areas 1, 3 and 4 above.

We also draw on Lange et al. [1], who set out an analytical framework for investigating four effects of digitalization on energy demand, including a methodology for quantifying change:

Effect 1: Energy consumption of ICT sector: growth of share of ICT in overall GDP, mitigated by energy efficiency improvements in delivery of ICT services

Effect 2: Energy efficiency and rebound effects: extent to which application of ICT improves energy efficiency of the rest of the economy, and leads to rebound effects in increasing service demands

Effect 3: Impact of digitalization on overall economic growth: impacts of increasing use of ICT on economic growth, in relation to labour productivity, income inequality and energy consumption

Effect 4: Sectoral change: share of ICT services in overall ICT sector and GDP.

As we don't have an economic model, we are interested in analysing trends in these effects and their interactions, in relation to (i) current trends of digitalization of the economy, (ii) alternative visions of plausible or desirable futures. These will be assessed in relation to impacts on energy consumption, economic growth (as measured by GDP), income inequality and time spent on non-consumption activities.

Considering our interest in the areas where digitalisation could reduce energy demand, we can detail the four potential effects within our interests as follows:

I. Direct effects include growth in number of ICT devices, use of devices, streaming and cloud services, and on the other hand increasing efficiency of individual devices, streaming and data/cloud services. We can group these together as one area.

II. Efficiency and rebound effects includes: It is useful for us here to consider different sectors and services, here such as: renewables and electricity grid; efficiency in transport; demateralisation of services; consumption patterns, rebound effects and other behaviours.

III. Economic growth including labour productivity, inequality, decoupling and its limits.

IV. Sectoral change – we found limited discussion of sectoral economic shifts, so we do not discuss this effect.

Note: it is useful for us to look at transport as a whole, considering both digital impacts increasing transport efficiency, and digital services reducing the need for transport. Likewise, it could be useful to group changes to consumption patterns, behaviour and (individual) rebound effects together.

Our initial analytical framework will consist of the above four potential effects of digitalisation on energy demand. The evolving framework will partly be decided by what we find in the scenarios.

2.3 *Selection of scenarios for analysis*

We do not attempt an exhaustive or even representative list of scenarios for analysis. Rather, we looked at several recent papers and reports looking at transitions to low-carbon societies, either at the UK / Britain level, or globally. We selected ten documents for our initial analysis, which are either high-profile, or of interest because of their different approaches. Our aim was to interrogate how different perspectives and assumptions towards the low-carbon transition, with different relations towards the digital revolution, can lead to a variety of pathways with different implications for energy demand. Making explicit the assumptions and drivers underlying the different pathways can contribute to assessing the feasibility and desirability of different scenarios. We include two scenarios that focus on digital futures, but include emissions and other environmental concerns.

The selected scenarios are detailed in Table 1.

Shorthand	*Title*, organisation or project, year	Area	Focus	Scenarios
CCC	*The Sixth Carbon Budget: The UK's Path to Net Zero*, Committee on Climate Change 2020 [15]	UK	Net Zero emissions by 2050	Central scenario and four exploratory scenarios
RSOC	*Digital Technology and the Planet: Harnessing Computing to Achieve Net Zero*, The Royal Society 2020 [16]		Net Zero – challenges for digital technologies	-
CAT	*Zero Carbon Britain: Rising to the Climate Emergency*, Centre for Alternative Technology (CAT), 2019 [17]		Zero carbon UK by 2030	Single scenario
CREDS	*The Role of Energy Demand Reduction in Achieving Net-Zero in the UK*, CREDS 2021 [18]		Net Zero emissions by 2050 – role of energy demand	Four scenarios by level of ambition
CDBB	*Four Futures, One Choice: Options for the Digital Built Britain of 2040*, Centre for Digital Built Britain (CDBB) 2021 [19,20]	Great Britain	Built environment in 2040 (including 1.5°C target)	Four scenarios (2X2); qualitative
NATGRID	*Future Energy Scenarios*, National Grid 2020 [21]		Net Zero emissions by 2050	Four scenarios (2X2)
INHERIT	*Reaching the 'Triple-Win', Four Future Scenarios of a Healthier, More Equitable and Sustainable Europe in 2040*, INHERIT project, 2018 [22]	EU	Triple Win (health, equality, sustainability)	Four scenarios (2X2); qualitative
BÖLL	*A Societal Transformation Scenario for Staying below 1.5°C*, Heinrich Böll Foundation, 2020 [23] –	Global	Staying below 1.5°C through societal transformation	Single Scenario
GRUBLER	*A Low Energy Demand Scenario for Meeting the 1.5°C Target and Sustainable Development Goals without Negative Emission Technologies*, paper by Grubler et al., 2018 [4]		Staying below 1.5°C through low energy demand	Single scenario
SMARTER	#SMARTer2030: ICT Solutions for 21st Century Challenges [24] – *GeSI and Accenture Strategy*		ICT solutions for emissions (and other challenges)	Technological (or socio-technical) potential

Table 1 The ten selected reports, our shorthand notation, their geographical area, focus and scenarios.

3 Relations, drivers and influences in the scenarios

Our first analysis is to look at how different scenarios consider the relation between the two transitions, and consider how their drivers of change relate to these transitions.

3.1 *Relation between the transitions*

The scenarios show a variety of perspectives and approaches to the relation between the low-carbon transition and the digital revolution. CAT [17] doesn't consider the digital transition beyond grid balancing, and BÖLL [23] focuses on societal change over technological solutions. The rest of the scenarios recognise the importance of digitalisation to some extent. Both CCC [15] and NATGRID [21] see digital technology as having an important role in the transition to and maintenance of a complex zero-carbon economy, although both offer limited detail. CREDS [18] includes digitalisation as one of the high-level trends enabling reductions in energy demand, including through improving transport logistics and mobility services and smart systems and services in buildings.

Several narratives highlight changes already evident, and greater future changes to everyday life, from the digitalisation of society. They all engage with the relation between the two transitions, although from different perspectives. INHERIT [22] and CDBB [20] both envision future societies that are highly digitalised and interconnected, and both show different levels of success in reducing energy or emissions in different scenarios. RSOC [16] highlights that policy is central in creating the conditions for digitalisation to catalyse a low carbon transition, recognising that ICT could potentially increase emissions. SMARTER [24] also suggests a role for policy, but focuses on how ICT can ensure economic growth under policy constrained emissions. Finally, GRUBLER [4] sees user-led change and consumer demand as the enabler of rapid uptake and pervasive digitalisation, in turn enabling optimisation and dematerialisation leading to emission reduction.

3.2 *Drivers and causation*

The assumed drivers and directions of causation in a low-carbon transition vary from scenario to scenario. CCC [15] suggests a transition driven by policy-led change, with government action and both public and private investment in low-carbon technologies. The spread of low-carbon electricity generation precedes electrification of transport and heating. RSOC [16] highlights the disruptive nature of digitalisation, and the need for policy and investment to ensure ICT expansion leads to more sustainable outcomes. NATGRID [21] suggests greater societal engagement, as well as policy action, can lead to faster decarbonisation.

BÖLL [23] suggests societal transformation reducing demand and increasing wellbeing is feasible; the difficulty is envisioning broader transformation. In complete contrast, the SMARTER [24] highlights the potential of ICT to save energy and increase wellbeing, with people as 'consumer power' driving change alongside policy. CAT [17] sits somewhere in between, maximising use of current, not future, technology, accompanied by societal change; the change is motivated by near future climate impacts galvanising support for collective action.

INHERIT [22] has different driving forces in different scenarios – business, government, local government, and government-business-citizens. Technology plays a bigger role in scenarios where the private sector is the driving force. CDBB [20] has two scenarios in which the 1.5°C is met; in both, government and industry decisions to focus on environmental and social value, including reducing greenhouse gas emissions, play a key role in the transition, alongside digitalisation. GRUBLER [4] stands apart in affording great change coming from people seeking better quality of life, and better digital products and services as part of them.

All in all, we see that policy, technology, societal change and bottom-up demand – not necessarily climate related – are all seen as possible, and inter-related, drivers for change.

3.2.1 **People**

The role of people, as citizens, activists, users and consumers, is central to scenarios. One way to look at people's role in the context of new digital technologies is to consider *new functionalities*, new practices that co-evolve between user and producer [25], as an emerging trend. In the context of a simulation or scenario, this requires behavioural shift – drivers that move users towards a new 'practice space' [26].

GRUBLER sees people as the driver of new functionalities through a search for a better quality of life. This suggests a high level of consumer empowerment. It's worth considering if this is plausible under current business models, where the trend is towards a few large companies controlling much of our digital world. Other scenarios include new functionalities as part of digitalisation, but not as strongly user-driven.

Another perspective is to look at *social change*. CREDS includes increasing environmental awareness and concern as a driver for actions reducing energy demand. INHERIT gives the public a more modest role, considering that consumers might demand more transparency as to the manufacturing of goods. CAT suggests that climate change impacts in the near future will provide motivation for change to both the public and policymaker, gathering momentum for the collective action required. NATGRID considers the level of societal change as one parameter distinguishing scenarios, in terms of ambition for decarbonisation, while CDBB considers social changes that result in 'greater value on lower-carbon activities, such as creative pursuits, sharing and repairing economies, careers in caring and spending time in nature with the people we love' [20] (p 39). BÖLL goes as far as social transformation – with less use for new technologies. INHERIT contrasts an individualistic dynamic with a collectivist society: we suggest GRUBLER's approach is more individualistic, and BÖLL more collectivist.

Whether collectivist or individualist, people's actions are important. We see in both the transport and home energy use effects many assumptions of people engaging with technology (and climate change) and changing their behaviour to reduce energy demand (see 5.2). We again stress that this is not necessarily the case: different assumptions about behaviour and lifestyle lead to different future projections.

