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

Noam Bergman, Tim Foxon

Abstract

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 WUDQVLWLRQ WR WKH µGLJLWDO UHYROXWLRQ¶. 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].

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 WKH WK ³HPSKDVL]HG LPSURYHG HQG-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].

transport through autonomous vehicles, lower energy costs through solar etc. Public

RZQHUVKLS RI WHFKQRORJ\ HQVXUHV EHQHILWV DUH GLV

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

KHOSV WKHP PDNH EHWWHU µHQHUJ\ FKRLFHV¶ H J JRY ments 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

ZRXOG ZRUN EHWWHU E\ µFLUFXPYHQWLQJ¶ XVHUV WR RS

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 agencyend 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

This reasonininguish between

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. µ,QGXVWU\ ¶ GLJLWDOLVDWLRQ RI SURGXFWLRQ SURF 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.

$V ZH GRQ¶W KDYH DQ HFRQRPLF PRGHO ZH DUH LQWHUH 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:

Shorthand	Title, organisation or project, year	Area	Focus	Scenarios
CCC	7KH 6L[WK &DUERQ %XGJHW ,7KH 8.¶V 3 Committee on Climate Change 2020 [15]		Net Zero emissions by 2050	Central scenario and four exploratory scenarios
RSOC	Digital Technology and the Planet: Harnessing Computing to Achiev Net Zero, The Royal Society 2020 [16]	UK	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 204, 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 Scenar 313.63 302.93 17.16 re f 1 0 0 1q63 302.93			

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] GRHVQ¶W FRQVLGHU WKH GL
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 SHRSOH DV µFRQVXPHU SRZHU¶ GULYLQJ FKDQJH DORQJV [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 WR ORRN DW SHRSOH¶V 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 PRYH XVHUV WRZDUGV [26]. QHZ µSUDFWLFH VSDFH¶

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, LW¶V worth considering if 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 µgreater 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 FROOHFWLYLVW VRFLHW\ ZH VXJJHVW *58%/(5¶V DSSURD more collectivist.

:KHWKHU FROOHFWLYLVW RU LQGLYLGXDOLVW SHRSOH¶V s 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

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 ±ZLOO LW EH XVHG IRU µSXEOLF JRRG¶ R ? 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 VXJJHVW WKDW GLJLWDO WHFKQRORJ\¶V UROH LV QRW WK 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.

of the tension between economic growth and decarbonisation ±\HW µLQFOXVLYH JURZW
mentioned.

CREDS highlights how reducing demand lowers the pressure to decouple. CAT questions

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 ec866

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.

ˆ ˆ 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.

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 KHDWLQJ IRU UHVLGHQWV¶ QHHGV [21]. 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 HQJDJH UHVLGHQWV LQ QHZ IRUPV RI KRXVHKROG ODERX
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 strate JLHV µSULRULWLVH GHYLFHV DQG H[SHFWDWLRQV
92).

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	x There is a need to insure continued improvements of devices ± design, repair and upgrades

Table3 Indirect effects: Efficiency and rebound in transport.

Effect	Details

Table4 Indirect effects: Efficiency and rebound in home energy use.

Effect	Details
Smart energy systems enable improvements	x 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]. x Energy management and automation could reduce up to 40% of KRXVHKROGV¶ &2[24]FRQVXPSWLRQ x Smart appliances, smart meters enable demand management and load shifting [21]. x [22, p 27] tell us that the behaviour of humans within the house, as well as indoor air qual

Table5 Digitalisation effects on economic growth.

Effect	Details
Rapid innovation cycles	x ,&7 HQDEOHV EHWWHU IRUHFDVWLQJ DQG PRQLWRULQJ RI HPLVVLRQV ologies to PDUNHW [15] DVWHU¶
Data as economic driver	x µAchieving 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] ([DPSOHV IRU µFUHDWLQJ YDOXH¶ DUH JLYHQ H J PRELOLW\ DV
Digital skills as economic driver	x Digitalisation has µopportunities 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	x µInnovative 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	x Competitive digitalisation is a catalyst for more growth ±and more energy use ±if the trend of digital futures shaped by big companies continues [23]

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

Indirect effects in relation to transport include virtual interactions substituting for travel,

6.2 Green growth and energy demand

In most of the μJUHHQ JURZWK¶ GHFDUERQLVDWLRQ VFHQDULRV, higher levels of investment and reducing costs of digitalisation are assumed to drive higher labour productivity and overall 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 ³the 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 F K D Q J H D F W L Q J D V µ V R F L D O W L S S L Q J S R L Q W V ¶ F R X O G K [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 GULYHUV DURXQG SHRSOH¶V EHKDYLRXU d policy and DQG DFWLRQ W 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 8. JRYHUQPHQW¶V VXSSRUW IRU 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.

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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 ² 4.

