The role of digitalisation in low carbon scenarios

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Abstract

Two of the major socio-technical transitions the world is currently facing are shifting to a low-carbon society, and a digital revolution. Despite some claims to the contrary, evidence suggests that spread and adoption of information and communications technologies (ICT) does not automatically lead to reduction in energy demand, if this stimulates new energy-using practices or wider economic growth (Lange, Pohl, and Santarius 2020). Despite this policy challenge, the two transitions are often considered separately.

We report from ongoing work investigating assumptions and framing of climate-focused transition scenarios, both global and UK-specific, to examine the role of digitalisation in these scenarios. We analyse the framing of the scenarios along several axes: (1) the relative focus on decarbonising energy supply or managing energy demand; (2) the relative focus on green growth or shifting to a focus on wellbeing (or even degrowth); (3) the relative focus of the narrative on dominant business models led by large ICT firms, or alternative business models which empowering communities and users; and (4) the relative focus on automation for optimising energy supply and demand or on empowering agency of users; as well as their specification of other economic, technical, user practice and political factors.

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, and in terms of their framing in the above axes, with many implicit assumptions. 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.

Introduction

In this paper, we report from ongoing work investigating assumptions and framing of a number of climate-focused transition scenarios, both global 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), along with associated business models and user practices, could affect energy demand, as part of the transition to a net zero carbon economy. We analyse the framing of each of these scenarios along several axes: (1) the relative focus on decarbonising energy supply or managing energy demand; (2) the relative focus on green growth or shifting to a focus on wellbeing (or even degrowth); (3) the relative focus of the narrative on dominant business models led by large ICT firms, or alternative business models which empower communities and users; and (4) the relative focus on automation for optimising energy supply and demand, or on agency, i.e. empowering users to better understand and control their energy use; as well as their specification of other economic, technical, user practice and political factors. We conclude by comparing these scenarios in relation to these different framings and factors, and discussing what this tells us in relation to the role of ICT in contributing to a net zero carbon transition, and how this could be illuminated by further work in this area.

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, and in terms of their framing in the above axes. The scenarios include many different, and often implicit, assumptions. 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.

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'. We use two main methods: First, an informal coding of the studies trying to tease out assumptions, drivers and main parameters in order to better describe their main narratives. Second, an interpretive positioning of each study along our chosen axes, to better understand the differences between them. In this paper, we focus on the axes as a demonstrable way of comparing and contrasting the studies.

CORE FRAMINGS OF SCENARIOS

We describe four axes that assist us in characterising studies and scenarios in terms of their underlying assumptions and relation to the digital revolution. The positioning of each study on each axis is interpretive and only semi-quantitative.

Axis 1: supply and demand

Energy efficiency research is well established, not least at eceee. Nonetheless, until recently, the focus of much of climate change mitigation research, including transition scenarios, has been on supply-side solutions, primarily technological solutions. Even Intergovernmental Panel on Climate Change (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" (Creutzig et al. 2018, 216). This is relevant to the role of ICT, as many applications of ICTs are argued to contribute to reducing energy demand (Grubler et al., 2018).

Here we ask: Does this scenario present decarbonisation as primarily a supply side or demand side process, or a combination thereof? 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. We place supply focused scenarios at one end of the axis, those that consider technical demand reductions closer to the middle of the axis, and those that consider more fundamental changes to the nature of energy demand at the other end.

Axis 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 (Britton and Woodman 2014)). Greenhouse gas emissions are often seen as a proxy for (environmental) sustainability, and at the left hand of this axis we situate narratives that focus on economic growth that is accompanied by reduced emissions, ignoring broader issues of environmental and social sustainability. Middle of the axis are narratives that consider human (and natural) wellbeing alongside economic growth, and furthest right sit narratives, such as degrowth, that 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., Hickel and Kallis 2019). An argument at the end of the access is that economic growth does not deliver societal benefit beyond a certain point, questioning whether it is the right model for developed economies (Jackson 2009).

At one end of this axis are scenarios considering green growth, possibly enabled or catalysed by ICT. 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. At the other are scenarios questioning the growth paradigm, such as degrowth narratives, with a focus on alternative well-being measurements. Those that consider the need for wellbeing and environmental focuses beyond growth, but do not question the need for growth, go somewhere in the middle.

Axis 3: business models and ownership

This draws on work such as Lange & Santarius (2020), who discuss how benefits from digitalisation are distributed in a highly inequitable manner. Kawalek (2020) 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."

At one end of this axis are scenarios in which a dominant business model sees large ICT firms (national to worldwide level), making technology-based changes, profiting from user data sales and other benefits as digitalisation and ICT penetrate more sectors of the economy. At the other end are more localised ICT (i.e., small enough for user or community engagement), a digital commons, and social and environmental aspects in addition to the technology.