3.2.2 **Technology and data**

The way digital technology is developed, regulated and adopted can have a large effect on energy demand. In terms of energy use by 'smart' devices, there is a tension between, on the one hand, growth in number and use of devices, and corresponding infrastructure, and on the other, improved energy efficiency. CREDS suggests the number of devices could be tempered by saturation in the Global North, while GRUBLER suggests multipurpose small devices, probably smart phones, could replace various larger devices, reducing energy consumption.

Further, the trajectory of technological development, including not only technical parameters but also dominant business models and public engagement with technology, has significant implications for energy demand and business and societal dynamics. An example of different trajectories can be seen in the role of data, which is highlighted in several scenarios. Technical implications for increased data use include more energy-using servers, increasing server efficiency, and moving data from device to cloud to save energy (see 5.1). Beyond this direct impact, data can be used to create efficiency in transport and electricity grids, and capturing its value can drive economic growth. INHERIT considers the importance and potential of data-based services, with different possible levels of control of data from the public and private sectors, and the challenges to privacy. CDDB suggests data could be seen as a public resource to ensure privacy in some scenarios. There is a question of power here, in terms of who controls the data – will it be used for 'public good' or for corporate profit? With current business models favouring larger companies, the current trend is arguably for the latter.

Finally, recent work on the plausibility of deep decarbonisation [27] suggests that technical alternatives are already available, while social and political drivers are necessary. This would suggest that digital technology's role is not to offer new technical solutions as much as to enable currently available solutions, without increasing energy demand. Unlike most of the scenarios, CAT focuses on currently available technology in its narratives pursuing zero carbon Britain.

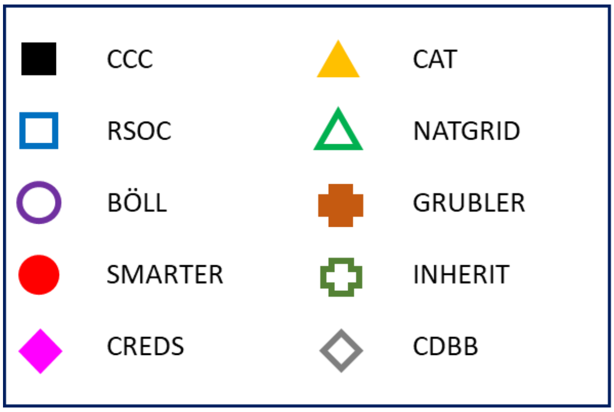
4 Comparison between scenarios

In this section, we provide a graphic representation of our interpretive analysis of where each scenario sits in relation to the four framing dimensions identified in Section 2; our analysis of each scenario is detailed in Appendix 1.

The overall view shows different emphases on supply or demand in the different scenarios, see Figure 1. While most consider both the demand and supply sides, there are differences in focus, with BÖLL [23] and GRUBLER [4] considering demand reduction – but in very different ways; the first considers significant reductions in demand for energy services, whilst the second considers digitalisation and dematerialisation. CREDS [18] considers both technological and social changes in its low carbon scenario. CAT [17] and NATGRID [21] show a balanced view of supply and demand (NATGRID has supply- and demand-focused scenarios), while the focus of INHERIT [22] and CDBB [20] is neither, but their narrative suggests a balance. The rest focus more on supply-side measures.

The question of continued economic growth as 'green growth', see Figure 2, shows a much starker divide between the narratives. Most of the scenarios assume a decoupling of energy (or emissions) from economic growth is both possible and plausible, although several suggest a shift to consider wellbeing and environmental sustainability alongside economic growth. For example, CCC [15] considers economic growth opportunities, with little if any discussion of the tension between economic growth and decarbonisation – yet ‘inclusive growth’ is mentioned.

CREDS highlights how reducing demand lowers the pressure to decouple. CAT questions GDP as a measure of wellbeing and critiques the mindset of perpetual growth, but does not go as far as degrowth; CDBB decentres growth, allowing the economy to shrink in some scenarios but does not set out to reduce its size. While several different papers project less growth in the Global North and more in the Global South, only BÖLL actively calls for shrinking the economy to save the environment.



Legend for Figures 1 – 4.

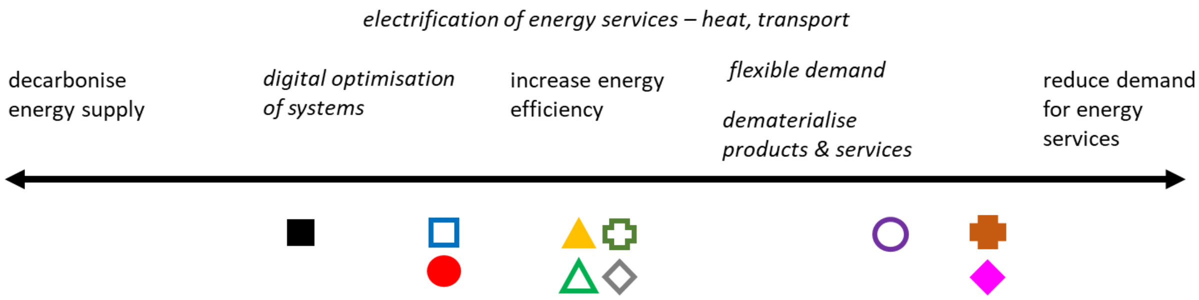


Figure 1 Focus on decarbonising energy supply (left) through increasing energy efficiency (middle) to reducing demand for energy services (right). The placement of the different scenarios is our interpretation. The italics labels show some common scenario events, and where they sit on the axis.

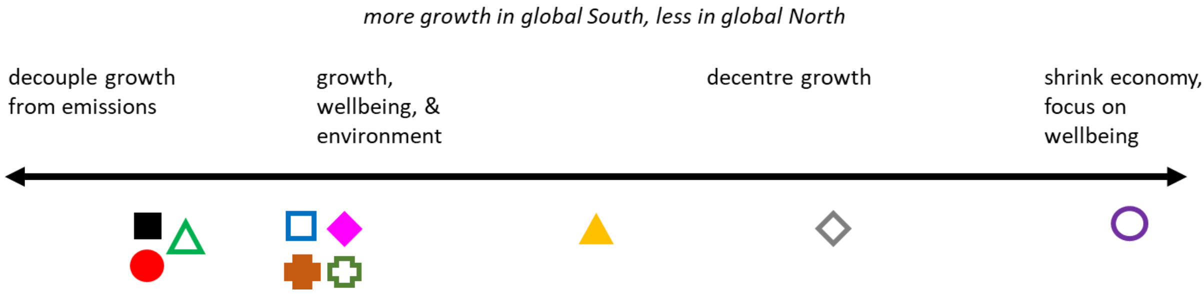


Figure 2 Perspectives on growth, from decoupling growth from emissions – i.e., green growth (leftmost), to including wellbeing and environment alongside growth in guiding the economy (middle left), to decentring growth and focusing on other parameters (middle right), to intentional shrinking of the economy to reduce environmental impact while focusing on wellbeing – i.e., degrowth (rightmost).

In relation to ICT business models and ownership, not all of the scenarios engage with these issues. To avoid over-interpretation, we do not assign a score to CAT, CREDS, and NATGRID. Among those that do consider business models, Figure 3, there is a large scatter, from a business as usual approach that effectively favours large incumbents, through to CDBB who press for regulation and more inclusive economic models, and BÖLL who question the need for digitalisation unless it has significant democratic oversight – a radical shift to avoid digitalisation being shaped by large corporations. Interestingly, INHERIT, at the opposite end of the axis, also warns against this. In their scenario, concentration of power and competition among a few superstar companies leads to efficient processes but holds the risk of these companies being 'more powerful than democratic mechanisms' (p 30), with challenges to data protection.

Finally, on the question of automation versus user agency, Figure 4, most of the scenarios are somewhere in the middle (CAT and BÖLL were left out to avoid over-interpretation). They discuss automation for efficiency, whilst giving users information and control over their personal energy use, but mostly consider them consumers. INHERIT suggests the most automation, with monitoring and artificial intelligence playing a major role in everyday life. The agency outlier is GRUBLER, that emphasises user-led change and diversification of roles from consumer to producer, citizen, and designer.

Figure 3 ICT narrative in the scenario, from business-as-usual (BAU) a small number of firms controlling the market (left) through new and disruptive business models (middle) to public ownership such as a 'digital commons' (right).

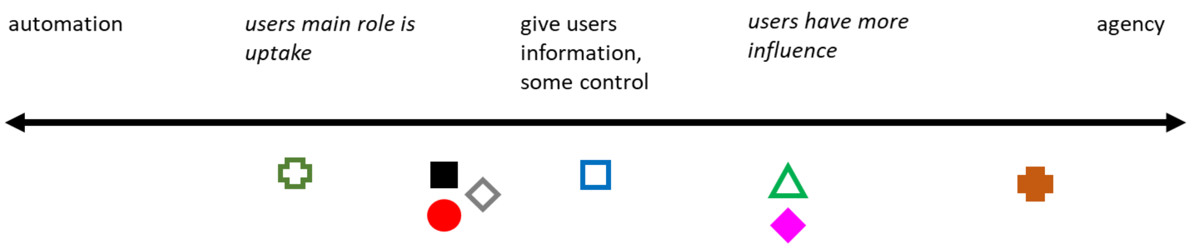


Figure 4 Control of ICT and digital energy services from automation (left) through giving users information and some control (middle) to full user agency (right).

5 Effects of digitalisation on energy demand

Here we consider the impacts of digitalisation on energy use as described in the different scenarios, considering the four effects as per Lange et al. [1] and two chosen areas – home energy use and transport – in which ICT indirectly impacts energy demand, as per Lange and Santarius [2]. Our data drawn from the scenarios is detailed in Table 2 – Table 5..