7.1 Climate Change Committee 2020 report ±CCC

7KH 8.¶V &OLPDWH &KDQJH &RPPLWWHH [K1] UHFRPPHQGDWL Sixth Carbon Budget (2033-2037), in the context of reaching net zero by 2050. It calls for FRQFHUWHG JRYHUQPHQW DFWLRQ RYHU WKH QH[W ross every \HD VHFWRU¶ LQ RUGHU WR HQDEOH WKH WUDQVLWLRQ

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 µIXQGDPHQWDO WR WKH RSHUDWLRQ RI D 1HW 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 µopportunities for economic growth as we transition to a green economy¶ S ZLWK µLQFOXVLYH JU 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 digital technologies in terms of jobs lost and created, for example changes in the transport VHFWRU¶V ZRUNIRUFH GXH WR IXWXUH DXWRPDWLRQ ,W suggests digital, data-rich, smart systems can RIIHU µDV D VHUYLFH¶ EXVLQHVV PRGHOV LQ YDULRXV VH

While digital technologies are seen as enablers and catalysts, perhaps even triggers under the right conditions, the right policies are needed to drive FKDQJH 7KLV LQFOXGHV SRO FULWLFDO GLJLWDO LQIUDVWUXFWXUHV IRU QHW]HUR¶ S 7KHUH LV D UHFRJQLWLRQ RI SRWHQWLDO µG\VWRSLDQ V 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

7.2.4 Automation/Agency

2Q WKH RQH KDQG WKHUH LV GLVFXVVLRQ RI PDFKLQH O
RQ µGDWDYHQ V\VWHPV¶ VXJJHsting significant automation. On the other hand, digital technologies are described as enablers, stressing that their development should be µinclusive and grounded in engagement with all stakeholders and communities affected by their use ¶(p 6). Further, there is a stress on µenabling 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 PDLQ WKHPHV DUH µSRZHULQJ GRZQ
µSRZHULQJ XS UHQHZDEOHV¶ This report calls for ambitious climate change policy, requiring a shift in policy priorities, although the focus is on societal and cultural change.

7KLV VFHQDULR XVHV µRQO\ WHFKQRORJ\ available now and currently in use, or technologies which
KDYH EHHQ GHPRQVWUDWHG WR ZRUN¶ S ERWK WR H
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.

7KHLU SODQ LV WR µUHWKLQN WKH HFRQRP\ EDVHG RQ K
ZLWK RXU HFRV\VWHPV¶ S +RZHYHU 7KH HFRQRPLF
e[SHFWHG 8. LQGXVWU\ IRU H[DPSOH µLV VLPSO\ D PRUH
WRGD\¶ S

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
IRFXVHG VFHQDULR ZLWK QXFOHDU ELRPDVV &&6 DQG L
VFHQDULR ZKLFK XVHV VROHO\ UHQHZDEOHV IRU VXSSO\
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

7.4.1 Supp37

includes more specification about supply, e.g., discussion of µresilient 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¶, µGDP 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

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 VPDOO HQHUJ\ HIILFLHQW OLYLQJ VSDFHV ZLWK D µ
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: µTraditional
JURZWK PRGHOV DUH FKDOOHQJHG E\ WKH QRWLRQ RI ³O
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, µThe 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 µCitizens 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 µYLUWXDO JUHHQ VSDFHV¶ IRU W
access to outdoor green space.

7.7.4 Automation/Agency

The narrative suggests high levels of automatio Q DV µ$UWLILFLDO LQWHOOLJHQ GLIIHUHQW WDVN V (p 29). Deep learning algorithms make health LQ HYHU\ GD\ OLIH¶ UHFRPPHQGDWLRQV DQG VHQVRUV DGMXVW KRPHV WR LQ Further, there is smart system and data-led automation ensuring efficiency, IRU H[DPSOH µthe behaviour of humans within the house, as well as indoor air quality are carefully monitored and integrated into the VPDUW KRPH¶ S Citiz HQ6 R SZ HU R OH µ WK H (p 26), this scenario leans LQ OLYLQ J VSDFHV¶ 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 µOLPLWLQJ JOREDO SURGXFWLRQ DQG FRQVXPSWLRQV DQ of envisioning a broader societal WUDQVIRUPDWLRQ¶ S 6SHFLILFDOO\ WKHLU 6RFLHWD economic activity in the Global North, while assuming increased consumption in the Global 6RXWK D µFRQWUDFW DQG FRQYHUJH¶ DSSU oach.

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 µWKHVH DVVXPSWLRQV PXVW EH UHJDUGHG DV FKDOOHQJ that can be overcome, not as arguments DJDLQVW D FRPSUHKHQVLYH VRFLHWDO WUDQVIRUPDWLR

7.8.1 Supply/Demand

The focus on social change in the Global North suggests a demand side approach, e.g., µwe 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 µGrowth 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: µInstead 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

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 GLJLWDOLVDWLRQ DQG µVPDUW¶ V\VWHPV WKDW HQDEOH n, 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 µend-use is the least efficient part of the global energy system and has the largest improvement potential ¶(p 515). This µGRZQVL]LQJ¶ RI WKH V\VWHP PDNHV D ORZ-carbon supply side more feasible. While supply is DOVR FRQVLGHUHG LW LV PRUH RI D µPDLQVWUHDP¶ GHF

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 µD SODQQHG UHGXFWLRQ RI WKH PDWHULDO DQG HQHUJ\ 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 IURP D SURGXFHU-WR-FRQVXPHU µEXVLQHVV PRGHOV DORQJVLGH VKDU

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

SHRSOH KHUH VHHPV-fitVHRQ GH \¶ LDPQ WHLQ IWR PµDXWLHRQ SURYLV

limited change to end-user roles.

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