Axis 4: automation or user agency

This reasoning for this axis draws partly on the smart homes literature, which finds two opposing narratives regarding control (Tirado Herrero, Nicholls, and Strengers 2018): 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 (HMG and Ofgem 2017; HMG 2017). 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 (Goulden et al. 2018), while trials suggest users limit themselves to the more basic functions of SHTs (Tirado Herrero, Nicholls, and Strengers 2018; Hargreaves, Wilson, and Hauxwell-Baldwin 2018); 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 (Goulden et al. 2018). Unlike this dichotomy, the *agency* end of our access is the engaged citizen. The Grubler et al. (2018) narrative of user-led change through new functionalities of digital technologies and services is an example of an agency-led narrative.

At one end of this axis are scenarios where automation circumvents users by algorithm and technical efficiency, minimising user interaction or behaviour change beyond 'uptake' of new technologies and systems. At the other, technology is an enabler, giving users more information and control, combining behaviour change with best use of technology and giving agency to users/prosumers.

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 seven 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.

The selected scenarios are:

1. The (UK) Climate Change Committee (2020) report *The Sixth Carbon Budget: The UK's Path to Net Zero*;
2. The (UK) Royal Society (2020) report *Digital Technology and the Planet*;
3. The Heinrich Böll Foundation's report *A Societal Transformation Scenario for Staying Below 1.5 °C* (Kuhnhenn et al. 2020);
4. The GeSI report (Accenture Strategy 2015), *#SMARTer2030, ICT Solutions for 21st Century Challenges*;
5. The Centre for Alternative Technology's (2019) *Zero Carbon Britain*, *Rising to the Climate Emergency*;
6. The National Grid (Great Britain)'s most recent (2020) scenario report, *Future Energy Scenarios*;
7. And a paper on meeting the 1.5 °C target globally, *Low Energy Demand scenario* 2018 (Grubler et al. 2018).

Scenarios and initial analysis

Here we give an overview of the main scenario(s) in each of the above documents and our interpretation of the narrative framing of the role of digitalisation in the scenario, in relation to our 4 axes. We limit our broader framing of each document for brevity.

1. CLIMATE CHANGE COMMITTEE 2020 REPORT

The UK's Climate Change Committee (2020) 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. This analysis focuses 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.

Framings

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.

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.

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.

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

2. ROYAL SOCIETY 2020 REPORT

This UK report from the Royal Society (2020) 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.

Framings

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.

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.

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.

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.

3. HEINRICH BÖLL FOUNDATION REPORT

The starting point of the report, *A Societal Transformation Scenario for Staying Below 1.5 °C*, (Kuhnhenn et al. 2020), is the difficulty of keeping to the 1.5 °C limit. It focuses on the difficulty reconciling the need for net zero by 2050 with the assumptions of IPCC scenarios that global economic growth must continue until 2100.

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

This scenario assumes fundamental changes to the economy, with 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).

Framings

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.

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).

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'.

Automation/Agency
While we might assume suspicion of digitalisation would lead to preferring agency, this topic is not discussed so we do not place it on this axis.

4. GESI'S #SMARTER2030 REPORT

This report on 'ICT Solutions for 21st Century Challenges' (Accenture Strategy 2015), developed for 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 with billions of people saving 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. People are seen as drivers of change through consumer power, with rapid change enabled through widespread uptake of digital technologies. However, people's end-user role remains firmly that of consumers or users.

The first recommendation to policymakers 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" (p 13). This doesn't put ICT at the centre of lowering carbon emissions, but rather as an enabler to grow the economy under the constraints.

Framings

Supply/Demand
The focus 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 place this narrative in the centre. 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.

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 CO_2e could be cut by 12 Gt by 2030, promoting a path to sustainable growth" (p 9). No tensions between growth and emission reduction, or environmental sustainability more broadly, are acknowledged.

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.

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.

5. CENTRE FOR ALTERNATIVE TECHNOLOGY REPORT

The latest (2019) Zero Carbon Britain report from the Centre for Alternative Technology (CAT) 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'.

The focus is very much on societal and cultural change, and this scenario uses "only technology available now and currently in use, or technologies which have been demonstrated to work" (p 32), to ensure the scenario is 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 – a shift, not a revolution. UK industry, for example, "is simply a more energy efficient version of industry today" (p 34).

This report calls for ambitious and forward climate change policy, requiring a shift in policy priorities. It is suggested that climate change impacts in the near future will provide motiva-

tion for change to both the public and policymaker, gathering momentum for the collective action required.