5.1 *Direct effects of digitalisation and ICT on energy demand*

As can be seen in Table 2, there is overall an agreed trend of significantly increased usage of ICT, its scope, infrastructure and associated data. Most scenarios see an increase in the number of devices, although different drivers are invoked, such as people seeking better quality of life [4], or competition in the market [23]. However, saturation of ICT appliances in the UK or more generally the Global North, integration of multiple devices into one (mostly smart phones), and cloud computing all act to reduce the number of devices [4,18].

The rise in data in turn leads to more data centres and higher energy demand, although this is tempered by cloud servers increasing efficiency, and increased efficiency of data centres (e.g., by using excess heat for other purposes) [15,16,21].

Devices' individual energy footprint could be reduced through increased efficiency, including through economies of scale, standardisation, and rapid innovation cycles. However, we suggest there is a tension between longevity (through policy or personal responsibility) and repairability (requiring political support) which could act to reduce energy use per device, and rapid innovation cycles, which might encourage shorter device life.

While overall most scenarios suggest direct energy demand of ICT can be reduced despite increased usage, this is not guaranteed. The increased efficiency of devices and cloud servers must balance out against increased usage, increased flow of data, and life cycle energy demand of devices.

Further, the rate of efficiency improvement is crucial: a model of global communication technology [28] show three scenarios from 2010 to 2030, with the same number of devices and data, but different annual improvements in efficiency of production, use, datacentres and network. Their model yields a 2030 ICT electricity footprint varying by an order of magnitude, from 2,700TWh (best) to 30,700TWh (worst). While the size of the gap between scenarios has been criticised [e.g., 29], this nonetheless shows the importance of clear, justified assumptions, including life cycle analysis, about devices, datacentres, other infrastructure, and shifts of energy use between them, as well as a clear narrative about the evolution of the internet of things.

5.2 *Energy efficiency and rebound effects*

We consider efficiency and rebound in two key domains where digitalisation has promise – home energy use and transport.

5.2.1 **Transport**

The impacts of digitalisation on transport are summarised in Table 3. Nearly all scenarios suggest that teleconferencing and remote working can reduce travel miles and save energy, especially in the Global North. This is invoked most frequently around commuting, but could be extended to leisure travel, studying and more.

Traffic management and integrated travel, using increasing data and sensors, and increased information provision to phones, are expected to improve congestion through smarter routes. ICT could also enable more efficient vehicles and ‘smart driving’ [24]. Freight could gain from smart logistics improving efficiency and enabling collaboration.

Meanwhile, digitalised, flexible, smart ticketing and timetables could make public transport more efficient and desirable. In addition, shared vehicles, possibly automated vehicles (AVs), could increase vehicle occupancy and usage. All together these act to provide *mobility as a service*. Business models are important, however, as privately owned AVs could increase travel [21].

Some scenarios suggest the benefits of digitalisation include reduced vehicle ownership and car production, saving energy and material resources. However, behaviour effects are generally not detailed, i.e., what determines people’s choice of travel mode, car purchase, or amount of travel. Further, rebound effects, e.g., increased travel as the smart transport system becomes more efficient, are hardly discussed. A recent European study [30] found that the potential effects of digitalisation on passenger transport could lead to opposite effects in both energy demand and emissions; they detail this as two scenarios, ‘responsible’ digitalisation and ‘selfish’ digitalisation. We note that most of the scenarios we analysed are much closer to responsible digitalisation.

5.2.2 **Home energy**

The impacts of digitalisation on home energy use in the scenarios are detailed in Table 4. There is overall agreement in increased ‘smartness’ of homes, including smart meters, appliances and heating. Most scenarios assume this leads to behaviour change through information provision, increased control (including remotely), smart tariffs and ‘encouragement’. Good engagement with people is thought to increase load shifting, for example through actively managing heating using residential thermal storage [21].

RSOC [16] optimistically suggests smart meters could contribute a 25% emission savings. However, the motivations for change are not always clear, and as the NATGRID [21] points out, people will not necessarily engage with their smart meters. Evidence so far from the UK’s smart meter roll out suggest a very modest energy savings in energy consumption, perhaps only 1-3% [31].

Smart appliances as part of smart energy systems are also predicted to reduce energy demand through automation, with sensors and artificial intelligence adjusting light, air quality and heating for residents' needs [22]. While smart homes could be designed to facilitate working and studying from home [20], CREDS [18] highlights the increased energy usage of working from home.

Overall, there are underlying assumptions that increased ICT and connectivity will improve quality of life while reducing energy use, partly through shaping behaviour and partly through automation. We suggest this is highly optimistic. First, because comfort and convenience are assumed, without considering rebound effects of increased consumption (of heat, lighting, data, or entertainment) due to ease of use and energy efficiency of appliances. An Australian study into smart homes [32] challenges convenience narratives, suggesting smart homes will engage residents in new forms of household labour, with 'keeping the home running' becoming a chore in itself.

Second, it is not clear how much energy can indeed be saved through smart home efficiency measures. Energy savings will need to be prioritised, as the same study [32] found that current marketing strategies 'prioritise devices and expectations likely to increase energy demand' (p 92). We suggest that 'smartness' might not be the top priority in saving energy. In the UK, for example, retrofitting homes for insulation and efficient heating systems might save energy more easily than smart heating (and cooling) controls.

5.3 *Impact of digitalization on economic growth*

We next consider how the scenarios assess impacts of digitalisation on economic growth, see Table 5. There is little analysis of effects on economic growth. We use minimal interpretation to show how some aspects of the scenario match Lange et al's (2020) third effect: 'impacts of increasing use of ICT on economic growth, in relation to labour productivity, income inequality and energy consumption'.

We note two things. First, the effects are portrayed primarily as positive. For example, more data 'creates value', and drives economic growth [16], although there are challenges related to data privacy [e.g., 20]. Other positive effects include shorter innovation cycles bringing new technologies to market faster [15]; and 'material light' businesses driving growth [24]. Further, increased digital skills and the flexibility and comfort digitalisation offers could increase productivity. However, there are also some negative impacts, such as potential job losses due to automation [18]. Finally, competitive digitalisation is tied with more growth and therefore higher energy use [23] – an economy wide rebound effect.

Second, in contrast to the previous categories of digitalisation impacts, there is no overall picture emerging from the different scenarios. Rather, we find a broad range of possible impacts. We suggest further research is needed on the effects of digitalisation on economic growth, and through it on energy demand, as the impacts are complex – including micro- and macro-economic parameters, interactions between different actors, policy dependence and more.

Table 2 Direct effects of digitalisation and ICT.

Effect	Details
Increased efficiency of devices	• There is a need to insure continued improvements of devices – design, repair and upgrades [15] • Longevity and repair – legislation needed for 'right to repair', alongside ensuring repairability, repair infrastructure [23]; behaviour change as an 'individual action' leads to using devices for longer [16] • Trend towards smaller, more efficient devices and commitment of leading operators to continue this [24] • Efficiency improvements in digital technologies including standardisation and economies of scale, rapid innovation cycles and learning effects; In addition, 'shorter lifetime accelerates the adoption of more efficient models contributing to rise the conversion efficiencies of the appliance stock more rapidly'. [4](supl. p 27)
Increased infrastructure	• Increased energy demand for operating a growing ICT infrastructure [16]
Increased number of devices	• Increased number of devices (and use) – shaped by the nature of 'competitive digitalisation' [23] • Huge increase expected, perhaps 100 billion by 2030 [24] • Drop in number of ICT appliances per household (UK) – by 10% due to demand saturation, sharing and cloud computing [18] • Integration of various services into a single device, especially smart phones, can yield 'up to a 100-fold potential power savings when in use' [4]; granular technologies are smaller and have a lower unit cost, therefore lower adoption barriers.
Increased usage	• A marked increase in activity (and number of devices) due to digitally enabled services leading to better quality of life; mostly in the GS [4] • 'Individual action' could lead to a reduction in usage, e.g., people 'streaming responsibly' [16]).
Increased usage of data	• There is a need to ensure continued improvement of data use (data centre efficiency) [15] • Moving to the cloud and server virtualisation increase efficiency of data, but there is need for more efficiency [16] • Increased communication leads to more data centres, energy needed for servers and cooling [21]

Table 3 Indirect effects: Efficiency and rebound in transport.

Effect	Details
Reduced travel	• Video conferencing and ICT-enabled working from home leads to reduced travel – mentioned in many scenarios. • ICT impacts through reduced need to travel for other purposes – health, learning, commerce also reduces travel [24]; virtual substitution reduces travel for various purposes, mostly in the Global North [4]. • Reduced travel leads to reduced level of car ownership, fewer cars manufactured [18].
Improved traffic management and integrated travel	• AI can improve significantly improve congestion prediction and smart parking similarly can greatly reduce congestion in busy city areas [16]. Similarly, [24] find that ICT can reduce travel time, distance and congestion through smart traffic control and fast parking platforms. • Apps and other ICT platforms enable ride sharing and car sharing, leading to reduced car km travelled and even a drop in demand for cars, leading to 15% reduction in car production (relative to the baseline) [24]. [4] similarly show an increase in vehicle usage and occupancy halving the number of cars globally by 2050. • Integrated urban transport networks include digitalised timetables and ticketing [18]
Digitalisation enabled behaviour change	• 'Business and operating models that offer 'mobility as a service' can leverage digital technologies to support more fundamental changes to how individuals access transport services, reducing the number of personal vehicles on the roads.' [16, p 27] • ICT enables significant rise in public transport use through more information, intelligent sensors, transparency and increased personal choice [24].
Increased efficiency of vehicles and driving	• ICT enables more efficient vehicles and smart driving technologies that save energy [24].
Autonomous vehicles enable change	• Ride hailing services provided by autonomous vehicles reduce vehicle ownership and travelled distance as they act as taxis or public transport. [4] also suggest AVs can be part of a shared vehicle fleet, increasing occupancy and reducing car numbers. [20] similarly suggest that artificial intelligence and AVS enable a smaller vehicle fleet. However, in scenarios where AVs are privately owned, they can increase average miles travelled [21].
Freight and delivery improvements	• 'digital technology can help consolidate demand and facilitate collaboration between delivery and logistics providers' [16, p 28]; Digitalised technologies improve freight logistics [18]; Smart logistics for fleets and routes, digital warehouses and operational agility could save 723 billion litres of fuel by 2030 [24]. • Dematerialisation moderates growth in freight transport [4].

