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Expert Workshop on Digitalisation Narratives and Climate Change Mitigation: *Synthesis Report*

February 2025

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Abstract

35 scientists and industry representatives gathered at the International Institute for Applied Systems Analysis (IIASA) outside Vienna in Austria on May 13-14, 2024, to build understanding of how both current and future trajectories of digital transformation impact emission-reduction efforts. This expert workshop on "Digitalisation Narratives and Climate Change Mitigation" was motivated by the weak *explicit* consideration of digitalisation in future scenarios and modelling assessments used to inform global climate policy.

Participants explored the impacts of digitalisation on energy, materials, firms, markets, lifestyles, and society, and what these impacts mean for greenhouse gas emissions. Workshop activities and insights in this report are organised in three parts: digitalisation impact pathways; future narratives for digitalisation; and digitalisation in the SSP scenario framework used in climate change analysis.

First, participatory system dynamic maps created during the workshop capture the main impact pathways of digitalisation in each of four domains: society and behaviour, economy and firms, governance and markets, energy and materials. Representing system behaviour in this way shows how coupled positive and negative feedback loops prevent runaway consequences of digitalisation even if the current evidence in some areas (e.g., market concentration) point to the dominance of some loops over others. The system maps also reveal the importance of cross-scale interactions (e.g., between households' consumption choices and institutions like social trust). Each map also highlights control strategies for mitigating the adverse consequences of digitalisation by strengthening certain loops over others (e.g., reskilling programmes to weaken job destruction dynamics).

Second, running the system dynamic maps forwards under different assumptions about which feedback loops dominate provided a structured basis for thinking through future narratives for digitalisation. Best- and worst-case worlds bound the future scenario space in which digitalisation could either deliver positive societal outcomes and align with climate goals, or the converse. Each of these extreme scenarios is the result of self-reinforcing dynamics with weak balancing loops to keep the trajectory of path-dependent change in check. In each scenario, key actors – firms, governments, regulators, households – pursue strategies shaped by market incentives and other enabling conditions. Several strategies emerge as ways to plan for desirable outcomes while mitigating risks of unfavourable outcomes. These strategies range from regulatory frameworks to avoid market concentration to concerted action to tackle income, livelihood, and access inequalities.

Third, the shared socioeconomic pathway (SSP) framework provides five alternative global development storylines used in global climate mitigation modelling analysis. Certain SSP elements – including growth, innovation, government effectiveness, and regional convergence - were linked into the digitalisation impact pathways mapped out by workshop participants. These linkages emphasised how digitalisation acts as an amplifier of both beneficial and adverse changes throughout the socioeconomic system, and as both the cause and the effect of change. The positive effects of digitalisation on productivity, innovation, growth and global trade and cooperative global institutions align most closely with SSP1 and SSP5 storylines. The negative effects of digitalisation on market concentration and power align most closely with SSP4, and on labour market, skills and access inequalities most closely with SSP3 and SSP4.

Finally, digital governance for climate mitigation themes emerged throughout the workshop. Digital governance for climate mitigation can be narrow or broad, but no consensus was reached on which was necessary. A narrow view was that climate governance establishes direction, while digital governance should

focus on issues unique to the sector including the energy footprint of ICT infrastructure, and misinformation risks to democratic institutions. A broad view was that digital governance should additionally tackle the indirect impacts of digitalisation on GHG emissions through substitution, productivity, rebound and other effects. The speed and scope of AI developments, which pose particular digital governance challenges, were another cross-cutting theme that came up throughout the workshop.

In sum, this synthesis report: (i) maps out the complexity and pervasiveness of digitalisation impacts across society and the economy; (ii) demonstrates how digitalisation is a double-edged sword with both positive and negative effects on jobs, on sustainable growth, and on user engagement and empowerment; (iii) counters a naïve perception that rapid digital transformation is necessarily aligned with climate goals; (iv) shows how firm and household-level digitalisation impacts have wider systemic consequences; (v) identifies common areas of understanding including on the importance of tackling the digital divide, fast paced AI developments, and societal risks from misinformation; (vi) exposes fault lines in expert opinion on the need for broad vs. narrow digital governance.

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Section I. Introduction.

1. **This report presents the results of an expert workshop on Digitalisation Narratives and Climate Change Mitigation. The workshop's aim was to understand how both current and future trajectories of digital transformation impact emission-reduction efforts.**
   1.1. The workshop took place on 13-14 May 2024 at the International Institute for Applied Systems Analysis (IIASA) outside Vienna in Austria. It was organised by Charlie Wilson and Elena Verdolini as part of the activities of their respective ERC projects iDODDLE and 2D4D, and was further supported by the RCN-DEE and EDITS networks as well as the Horizon Europe projects CircEUlar and AdJUST.
   1.2. The workshop gathered 35 scientists and industry representatives to explore and discuss the impacts of digitalisation on energy, materials, the economy, markets, lifestyles, and society, and how these impacts directly or indirectly affect greenhouse gas emissions.