Framings

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.

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.

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.

6. NATIONAL GRID'S FUTURE ENERGY SCENARIOS
The National Grid's (2020) 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 (CCS) are seen as necessary, with emissions from the power sector going negative by 2033 in net zero scenarios. Energy efficiency and decarbonising heating also mentioned. Level of electrification and energy efficiency varies between scenarios.

"Open data and digitalisation underpin the whole system thinking required to achieve net zero. This is key to navigating increasing complexity at lowest cost for consumers." (p 6) However, there is little discussion of digitalisation beyond smart appliances, smart electric vehicle (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.

Framings

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.

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.

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.

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. GRUBLER ET AL. LOW ENERGY DEMAND SCENARIO
This paper (Grubler et al. 2018) 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.

Framings

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.

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, even if it is not challenged.

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 where the profits go.

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.)

Results: comparison between scenarios

The overall view shows different emphasis on supply or demand in the different scenarios, Figure 1. While most consider both the demand and supply sides, there are differences in emphasis, with the Heinrich Böll Foundation and Grubler et al. scenarios 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. CAT and the National Grid show a balanced view of supply and demand (National Grid has supply- and demand- focused scenarios), and the rest focus more on supply-side measures.

The question of continued economic growth as 'green growth', Figure 2, shows a much starker divide between the narratives. Most of the scenarios do assume decoupling energy or emissions from economic growth is both possible and plausible. CAT questions GDP as a measure of wellbeing and critiques the mindset of perpetual growth, but does not go as far as degrowth, with only Heinrich Böll Foundation actively calling for shrinking the economy to save the environment. Several different papers project less growth in the global North and more in the global South.

In relation to ICT business models and ownership, not all of the papers have enough information to interpret where they sit. The CAT scenarios, for example, do not engage enough with these issues to assign them a score. The ICT narrative of control, Figure 3, shows a large scatter, from a business as usual approach that favours large incumbents, to a need for 'democratic oversight' of digitalisation expressed in the Böll narrative. The question of automation versus user agency, on the other hand, Figure 4, shows most of the papers somewhere in the middle. They discuss automation for efficiency, whilst giving users information and control over their personal energy use, but mostly consider them consumers. The outlier is the Grubler et al. paper, that emphasises user-led change and diversification of roles from consumer to producer, citizen, and designer.

Discussion and conclusions

Two of the major socio-technical transitions the world is currently facing are 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., Lange, Pohl, and Santarius 2020). Despite this policy challenge, the two transitions are often considered separately. Our review of selected low-carbon transition scenarios has investigated 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*. This has implications for understanding the feasibility and desirability of these net zero scenarios, as we now discuss.

All the net zero scenarios we reviewed incorporate the need for actions on the supply-side for innovation and diffusion of low-carbon technologies and fuels, and actions for societal and behavioural changes, focussed on the demand-side, but they differ in the relative importance that they assign to these. For example, the CCC Balanced Net Zero Pathway estimates that nearly 60 % of changes needed will involve some societal and behavioural changes (Committee on Climate Change 2020). Questions about supply-side options tend to focus on feasible

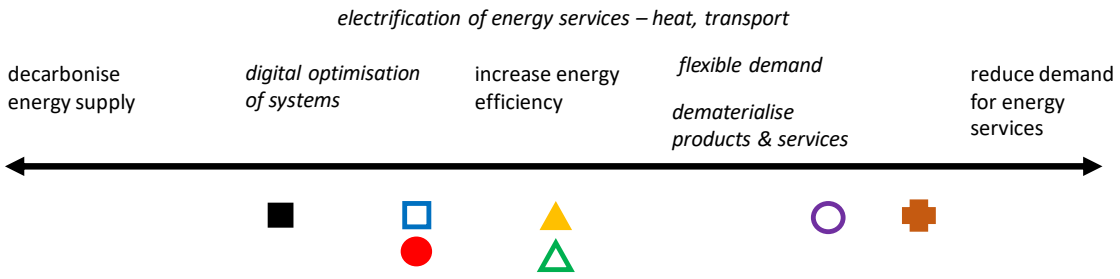

Figure 1. Focus on supply (left) or demand (right) of electricity/energy.