Table 4 Indirect effects: Efficiency and rebound in home energy use.

Effect	Details
Smart energy systems enable improvements	• 'Smart meters could contribute a 25% emissions saving from UK homes by 2035 (compared with 2015 levels), by enabling a flexible, decentralised and decarbonised energy system' [16, p 26]. • Energy management and automation could reduce up to 40% of households' CO2 consumption. [24] • Smart appliances, smart meters enable demand management and load shifting [21]. • [22, p 27] tell us that 'the behaviour of humans within the house, as well as indoor air quality are carefully monitored and integrated into the smart home. Sensor-based environments adjust to the needs of the inhabitants (light, air quality, heat).'
Enabled behaviour change	• Smart home technologies and data analytics, alongside dashboards and apps allow people to understand their energy usage and emissions, and encourage changes to individual behaviour change, saving energy. [16] • Smart meters show how much energy households use, motivating cutbacks in consumption. [24]. Further, visualisations help consumers understand their consumption. All in all this amounts to 8% energy reduction in households. • Smart technology integration and 'digital lighting' gives consumers more control over energy use, even when away from home [18]. • Not all scenarios show engagement with smart meters! [21] • Cost reflective charges and smart tariffs enable load shifting [15]
Increased working from home	• Increased working from home increases home energy use [18]. • [20] focus on social housing, where 'homes are designed to enable customisation and upgrades, with ICT-connected study and workspaces designed into units to facilitate remote working and learning' (p 41)
Demand management	• 'As many as 8.1m homes actively manage heating demand with residential thermal storage and load shifting by 2050.' [21, p 8].

Table 5 Digitalisation effects on economic growth.

Effect	Details
Rapid innovation cycles	• ICT enables better forecasting and monitoring (of emissions); this could 'shorten innovation cycles to bring new energy technologies to market faster'. [15]
Data as economic driver	• 'Achieving this transition requires business models and technology approaches that can create economic value from the use of data, supported by action at different levels to ensure everyone in society can access these and participate in new forms of economic activity.' [16, p 90]. Examples for 'creating value' are given, e.g., mobility as a service, distributed energy sales.
Digital skills as economic driver	• Digitalisation has 'opportunities for individuals to reskill and upskill as the nature of their job changes due to digitalisation' [16, p 12] – leading to increased productivity.
Asset-light business models driving growth	• 'Innovative new business models are disrupting existing businesses, delivering exponential growth with asset-light business structures. ... As digital density increases through rapid smartphone penetration, new business models unimaginable a decade ago have the potential to transform our lives and to drive strong growth opportunities across the different sectors.' [24, p 27]
Competition driving growth	• Competitive digitalisation is a catalyst for more growth – and more energy use – if the trend of digital futures shaped by big companies continues [23]
Productivity driving growth	• People can work wherever they are (without travelling to the office) leads to a higher quality of life, and hence productivity: 'Increase in worker productivity due to a better working atmosphere and living quality' [24, p 131].
Job losses, working hours	• Some studies suggest 30% of UK jobs are vulnerable to automation, which could have an effect of inequality. However, full time work week has not changed in the past 20 years despite automation – there are various factors involved, including the need for increasing labour productivity. Working less could feasibly be supported by increased automation [18].
Automation, AI	• Many businesses invest in automation (and other technological solutions) as it becomes cheaper than human labour; this is especially the case with a shrinking workforce due to an ageing population [20]. Furthermore, there is 'Increasing digitalisation of many professions to support a smaller workforce in maintaining productivity' [20]

6 Discussion and conclusions

Our discussion starts with the results of Section 5 on digitalisation and energy demand, and lessons for policy-oriented scenarios. We then turn to questions of digitalisation and economic growth. We then consider some implications of our work for scenario building, before listing a few final conclusions.

6.1 *Direct, indirect and rebound effects*

As discussed in Section 5, the main potential driver of increasing energy demand is the massive projected increase in the number and usage of ICT devices. Particularly where energy use represents a significant input cost for suppliers and users, this will stimulate improvements in energy efficiency and some changes in user behaviour that will act to offset this increasing energy use. However, the extent of this offsetting will depend significantly on the path of digitalisation.

Indirect effects of digitalization on home energy use and transport are also likely to be significant. Smart energy systems within homes offer the potential for users to reduce their energy demand whilst maintain or enhancing service provision, and to provide services to the system, such as demand management and load shifting, which will improve system efficiency and mitigate primary energy inputs. However, the realisation of these benefits will depend partly on user behaviour. We found that the scenarios show different balances between automation of energy services and artificial intelligence to reduce the need for user inputs, and empowerment of users to engage with the technologies and manage their demand more actively. Again, this implies the need for more policy-linked analysis of the effects of different pathways of digitalisation on energy demand.

Similarly, increases in ICT-enabled working from home are assumed to lead to reductions in travel and overall energy use. However, recent research [33,34] has argued that there may be significant rebound effects, such as home-workers or their family members making additional trips for shopping or leisure and longer commutes on days in which they do travel to work if they choose to live further away, as well as the additional home energy use, which could together negate some or all of the energy saving. If these types of rebound effect are not fully represented in low carbon scenarios, these scenarios may over-estimate the potential energy savings due to digitalisation.

Indirect effects in relation to transport include virtual interactions substituting for travel, smarter traffic flow management in cities and facilitation of new ‘mobility as a service’ business models. Again, these effects could lead to significant reductions in energy demand. However, energy savings due to these effects may be offset by rebound effects for users and businesses. Better traffic flows could lead to increased travel, and privately owned autonomous vehicles could lead to new energy-demanding practices. Cheaper and more flexible services could lead to higher energy service demands, such as improved logistics leading to increases in on-demand delivery of goods and services. Our findings across these different scenarios and end uses reflect a recent quantitative analysis [30], who found that transport energy demand could be 60% higher in a ‘selfish’ digitalization scenario, focussed on more individualised forms of mobility, compared to a ‘responsible’ digitalization scenario, focussing on more collective provision through shared mobility solution.

How these effects will play out will depend on the social and technological evolution of ICT systems. This will require policy-oriented scenario analysis to pay more attention to factors including user engagement with technologies, consumer awareness and new user roles as prosumers; efficiency and longevity of devices, and changes to number of devices, usage and data; and development and adoption of new business models. Our analysis also shows that high-level framings could influence this evolution, including the extent to which ownership of key ICT businesses continue to be highly concentrated or are challenged by public ownership and digital commons, and approaches to automation of services vs empowering user engagement.

Overall, if, as some scenarios argue, a greater policy focus on the role of energy demand reduction within decarbonisation strategies is necessary to achieve net zero goals, then policy-oriented decarbonisation scenarios will need to pay greater attention to future pathways adopted for digitalisation. Scenarios should go beyond simplistic assumptions of how ICT usage can reduce energy demand, and examine direct, indirect and rebound effects associated with different pathways for digitalisation. This would help to inform policy focus and decisions affecting the role of digitalisation in relation to the feasibility and acceptability of achieving net zero goals.

6.2 *Green growth and energy demand*

In most of the 'green growth' decarbonisation scenarios, higher levels of investment and reducing costs of digitalisation are assumed to drive higher labour productivity and overall economic growth. This higher level of economic activity is assumed to feed through into overall improvements in social welfare. However, some scenarios, such as CREDS [18], argue that focussing the advances from digitalisation and other social megatrends on measures to improve social wellbeing, health and local environmental benefits, rather than on purely economic gains, could enable energy demand reductions which would enhance the feasibility and acceptability of a net zero transition.

Digitalisation raises important questions in relation to job creation or destruction and data and surveillance, which will have implications for the feasibility and public acceptability of these technological changes and their contribution to a net zero carbon transition. Scenarios that focus on supply-side solutions tend to be framed within a 'green growth' narrative that assumes the potential for decoupling economic growth from carbon emissions, including through the role of ICTs in providing dematerialised services. Scenarios that focus on demand-side solutions tend to be more sympathetic to a 'degrowth' narrative and argue that this focus would enable continuing wellbeing of citizens whilst achieving rapid carbon reductions. However, GRUBLER [4] combines an emphasis on demand-side solutions with a narrative suggestive of green growth – although this has been interpreted as a degrowth scenario due to the reduction of material through put (see Appendix 7.9.2). However, we would suggest the green growth scenarios do not sufficiently engage with the tensions between growing the economy and reducing energy demand. Digitalisation driving energy efficiency improvements and economic growth could lead to increased demand for goods and services, including demand for energy, effecting an economy-wide rebound effect [35].

6.3 *Implications for scenario building*

We next consider implications for building scenarios of digitalisation and energy demand from our work. First, there is limited engagement and inconsistent representation of how digitalisation will affect demand for energy services. All the scenarios incorporate some action for societal and behavioural changes to address the demand-side, but they differ in the relative importance that they assign to these and the underlying drivers of change. This is in line with the broader literature: questions about demand-side options tend to focus on public acceptability and the feasibility of economic and social structural changes that may be needed to introduce these options, rather than investigating the drivers of increasing service demand [36].