2. **The workshop was motivated by the weak explicit consideration of digitalisation in future scenarios and modelling assessments used to inform EU and global climate policy.**
   2.1. Digitalisation comprises a very wide range of technologies and applications from platforms and cloud computing to internet of things and AI.
   2.2. Few of the thousands of scenarios reviewed in the IPCC's recent 2022 assessment mention digitalisation as a transformative force shaping economic and social life.
   2.3. Yet, digitalisation creates both opportunities and risks for greenhouse gas (GHG) emission reductions across all sectors and domains (Blanco, Coninck et al. 2022).
   2.4. This implies that digital and climate governance need to be better integrated, in turn requiring joint scientific assessment of digital impacts on climate-relevant issues, and vice versa (Creutzig, Roy et al. 2022).
   2.5. Digitalisation (AI) and climate also both constitute global existential risks and can be managed as global public goods or commons.
   2.6. The *aim of the workshop* was to map out future narratives describing how digitalisation interacts with emission reduction efforts through the impacts it may have on energy, society, economy, and governance.

3. **Workshop activities were organised in three interrelated sessions: impact mapping, future narratives, intervention strategies.**
   3.1. In a first session, participatory system dynamics methods were used in small break-out groups for each of four domains: (a) society and behaviour, (b) economy and firms, (c) governance and markets, (d) energy and materials. In each domain, participants identified dominant variables, causal relationships, and feedback loops. Impact pathways were then iteratively extended, discussed, and revised.
   3.2. In a second session, participants in the breakout groups used the systems maps and a future thinking approach to help characterise alternative possible digitalisation futures. They were tasked to explore a wide future possibility space, bounded by best- and worst-case assumptions on which causal relationships or feedback loops dominated. Each future narrative was characterised by a set of drivers, dynamics, conditions, actor strategies, and outcomes.
   3.3. In a third session, participants were asked to build on the digitalisation narratives to discuss intervention strategies for aligning digitalisation with climate goals over the near (to 2035) to medium-term (to 2050).

4. **This report presents results and insights from the workshop.**
   4.1. Section II presents the main feedback loops emerging from the discussions and systems dynamics maps produced by the groups. The original maps were digitised, studied and simplified to highlight main reinforcing and dampening loops. Intervention points and linkages between the maps in the different breakout groups were identified.
   4.2. Section III presents two different digitalisation narratives, one in which digital technologies support the achievement of good societal outcomes and one in which digital technologies contribute to the

achievement of bad societal outcomes. These narratives were developed by analysing and comparing the notes of the different break-out groups, as well as the recorded conversations.

4.3. Section IV focuses on the links and intersection points between digitalisation narratives and climate mitigation. Specifically, researchers looked for common themes/connections and/or key points of divergence or 'branching points' and tried to identify intervention points.

4.4. Section V focuses on issues of digital governance. It summarises the main insights emerging from the discussion on how to ensure that digital futures are aligned with climate futures.

5. Short framing talks during the workshop - as well as a background briefing paper circulated to participants prior to the workshop - set out the key issues for discussion, defined key terms and concepts, and set the scope for workshop activities.

5.1. Certain terms from the workshop are also used throughout this report.

5.2. *Digitalization* is the widespread use of digital technologies by people and organisations, and the changes or restructuring effects this has on society and the economy (Brennen and Kreiss 2016).

5.3. *Information and communication technologies* (ICTs) include both upstream infrastructure (e.g., data centres), networks and end-use devices

5.4. *Digitalization impacts* are the causal pathways or mechanisms through which the use of digital technologies causes change in different domains of social and economic activity.

5.5. *Energy and material demand* is impacted by digitalisation both directly through digital infrastructure itself and indirectly through digital applications enabled by that infrastructure.

5.6. Energy demand is of particular interest as it is the precursor of *GHG emissions*, depending on the carbon intensity of the energy supply.

6. A common taxonomy of how digitalisation impacts energy and GHG emissions distinguishes direct, indirect, and systemic impacts.

6.1. Direct impacts are from the energy used to build and operate ICT infrastructure. The current generative AI boom has increased the salience of direct impacts.

6.2. Indirect impacts are from how digital applications change energy-using processes, systems, and behaviours (Horner, Shehabi et al. 2016, Kaack, Donti et al. 2022). For example, smart control systems can improve the energy efficiency of industrial production or urban transport systems.

6.3. The indirect impacts of digitalisation on energy demand can trigger higher order effects such as rebound if efficiency or productivity improvements stimulate more demand (Coroamă and Mattern 2019).