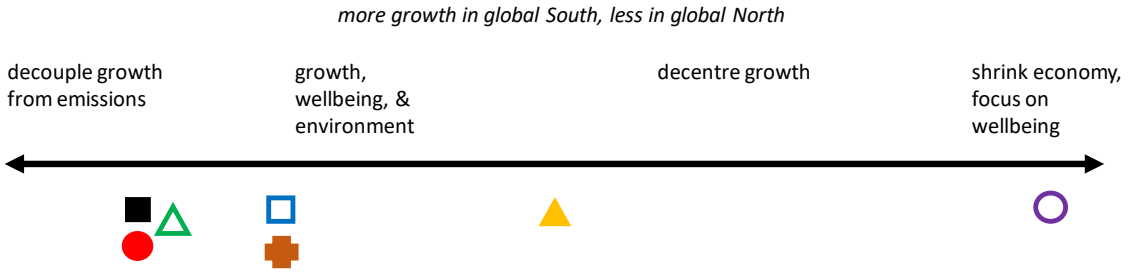

Figure 2. Perspectives on growth, from green growth (left) to degrowth (right).

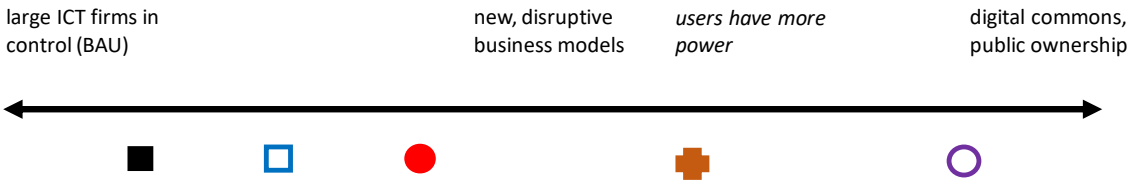

Figure 3. ICT narrative from a small number of firms controlling the market (left) to public ownership or a digital commons.

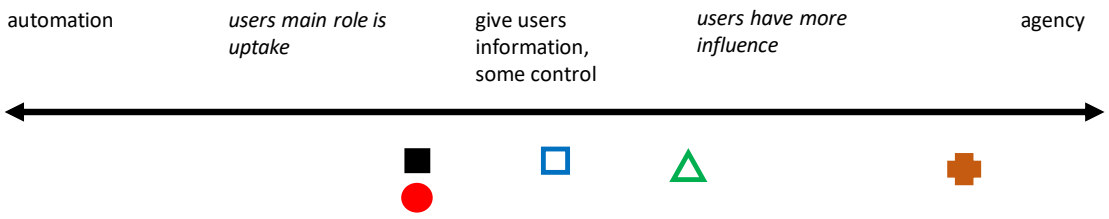

Figure 4. Control of ICT and energy services via automation (left) to user agency (right).

rates of innovation and diffusion of new low-carbon technologies, such as hydrogen and carbon capture and storage. 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, as well as the extent to which these could contribute to other goals, such as contributing to wellbeing and social equity and reducing other environmental impacts (Eyre and Killip 2019). 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 (Lange, Pohl, and Santarius 2020).

Digitalisation also 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, the Grubler et al. scenario combines an emphasis on demand-side solutions with a green growth narrative.

RELATION BETWEEN THE TRANSITIONS

Discussion of the roles of business models and ownership and agency/automation provides insights into drivers of change and the direction of causation in the scenarios. The scenarios show a variety of perspectives and approaches to the relation between the low-carbon transition and the digital revolution. The Centre for Alternative Technology (CAT) scenario doesn't consider the digital transition beyond grid balancing, and the Heinrich Böll Foundation's Societal Transformation Scenario focuses on societal change over technological solutions. The other five scenarios recognise the importance of digitalisation to some extent. Both the CCC and the National Grid see digital technology as an important role in the transition and in maintaining a complex zero-carbon economy, although both offer limited detail.

The remaining three narratives all highlight changes already evident, and great changes to everyday life in the future, from digitalisation of society. They all engage with the relation between the two transitions, although from different perspectives. The Royal Society highlights that policy is central in creating the conditions for digitalisation to catalyse a low carbon transition, recognising that ICT could potentially increase emissions. The Smarter2030 report also suggests a role for policy, but focuses on how ICT can ensure economic growth under policy constrained emissions. Finally, the Grubler et al. LED scenario 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.

DRIVERS AND CAUSATION

The assumed drivers and directions of causation in a low-carbon transition vary from scenario to scenario. The Climate Change Committee (CCC) 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. The Royal Society highlights the disruptive nature of digitalisation, and the need for policy and investment to ensure ICT expansion leads to more sustainable outcomes. The National Grid suggests greater societal engagement, as well as policy action, can lead to faster decarbonisation.

The Heinrich Böll Foundation suggests societal transformation reducing demand and increasing wellbeing is feasible; the difficulty is envisioning broader transformation. In complete contrast, the GeSI Smarter2030 report highlights the potential of ICT to save energy and increase wellbeing, with people as 'consumer power' driving change alongside policy. The CAT 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.