While the emergence of such new functionalities is recognised in some scenarios, more attention to the implications for energy demand is needed. For example, while a few of the scenarios consider the changes in work and leisure practices associated with moves to augmented reality (AR) and virtual reality (VR) as part of the digital world, the potential energy demand implications of these shifts is not captured.

Second, we suggest some scenarios have a simplistic approach to both individual behaviour and social change, not considering the wealth and depth of social science available on these topics. Further, we note that some scenarios assume optimised social engagement with technology that maximises energy savings. There are explicit or implicit assumptions in some narratives about behaviours compatible with, or even assisting, deep decarbonisation; and about technological development pathways that lead to efficiency improvements that more than offset increased energy use from digital technologies. We suggest digitalisation pathways need better justification for such narratives, with lessons for policy makers on governance of digitalisation of society that will maximise energy demand reduction.

Third, we suggest more attention needs to be given to the *plausibility* of scenarios, and specifically to the various social changes they assume. A recent report [27] considers what makes future scenarios plausible in the context of climate change, breaking with "the optimism bias that pervades much of existing decarbonization research" (p 30). In consideration of different social drivers, they found that both corporate responses and consumption patterns currently inhibit decarbonisation, and overall assess that deep decarbonisation by 2050 is not plausible – although such futures could become more plausible with public pressure and consistent litigation and action from government. Nonlinear social change acting as 'social tipping points' could help mitigate climate change [37], with (mostly government led) interventions to precipitate them; others consider the importance of civil society and social movements as agents of change [38]. Scenarios would do well to consider the magnitude and non-linearity of social changes they assume, and justify the plausibility of such changes, including the precipitating events and actors.

6.4 *Conclusions*

This paper has highlighted the importance of considering the interactions between the digital revolution and the net zero carbon transformation of energy and economic systems, but the need for this to be further explored through scenario analysis and participatory dialogue. The direction of causality between factors is not always clear in the scenarios, and aspects of this causality need to be further unpacked in future work. Assumptions about social, technological and economic drivers lead to very different futures. In particular, we note that assumed drivers around people's behaviour and action, technological development, and policy and governance can lead to different futures.

We suggest that policy support for technology is not enough, as there are different trajectories for technological development, as discussed above. Some choice in trajectory, a *directionality* of policy [39], is needed for digital innovation to support social goals such as energy demand reduction and decarbonisation. For example, the UK government's support for electric vehicles [40] builds towards a technological substitution aiming to decarbonise surface transport. However, this search for a techno-fix might hinder a deeper shift to a lower energy (and emissions) personal transport sector, as it maintains a high-demand and high-energy transport sector [41].

A transition to a net zero society by 2050 or earlier will require many interacting changes in technologies, institutions, business models and user practices, in which ICTs will have a crucial role to play. Achieving wide public consent for these changes and overcoming the resistance of vested interests to changes will require informed public debate on these issues. The further development of more integrated low-carbon and ICT scenarios, explicitly including different drivers and causation patterns, could play an important role in this. The role of digitalisation in these debates is important, as ICTs and associated new business models and practices have the potential for reducing energy demand through improving energy efficiency and stimulating economic structural changes, but also the potential for increasing energy demand through direct energy use and stimulating re-spending leading to economic growth and economy-wide rebound effects.

References

1. Lange, S., Pohl, J. & Santarius, T. Digitalization and energy consumption. Does ICT reduce energy demand? *Ecol. Econ.* **176,** (2020).

2. Lange, S. & Santarius, T. *Smart Green World? Smart Green World?* (Routledge, 2020). doi:10.4324/9781003030881

3. Creutzig, F. *et al.* Towards demand-side solutions for mitigating climate change. *Nat. Clim. Chang.* **8,** 260–263 (2018).

4. Grubler, A. *et al.* A low energy demand scenario for meeting the 1.5 °c target and sustainable development goals without negative emission technologies. *Nat. Energy* **3,** 515–527 (2018).

5. Britton, J. & Woodman, B. Local Enterprise Partnerships and the low-carbon economy: Front runners, uncertainty and divergence. *Local Econ.* **29,** 617–634 (2014).

6. Hickel, J. & Kallis, G. Is Green Growth Possible? *New Polit. Econ.* **25,** 469–486 (2019).

7. Jackson, T. *Prosperity without growth?* (Earthscan, 2009).

8. Keyßer, L. T. & Lenzen, M. 1.5 °C degrowth scenarios suggest the need for new mitigation pathways. *Nat. Commun.* **12,** (2021).

9. Kawalek, P. The Digital: Eating The World? in *Digital Technology Research Seminar, University of Sussex Business School* (2020).

10. Tirado Herrero, S., Nicholls, L. & Strengers, Y. Smart home technologies in everyday life: do they address key energy challenges in households? *Current Opinion in Environmental Sustainability* **31,** 65–70 (2018).

11. HMG & Ofgem. *Upgrading Our Energy System: Smart Systems and Flexibility Plan*. (HM Government, 2017).

12. HMG. *The Clean Growth Strategy: Leading the way to a low carbon future*. (HM Government, 2017).

13. Goulden, M., Spence, A., Wardman, J. & Leygue, C. Differentiating 'the user' in DSR: Developing demand side response in advanced economies. *Energy Policy* **122,** 176–185 (2018).

14. Hargreaves, T., Wilson, C. & Hauxwell-Baldwin, R. Learning to live in a smart home. *Build. Res. Inf.* **46,** 127–139 (2018).

15. Committee on Climate Change. *The Sixth Carbon Budget: The UK's path to Net Zero*.

(2020).

16. The Royal Society. *Digital technology and the planet: Harnessing computing to achieve net zero*. (The Royal Society, 2020).

17. Centre for Alternative Technology. *Zero Carbon Britain: Rising to the Climate Emergency*. *CAT Publications* (Centre for Alternative Technology, 2019).

18. Barrett, J. *et al. The role of energy demand reduction in achieving net-zero in the UK.* (Centre for Research into Energy Demand Solutions, 2021).

19. Broo, D. G. *et al.* Built environment of Britain in 2040: Scenarios and strategies. *Sustain. Cities Soc.* **65,** 102645 (2021).

20. Broo, D. G. *et al. Four Futures, One Choice: Options for the Digital Built Britain of 2040*. (2020). doi:10.17863/CAM.59803

21. National Grid. *Future Energy Scenarios*. (National Grid ESO, 2020).

22. Guillen-Hanson, G., Strube, R. & Xhelili, A. *INHERIT: Reaching the 'Triple-Win', Four Future Scenarios of a Healthier, more Equitable and Sustainable Europe in 2040.* (2018).

23. Kuhnhenn, K., Costa, L., Mahnke, E., Schneider, L. & Lange, S. A societal transformation scenario for staying below 1.5°C. *Schriften zu Wirtschaft und Soziales.* **23,** (2020).

24. Accenture Strategy. *#SMARTer2030: ICT Solutions for 21st Century Challenges*. (Global e-Sustainability Initiative (GeSI), 2015).

25. Geels, F. W. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technol. Forecast. Soc. Change* **72,** 681–696 (2005).

26. Haxeltine, A. *et al.* A Conceptual Framework for transition modelling. *Int. J. Innov. Sustain. Dev.* **3,** 93–114 (2008).

27. *Hamburg Climate Futures Outlook 2021. Assessing the plausibility of deep decarbonization by 2050.* (Cluster of Excellence Climate, Climatic Change, and Society (CLICCS)., 2021).

28. Andrae, A. S. G. & Edler, T. On Global Electricity Usage of Communication

Technology: Trends to 2030. *Challenges* **6,** 117–157 (2015).

29. Belkhir, L. & Elmeligi, A. Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *J. Clean. Prod.* **177,** (2018).

30. Noussan, M. & Tagliapietra, S. The effect of digitalization in the energy consumption of passenger transport: An analysis of future scenarios for Europe. *J. Clean. Prod.* **258,** 120926 (2020).

31. Sovacool, B. K., Kivimaa, P., Hielscher, S. & Jenkins, K. Vulnerability and resistance in the United Kingdom’s smart meter transition. *Energy Policy* **109,** 767–781 (2017).

32. Strengers, Y. & Nicholls, L. Convenience and energy consumption in the smart home of the future: Industry visions from Australia and beyond. *Energy Res. Soc. Sci.* **32,** 86–93 (2017).

33. Calderola, B. & Sorrell, S. The impact of teleworking on English travel. in *eceee 2021 Summer Study proceedings* 679–689 (2021).

34. Calderola, B. & Sorrell, S. Do teleworkers travel less? Evidence from the English National Travel Survey.

35. Brockway, P. E., Sorrell, S., Semieniuk, G., Heun, M. K. & Court, V. Energy efficiency and economy-wide rebound effects: A review of the evidence and its implications. *Renew. Sustain. Energy Rev.* **141,** 110781 (2021).

36. *Shifting the focus: energy demand in a net-zero carbon UK*. (Centre for Research into Energy Demand Solutions, 2019).

37. Otto, I. M. *et al.* Social tipping dynamics for stabilizing Earth’s climate by 2050. *Proc. Natl. Acad. Sci. U. S. A.* **117,** (2020).

38. Smith, S. R., Christie, I. & Willis, R. Social tipping intervention strategies for rapid decarbonization need to consider how change happens. *Proc. Natl. Acad. Sci.* **117,** (2020).

39. Mazzucato, M. From market fixing to market-creating: a new framework for innovation policy. *Ind. Innov.* **23,** (2016).

40. *Automated and Electric Vehicles Act 2018*. (UK Houses of Parliament, 2018).