The Grubler et al. lower energy demand (LED) scenario 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.

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, and 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 selected scenarios, and aspects of this causality need to be further unpacked in future work on these and other scenarios.

In particular, the different visions of green growth vs degrowth and wellbeing, concentrated ownership vs digital commons, and automation vs enhanced user agency, whilst informed by technical considerations, need to be the focus of wider public debate on the desirability of alternative low-carbon scenarios. 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.

References

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

Britton, Jessica, and Bridget Woodman. 2014. "Local Enterprise Partnerships and the Low-Carbon Economy: Front

Runners, Uncertainty and Divergence." *Local Economy* 29 (6–7): 617–34.

Centre for Alternative Technology. 2019. "Zero Carbon Britain: Rising to the Climate Emergency." *CAT Publications*. Machynlleth: Centre for Alternative Technology.

Committee on Climate Change. 2020. "The Sixth Carbon Budget: The UK's Path to Net Zero." London. www.theccc.org.uk.

Creutzig, Felix, Joyashree Roy, William F. Lamb, Inês M.L. Azevedo, Wändi Bruine De Bruin, Holger Dalkmann, Oreane Y. Edelenbosch, et al. 2018. "Towards Demand-Side Solutions for Mitigating Climate Change." *Nature Climate Change* 8: 260–63. https://doi.org/10.1038/s41558-018-0121-1.

Eyre, Nick, and Gavin Killip, eds. 2019. *Shifting the Focus: Energy Demand in a Net-Zero Carbon UK*. Oxford, UK: Centre for Research into Energy Demand Solutions.

Goulden, Murray, Alexa Spence, Jamie Wardman, and Caroline Leygue. 2018. "Differentiating 'the User' in DSR: Developing Demand Side Response in Advanced Economies." *Energy Policy* 122: 176–85.

Grubler, Arnulf, Charlie Wilson, Nuno Bento, Benigna Boza-Kiss, Volker Krey, David L. McCollum, Narasimha D. Rao, et al. 2018. "A Low Energy Demand Scenario for Meeting the 1.5 °c Target and Sustainable Development Goals without Negative Emission Technologies." *Nature Energy* 3: 515–27. https://doi.org/10.1038/s41560-018-0172-6.

Hargreaves, Tom, Charlie Wilson, and Richard Hauxwell-Baldwin. 2018. "Learning to Live in a Smart Home." *Building Research & Information* 46 (1): 127–39. https://doi.org/10.1080/09613218.2017.1286882.

Hickel, Jason, and Giorgos Kallis. 2019. "Is Green Growth Possible?" *New Political Economy* 25 (4): 469–86. https://doi.org/10.1080/13563467.2019.1598964.

HMG. 2017. "The Clean Growth Strategy: Leading the Way to a Low Carbon Future." HM Government. https://www.gov.uk/government/publications/clean-growth-strategy.

HMG, and Ofgem. 2017. "Upgrading Our Energy System: Smart Systems and Flexibility Plan." HM Government. https://www.gov.uk/government/publications/upgrading-our-energy-system-smart-systems-and-flexibility-plan.

Jackson, Tim. 2009. *Prosperity without Growth?* Earthscan.

Kawalek, Peter. 2020. "The Digital: Eating The World?" In *Digital Technology Research Seminar, University of Sussex Business School*.

Kuhnhenn, Kai, Luis Costa, Eva Mahnke, Linda Schneider, and Steffen Lange. 2020. "A Societal Transformation Scenario for Staying below 1.5 °C." *Schriften Zu Wirtschaft Und Soziales.* 23.

Lange, Steffen, Johanna Pohl, and Tilman Santarius. 2020. "Digitalization and Energy Consumption. Does ICT Reduce Energy Demand?" *Ecological Economics* 176 (106760). https://doi.org/10.1016/j.ecolecon.2020.106760.

Lange, Steffen, and Tilman Santarius. 2020. *Smart Green World? Smart Green World?* Routledge. https://doi.org/10.4324/9781003030881.

National Grid. 2020. "Future Energy Scenarios." National Grid ESO. https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2020-documents.

The Royal Society. 2020. *Digital Technology and the Planet: Harnessing Computing to Achieve Net Zero*. London: The Royal Society. https://royalsociety.org/topics-policy/projects/digital-technology-and-the-planet/.

Tirado Herrero, Sergio, Larissa Nicholls, and Yolande Strengers. 2018. "Smart Home Technologies in Everyday Life: Do They Address Key Energy Challenges in Households?" *Current Opinion in Environmental Sustainability*. https://doi.org/10.1016/j.cosust.2017.12.001.