41. Bergman, N., Schwanen, T. & Sovacool, B. K. Imagined people, behaviour and future

mobility: Insights from visions of electric vehicles and car clubs in the United Kingdom. *Transp. Policy* **59,** 165–173 (2017).

42. Xhelili, A. *et al.* A technological scenario for a healthier, more equitable and sustainable Europe in 2040: Citizen perceptions and policy implications. *Int. J. Environ. Res. Public Health* **17,** 231 (2020).

43. Guillen-Hanson, G., Strube, R., Xhelili, A. & Liseri, M. Impactful Trends in Europe towards 2040: Related to health, health equity and the environment following the STEEPLE (Social, Technological, Economic, Environmental, Political, Legal and Ethical) framework. (2017).

44. Hickel, J. Degrowth: a theory of radical abundance. *Real-World Econ. Rev.* **87,** 54–68 (2019).

7 Appendix 1: Interpretation of dimensions

Here we give our interpretation of the narrative framing of the role of digitalisation in each scenario, in relation to our four dimensions represented as the four axes in Figures 1—4.

7.1 *Climate Change Committee 2020 report – CCC*

The UK's Climate Change Committee [15] report details recommendations for the UK's Sixth Carbon Budget (2033-2037), in the context of reaching net zero by 2050. It calls for concerted government action over the next 10 years, with policy scaling up 'across every sector' in order to enable the transition.

The digital revolution is mentioned alongside the low-carbon transition, although it is not discussed in detail. Digital technology is seen as having the role of an enabler, and digitalisation will be 'fundamental to the operation of a Net Zero economy' (p 404), with a flexible energy system reducing the cost of the transition.

The report details pathways to net zero carbon, focusing primarily on decarbonising supply and uptake of low carbon technologies. We focus on the main narrative, the *Balanced Pathway to Net Zero*, in which missions fall most rapidly in the electricity supply sector, primarily through renewables. Buildings, transport and other sectors build up to peak rates of decarbonisation during the 2030s, as heat pumps and electric vehicles replace existing technology. This pathway requires scaling up investment in low-carbon options.

7.1.1 Supply/Demand

There is a supply side focus, in decarbonisation of the electricity grid, with demand side measures mostly restricted to uptake of low-carbon technology, via electrification of vehicles and heating. Reduced demand for energy services, e.g., though changes to diet or travel, accounts for only 10% of emission reductions, and efficiency gains for 5%. Demand side measures make a proportionality larger contribution to emissions reductions in the early period up to 2030.

7.1.2 Growth

Economic growth is part of the narrative, assuming GDP growth of 1.6% from 2027 to 2050. The narrative takes a green growth approach, suggesting there are ‘Opportunities for economic growth as we transition to a green economy’ (p 289), with ‘inclusive growth’ also mentioned. Tension between economic growth and decarbonisation is not discussed explicitly, although there is consideration of emissions as a function of growth in demand in different sectors.

7.1.3 Business models and ownership

The lack of specification suggests persistence of dominant large firms and current business models for ICT. This can be seen in the general approach that low carbon technologies, products and services are driven by an investment-driven shift, led by the private sector. While the narrative highlights support for new innovations, there is no similar move towards new types of business models.

7.1.4 Automation/Agency

This is not discussed explicitly, so hard to gauge. The emphasis on optimisation through smart technologies suggests a slight lean towards automation.

7.2 *Royal Society 2020 report – RSOC*

This UK report from the Royal Society [16] on the role of digitalisation in achieving net zero stresses how digital technologies have already transformed the economy and changed our lives, not least through communication during the COVID pandemic. It argues that they will be an essential part of the transition to a net zero economy. It considers the disruption of digital technologies in terms of jobs lost and created, for example changes in the transport sector's workforce due to future automation. It suggests digital, data-rich, smart systems can offer 'as a service' business models in various sectors.

While digital technologies are seen as enablers and catalysts, perhaps even triggers under the right conditions, the right policies are needed to drive change. This includes policies 'to create critical digital infrastructures for net zero' (p 6), strongly connecting the two transitions. There is a recognition of potential 'dystopian scenarios', in which digital technologies cause a rise in emissions. This includes data-driven unsustainable scenarios, where data and ICT offer cheap production and efficient deliveries, bolstering consumption, and digital technology increasing efficiency of fossil fuel extraction, maximising its use.

7.2.1 **Supply/Demand**

While both the demand and supply side are addressed, this report leans towards supply side management with renewable and decentralised supply. The demand side changes are around data and smart tech improving flexibility and optimising systems, alongside 'supporting' lower energy behaviour. However, there is little engagement with changing behaviours to reduce demand for energy services.

7.2.2 **Growth**

There is an implicit 'green growth' agenda pursued here, although growth isn't discussed explicitly. This can be seen in lack of questioning the existing economic paradigm. For example, there is discussion of investment in green infrastructure stimulating the economy and generating jobs.

7.2.3 **Business models and ownership**

There is a call for new business models around digital platforms and value creation from data in an inclusive way. For example (p 90), 'a number of digital platforms are already supporting the sharing and circular economies, such as online marketplaces specialising in the sale of second-hand items, or apps that let people borrow tools from their neighbours. These new forms of business allow value creation without the need to manufacture new products.' While there are some elements of a digital commons in this approach, it portrays people as users of ICT systems, not developers or 'citizens'. Therefore, this does not challenge the business as usual dominance of large ICT firms.

7.2.4 **Automation/Agency**

On the one hand, there is discussion of machine learning and ‘smart machines’, with a focus on ‘data-driven systems’, suggesting significant automation. On the other hand, digital technologies are described as enablers, stressing that their development should be ‘inclusive and grounded in engagement with all stakeholders and communities affected by their use’ (p 6). Further, there is a stress on ‘enabling individuals to interrogate the output of digital systems for net zero’ (p 61). This suggests a balance between automation and agency.

7.3 *Centre for Alternative Technology report – CAT*

The latest [17] Zero Carbon Britain report from the Centre for Alternative Technology does not model or show pathways, but rather aims to show a viable, technically feasible picture of the UK in 2030 at zero carbon. Its two main themes are ‘powering down demand’ and ‘powering up renewables’. This report calls for ambitious climate change policy, requiring a shift in policy priorities, although the focus is on societal and cultural change.

This scenario uses ‘only technology available now and currently in use, or technologies which have been demonstrated to work’ (p 32), both to ensure realistic and because of the urgency to act. While digital life is not discussed, smart appliances and smart electric car charging are considered alongside storage to help balance the renewable energy powered grid.

Their plan is to ‘rethink the economy, based on harvesting our renewable assets and working with our ecosystems’ (p 118). However, The economic changes are not as radical as might be expected. UK industry, for example, ‘is simply a more energy efficient version of industry today’ (p 34).

7.3.1 **Supply/Demand**

This scenario assumes great changes in both supply and demand, with detailed analysis of balancing a grid with renewables, storage and flexibility. Within this, they have one supply focused scenario, with nuclear, biomass, CCS and imports; one ‘personal demand reduction’ scenario, which uses solely renewables for supply; and one ‘technical supply reduction’ scenario, with insulation and efficient appliances reducing the need for lifestyle change, also renewables powered.

Overall there is a reduction of about 25-60% in energy demand, depending on scenario. Meanwhile, coal, oil and natural gas are phased out completely. Renewables, biofuels and ambient heat all increase, and there is increased electrification. This is a balanced supply/demand narrative.

7.3.2 Growth

This report critiques both GDP as a measure of wellbeing and the mindset of perpetual growth, emphasising that that climate change cannot be seen just in terms of its costs. However, there is no degrowth agenda here. There is a focus on wellbeing, with decarbonisation met alongside social and environmental sustainability, including the benefits and standard of living of a modern society.

Rather, there is a call to ‘rethink the economy, based on harvesting our renewable assets and working with our ecosystems’ (p 118), while the global move towards net-zero puts the UK ‘in a good position to further develop expertise and benefit from economic growth and job creation’ (p 128). Further, there is the suggestion that growth should be concentrated in developing countries; wealthy regions should ‘plan for low growth and a transition to steady state economies’ (p 124). This mixed message puts the report in the middle of this axis.

7.3.3 Business models and ownership; Automation/Agency

Beyond smart technology balancing the grid, digitalisation is not discussed, so we do not position this report on either of these axes.

7.4 *CREDS scenarios*

The report from CREDS (Centre for Research into Energy Demand Solutions) [18] focuses on the challenging task of meeting the net zero target, including considerably increasing the size of the electricity grid in addition to decarbonising it. The report highlights how reducing energy demand will make this task more manageable, and reduce the risk of relying on new technologies being successfully developed and taken up.

CREDS specify four scenarios with different possible scales of change in energy demand, from *Ignore demand* and up to *Transform demand*, which considers ‘transformative change in technologies, social practices, infrastructure and institutions’ (p 21).

CREDS used a modelling approach combining existing models for mobility, nutrition and agriculture, domestic buildings, non-domestic buildings and industry, with their own work. Digitalisation is one of the trends explored in all scenarios, recognising its transformative potential, but also that it will not necessarily bring about a reduction in energy demand.

7.4.1 **Supply/Demand**

The focus of the report is the role of reducing energy demand in achieving net-zero, so naturally this scenario is near the demand side end of the axis. The role of supply is acknowledged; the emphasis here is that reducing demand can significantly reduce investments needed in the supply side, especially in low-carbon electricity.

7.4.2 **Growth**

There is no explicit economic output of the scenario modelling. However, there is no challenging of the economic system as a whole, and a suggestion that reduction in final energy demand reduces the reliance on decoupling GDP from energy use. This suggests this a 'green growth' scenario. However, the scenarios 'build upon an underlying trend of an increasing focus on health, wellbeing and quality of life, at the policy level and by individuals' (p 24), suggesting a move towards considering wellbeing alongside growth.

7.4.3 **Business models and ownership**

While digitalisation 'is already driving significant changes in the energy sector and is likely to accelerate change in the future by promoting new energy business models through to changing how consumers interact with energy services' (p 21), there is no explicit discussion of maintaining or significantly changing ownership of ICT. We do not assign a value, to avoid over-interpretation.

7.4.4 **Automation/Agency**

Automation is discussed mostly in the context of work and productivity. In everyday life, ICT mainly provide information, e.g. 'nutrition tracking technologies' promote healthier diets. In the home, 'smart systems helps to change our building heating habits...' (p 36). However, this work also considers 'the impacts of behavioural change to use appliances more efficiently and less often, and the potential to reduce the number of appliances per household without compromising quality of life' (p 37). Only in the most extreme *Transform demand* scenario is there a significant 'reduction in energy use from ICT and other appliances through replacing manual with automated building management controls' (p38). Overall, this leans towards agency over automation.

7.5 ***CDBB scenarios***

Scenario work from the Centre for Digital Built Britain [19,20] looks at the future of the built environment in Britain[1] in 2040. This work has four scenarios based on a two-by-two matrix of two variables: First, whether the UK (and the world) will meet SDG targets by 2040, and second, UK demographics in terms of dependency ratio (size of workforce relative to dependent population), i.e. will we have a high dependency ratio due to an ageing society, or more of a working age population. The four resulting futures are explored across five dimensions: Built environment, economy, digital technology, society and natural environment.

We focused on the scenario *A Legacy of Hope*, which presents a future where (1) the SDGs are globally on target (at least 80% implemented), the UK is on target to meet its net zero emission target, and global warming has been limited to 1.5°C above pre-industrial levels; and (2) there is a high dependency ratio in the UK, due to global migration decreasing following a fall in unrest, and an ageing population in the UK. In this scenario, the built environment is highly interconnected via digital technologies, with robust governance and technology ensuring data privacy. Energy demand has decreased due to large changes in the construction sector and elsewhere, a circular economy, and reduced demand for consumer goods. Automation and other technological solutions are cheaper than human labour, especially with a shrinking workforce.

7.5.1 **Supply/Demand**

While not discussed explicitly, the suggestion is of a combination of renewable energy and digitalisation enabled efficiency, with some reduction in demand. In the scenario *A Legacy of Hope*, the reduction in energy demand comes from a combination of efficiency, circular economy and reduced demand for goods due to an ageing population. We are told that '...the people and businesses of the UK have placed greater value on lower-carbon activities, such as creative pursuits, sharing and repairing economies, careers in caring and spending time in nature with the people we love' (p 39), suggesting more of a demand focus. But there is also a rise jobs in the green energy sector and development of green energy sources. The scenario *Generation Zero* (SDGs on target, low dependency ratio) has higher energy demand so

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[1] Britain, i.e., England, Scotland and Wales, not Northern Ireland.

includes more specification about supply, e.g., discussion of ‘resilient microgrids running on 100% renewable sources’ (p50). The focus on a digitally-enabled efficient built environment puts it somewhere in the middle – smart, efficient cities and homes is a big shift in how services are delivered, but not in what services we require. Overall, this is a balance of supply and demand, or middle of the axis.

7.5.2 Growth

In the scenario *A Legacy of Hope*, ‘GDP is in a long decline, and by traditional measures this would be an economic depression. However, today our economic models value the natural environment and human wellbeing alongside economic growth’ (p 44). This suggests growth is not abandoned, but is only one economic measure; GDP decline is a result of shrinking consumption due to an ageing population and high dependency ratio. In the *Generation Zero* scenario, GDP rises. The scenarios decentre growth, but do not explicitly aim to shrink the economy, putting it midway towards the degrowth end of the axis.

7.5.3 Business models and ownership

While there is no explicit discussion of business models, the strong emphasis on policy and regulation protecting vulnerable populations and ensuring privacy of data suggests some challenging of current corporate power. The underlying philosophy of this scenario is using data as a resource, and AI for the public good, and ‘more inclusive economic models’. However, new business models are not a complete disruption, nor are they a transfer of power to the public. This is in line with the Lange & Santarius [2] argument of ensuring digitalisation is aligned with the common good for more equitable, and suggests a middle of the road value.

7.5.4 Automation/Agency

The CDBB papers concluded that how pervasive digital technology becomes is a key variable in their scenarios. AI plays a central role in the scenario *A legacy of hope*, for example, ‘Connected digital twins and cyber-physical systems are autonomously analysing and optimising processes for greater sustainability’ (p 42). There are also ‘collaborations between responsible AI and human stakeholders to make better decisions about, for instance, health care’ (p 42). The emphasis on safe and benign AI suggests a high degree of automation, with robust governance and human oversight of technology protecting vulnerable groups and ensuring data privacy, as can be seen with the investment in digital skills. This leans slightly towards automation.

7.6 *National Grid's 2020 Future Energy Scenarios – NATGRID*

The National Grid's [21] Future Energy Scenarios result from modelling and stakeholder engagement, leading to four different pathways depending on level of societal change and speed of decarbonisation. Greater change mostly corresponds to faster decarbonisation. Three of the four scenarios successfully reach net zero by 2050. Decarbonisation of the electricity system is central here. Hydrogen and carbon capture and storage are seen as necessary, with emissions from the power sector going negative by 2033 in net zero scenarios. Energy efficiency and decarbonising heating are also mentioned. The level of electrification and energy efficiency varies between scenarios.

The report declares that 'Open data and digitalisation underpin the whole system thinking required to achieve net zero' (p 6). However, there is little discussion of digitalisation beyond smart appliances, smart EV charging and storage to manage a more flexible demand.

Reaching net zero requires 'immediate action across all key technologies and policy areas, and full engagement across society and end consumers' (p 6). Government policy and initiatives, both existing and future, enable various parts of the transition. This includes support for low carbon energy and technologies, investment in flexible generation and management, and more. Behaviour change plays a part in all the scenarios, primarily around uptake of energy efficiency measures, efficient appliances and upgraded heating systems, switching to EVs or public transport, and consumer choice influencing products and services.

7.6.1 **Supply/Demand**

Both demand and supply are included in the scenarios. Supply considers renewable energy, hydrogen, carbon capture and storage, and significant electrification. The demand actions are primarily about efficiency, electrification, smart appliances and systems, and upgrading heating, and to a lesser extent mode switching in transport and choice of products. However, there is limited change in demand for energy services. This suggests a middle of the axis value.

7.6.2 **Growth**

There is an implicit assumption of (the need for) growth, but it's not discussed in detail. For example, there are multiple references to the UK Government's Clean Growth Strategy 2030, with aims of 'delivering increased economic growth and decreased emission' (p 116). This suggests a green growth framing. Aspects of sustainability beyond emissions are hardly mentioned.

7.6.3 **Business models and ownership**

There is little discussion of ICT beyond the ability of smart systems to make demand (and supply) more flexible, so we do not interpret a position on this axis.

7.6.4 **Automation/Agency**

This report does not engage closely with the subject of this axis. However, we find that the higher societal change scenarios assume a degree of automation, suggesting that rapid transformation and change requires some automation. We interpret this as leaning slightly towards the agency side.

7.7 ***INHERIT scenarios***

INHERIT is an EU project looking for 'triple-win' futures for 2040: policies, strategies and innovation that can reduce environmental impacts, improve health, and increase health equity [22,42]. They include four qualitative future scenarios out to 2040, based on a two-by-two matrix of two characteristics: the driving sector (public or private) and dominant social dynamics (individualistic or collectivist**)**.

INHERIT developed an array of future trends to shape their scenarios, including implementation of mixed reality experiences (mixed and virtual reality); higher appreciation of wellbeing; aging population; urbanisation; and increasing consumer demand for transparency regarding design, use and origin of components of the products used [43]. The scenarios offer useful insights: changes to business practices and the focus on GDP or wellbeing varies between the scenarios; the level of digitalisation and its governance varies, e.g., in control of data; and the power of private ICT firms, the 'superstars' varies, with localism dominant in some.

The most relevant scenario for us is *My life between realities*. In this scenario, the private sector is the driver and society is primarily individualistic. Life is digitally connected and personalised, and technological solutions are a driving factor of the transition to healthier, more equitable and sustainable lifestyles in Europe by 2040. AI and automation taking over many everyday tasks, and companies use large amounts of data to offer personalised services. There are small, energy efficient living spaces with a 'smart everything'. Environmental benefits are not guaranteed due to resource use and waste from the high level of technology

7.7.1 **Supply/Demand**

The focus here is on renewable energy and efficiency of demand, with less attention to reducing demand for services. However, some demand becomes virtual, reducing travel, for example and smart systems maximise energy efficiency. This suggests a middle of the road value.

7.7.2 **Growth**

Economic futures are not detailed, although the focus on health, equity and environment show that wellbeing is central to this work in all four scenario. Nonetheless, there is no consideration of limitations of growth here. In our chosen scenario *My life between realities*, the dominance of markets and powerful companies suggest a position towards the green growth end of the axis.

We also note that in the *Less is more to me* scenario (public sector driven, individualistic social dynamics), there is a more explicit departure from current economics: 'Traditional growth models are challenged by the notion of "less is more" as reaffirmation of sufficiency, which challenges established business and fiscal models' (p 38), putting in further towards the degrowth end of the axis, highlighting differences between scenarios.

7.7.3 **Business models and ownership**

In this private sector driven scenario, 'The concentration of power and competition between few large companies leads to efficient processes but holds the risk of these companies being more powerful than democratic mechanisms' (p 30) – this suggests a few superpower companies, firmly at one end of the axis, with challenges to data protection. So while 'Citizens are critical consumers and ensure that companies act in environmentally and socially sustainable ways' (p 66), we suggest they have limited power to challenge large powerful companies that control data and even sponsor 'virtual green spaces' for those with limited access to outdoor green space.

7.7.4 **Automation/Agency**

The narrative suggests high levels of automation, as 'Artificial intelligence has taken over different tasks in everyday life' (p 29). Deep learning algorithms make health recommendations and sensors adjust homes to inhabitants' needs. Further, there is smart system and data-led automation ensuring efficiency, for example, 'the behaviour of humans within the house, as well as indoor air quality are carefully monitored and integrated into the smart home' (p 27). So while 'Citizens program their living spaces' (p 26), this scenario leans towards the automation end of the axis.

7.8 ***Heinrich Böll Foundation report – BÖLL***

The starting point of the report, *A Societal Transformation Scenario for Staying Below 1.5°C*, [23], is the difficulty of keeping to the 1.5°C limit. It focuses on the challenges in reconciling the need for net zero by 2050 with the assumptions of IPCC scenarios that global economic growth must continue until 2100.

The report is critical of the IPCC for failing to address behaviour change and focusing on technological options. It includes societal change pathways not currently considered in the IPCC reports, and suggests these are lacking in public debate. Their pathways highlight 'limiting global production and consumptions and of envisioning a broader societal transformation' (p 9). Specifically, their Societal Transformation Scenario includes reduced economic activity in the Global North, while assuming increased consumption in the Global South, a 'contract and converge' approach.

This scenario assumes a shift from growth to a focus on well-being and reducing consumption. This means scaling down of energy-intensive parts of the economy, destroying established profitable business models, leading to a decline in economic growth, axing current jobs and clashing with lifestyle habits. They acknowledge that some might see their narrative as unrealistic, but suggest these stem from assumptions about current societal constraints, and 'these assumptions must be regarded as challenges that can be overcome, not as arguments against a comprehensive societal transformation as such' (p 73).

7.8.1 **Supply/Demand**

The focus on social change in the Global North suggests a demand side approach, e.g., 'we chose societal changes that lead to substantial emission reductions' (p 32). In the STS scenario, the drop in demand means primary energy production falls by 60% by 2050, less than 10% of which comes from carbon-based fuels. However, supply plays a role too, with scenario assumptions of ambitious renewable and energy storage development.

7.8.2 Growth

This report questions the growth paradigm, as ‘Growth is neither a good indicator of quality of life nor a realistic and effective strategy to alleviate poverty (in the countries of the Global North)’ (p 21). Wellbeing is prioritised: ‘Instead of focusing on material welfare – fostering economic growth, competition and profit-making – we focus on fulfilling concrete human needs and serving common welfare – fostering cooperation, care, solidarity and sustainability in order to achieve a good life for all’ (p 66). This is a degrowth scenario.

7.8.3 Business models and ownership

The narrative suggests a clear preference for a digital commons type approach, criticising competitive digitalisation as a catalyst for more growth and energy use. Digitalisation is only compatible with their narrative with ‘democratic oversight’. An example is legislation for the ‘right to repair’, ‘allowing consumers to repair and modify their consumer electronic devices’ (p 46), as well as product standards to ensure repairability and subsidies for ‘repair infrastructure’.

7.8.4 Automation/Agency

While we might assume suspicion of digitalisation would lead to preferring agency, this topic is not discussed so we do not assign a value.

7.9 *Grubler et al. Low Energy Demand scenario – GRUBLER*

This paper [4] describes a scenario focused on the great potential for efficiency gains in energy end-use. The narrative is based on observable current trends that lead to reduced energy demand, extending them into the future. The work uses an integrated assessment modelling framework for quantitative results, and considers differences between Global North and South.

User behaviour is central, both in demand for better services from ICT products and systems, and in a diversification of user roles. Also central are smart connected systems and small devices, particularly smartphones, serving multiple functions and replacing other larger devices, yielding huge energy savings and offering demand response options. Dematerialisation is enabled through smart services such as shared cars.

The dynamic includes rapid social and institutional change in energy systems, not just technological change. It is less dependent on climate policy than most low carbon scenarios, as downstream changes drive structural change in intermediate and upstream sectors, causing a supply side transformation.

This narrative strongly ties the low carbon transition to digital revolution. It is the pervasive digitalisation and 'smart' systems that enable dematerialisation, optimisation of services, and other energy and emissions saving phenomena.

7.9.1 **Supply/Demand**

The focus of the work is a low energy-demand scenario, as 'end-use is the least efficient part of the global energy system and has the largest improvement potential' (p 515). This 'downsizing' of the system makes a low-carbon supply side more feasible. While supply is also considered, it is more of a 'mainstream' decarbonisation model.

7.9.2 **Growth**

There is no direct engagement with the question of green growth. However, the paper acknowledges that the transformational changes in the narrative have implications for economic growth, commodity prices, trade patterns and other economic indicators, suggesting they are not challenging the green growth paradigm. The dematerialisation focus suggests a belief in significant decoupling. On the other hand, the drivers towards quality of life, and especially raising living standards in developing countries, suggests a focus on wellbeing beyond mere economic growth, and we assign a value leaning towards green growth. However, Keyßer and Lenzen [8] note that while the Grubler et al. do not explicitly consider the effects of their scenario on GDP, Hickel [44] considers it a degrowth scenario, as it shows 'a planned reduction of the material and energy throughput of the global economy' (p 56). Keyßer and Lenzen interpret this as GDP shrinking, as the drop in energy demand would otherwise demand an unrealistic decoupling

7.9.3 **Business models and ownership**

The diversification of user roles, including producer, designer, community member and citizen, suggest a move away from business as usual practices of ICT development; changes in organisational forms, business models and ownership are part of the model. There is a shift from a product to 'use-based' business models, alongside sharing economies, but this is based on consumer/user power; it doesn't go as far as public ownership or common good as a guiding principal, and considers access, but not equality or distribution of profits. We interpret this as slightly leaning towards the digital commons end of the axis.

7.9.4 **Automation/Agency**

The narrative of user-led change through new functionalities of digital technologies and services is an example of an agency-led narrative, as end users demand improved changes which lead to rapid transformation. At the same time, the 'digitalisation of daily life' does include levels of automation: 'Energy services become easier, cheaper, and more practically controlled to suit and respond to users' needs. New control functionality enables both user specifications (inputs, preferences, routines) but also user passivity (learning algorithms, intelligent automation).' (supplementary information, p 12).

7.10 ***Accenture and GeSI's #SMARTer2030 report***

This report on 'ICT Solutions for 21st Century Challenges' [24], developed for GeSI, a consortium of businesses, aims to show the potential ICT has in addressing environmental and economic challenges. It is a techno-optimistic scenario, suggesting that ICT can not only reduce significant emissions from all sectors of the economy by 2030, but simultaneously enable huge social and economic benefits, while the percentage of global emissions coming from ICT falls.

It is a vision of a high-tech future where billions of people save energy by telecommuting; smart buildings ensure energy savings, environmental and social benefits; and big data and monitoring are seen as a route to optimisation and efficiency. Consumer power is a driver of change, enabling rapid shifts through widespread uptake of digital technologies. However, people's end-user role remains firmly that of consumers or users.

The first recommendation to policymakers (p 13) is: 'Set and enforce global and national emissions targets and recognize ICT solutions as a core tool to securing continued economic growth under these constraints'. This doesn't put ICT at the centre of lowering carbon emissions, but rather as an enabler to grow the economy under the constraints.

7.10.1 **Supply/Demand**

The focus is on energy efficiency and good supply and demand management through smart systems, data and sensors, as well as uptake of smart appliances and smart meters. While there are behavioural changes, these are due to supplying the same services more efficiency, with virtual or online work and other technology-based efficiency improvements taking centre stage. There is, however, no questioning of demand for energy services per se. We therefore place this scenario slightly towards the supply end of the axis.

7.10.2 **Growth**

The report is strongly in the green growth column: 'We have found that by rolling out identified ICT solutions across the global economy, total global emissions of CO2e could be cut by 12Gt by 2030, promoting a path to sustainable growth.' (p 9) No tensions between growth and emission reduction, or environmental sustainability more broadly, are acknowledged.

7.10.3 **Business models and ownership**

One the one hand, this scenario sees less of a grip by large ICT firms. For example, conventional utilities are disrupted by microgrids and energy storage technologies. 'Worldwide growth of the digital economy continues to accelerate, providing the scale necessary to drive greater connectivity and new, disruptive business models. And, as opposed to the old production-line economy, individuals are firmly at the center of this process.' (p 8)

On the other hand, this not a 'digital commons'. For example, there is a call for policymakers to 'Establish a fair, balanced and consistent regulatory approach to ICT that promotes innovation and investment, protects intellectual property rights and ensures consumer privacy and security' (p 13). Disruptors discussed are Uber and AirBnB, which do not necessarily level the playing field. Rather, this is change driven by consumer demand. We interpret this as slightly leaning towards business as usual.

7.10.4 **Automation/Agency**

Here too there is a mix. For example, in the buildings section, on the one hand, people's awareness and options are highlighted, e.g. 'ICT-enabled solutions combined with user-friendly consumer interfaces like apps and dashboards will be able to enhance peoples' awareness of their energy and resource consumption' (p 39). On the other hand, the benefits of automation are equally highlighted, as 'Automated building heating, cooling, ventilation and lighting control systems are already gaining ground, based on motion and light sensors, turning lighting off when there is enough daylight, or turning heating off when no one is around' (p 39). On balance, this leans slightly towards the automation, as the agency afforded people here seems to be limited to ‘user-friendly’ and information provision approach, with limited change to end-user roles.

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