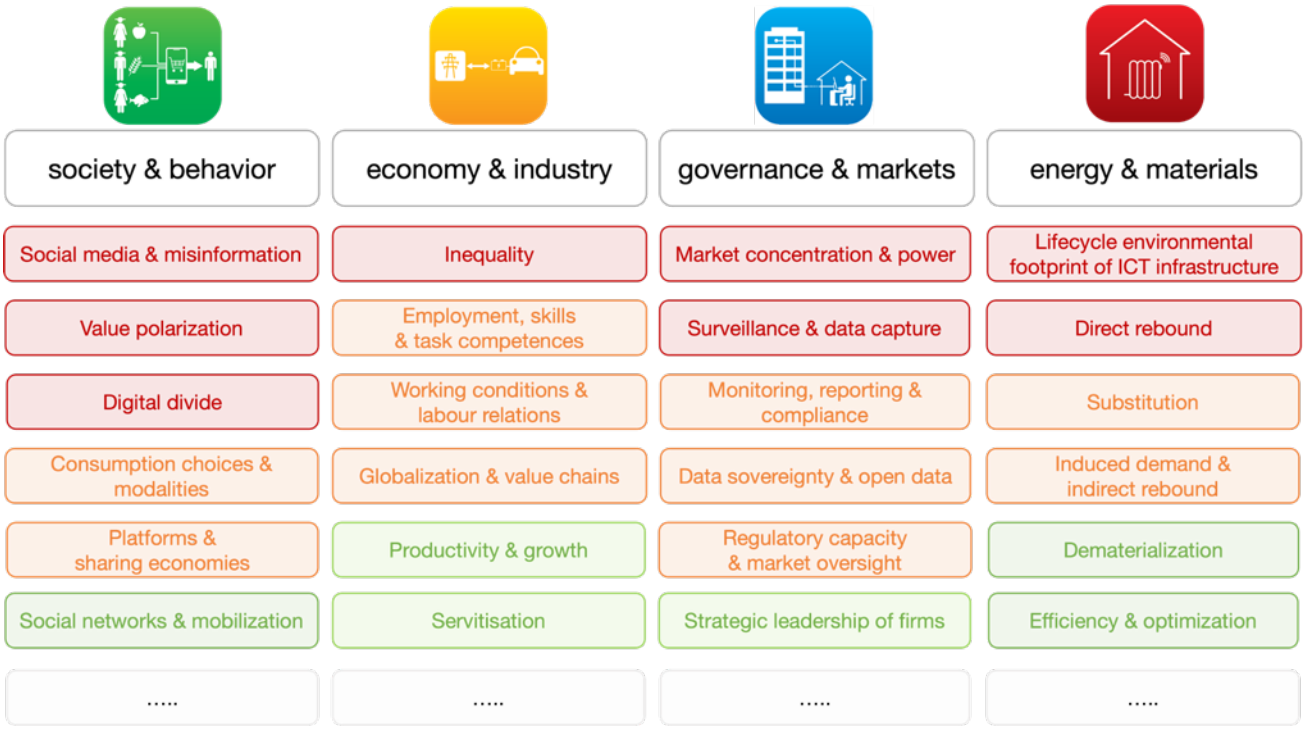
6.4. Digitalisation also has systemic effects on labour markets, on the structure of economic activity, on social norms and patterns of interaction, and so on. These may also have implications for energy and material demand, and so GHG emissions. Mapping these systemic impacts is one of the workshop aims.

7. Four domains were used to organise and focus workshop discussions: (a) Society and Behaviour; (b) Economy and Firms; (c) Governance and Markets; (d) Energy and Materials.

7.1. Digitalization is driving large-scale structural changes in each of these domains. Figure 1 provides examples. The energy and materials domain links digitalisation across society and the economy to its resource impact with implications for GHG emissions.

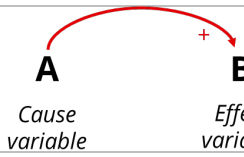
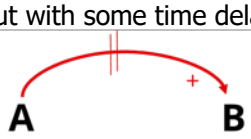
7.2. These four domains helped make the mapping of impact pathways more manageable. However, there are many interconnections between impacts in different domains, as well as cross-cutting themes related to governance, AI as a potential gamechanger, and so on.

FIGURE 1. EXAMPLES OF DIGITALIZATION IMPACTS IN DIFFERENT DOMAINS. TRAFFIC LIGHT COLOURING DENOTES NEGATIVE (RED), POSITIVE (GREEN), NEGATIVE OR POSITIVE (AMBER) IMPACTS FROM A SOCIETAL PERSPECTIVE.



8. **Participatory system dynamics methods were used in the workshop to map out chains of causal relationships and feedback loops that characterise digitalisation impacts in each of the four domains.**
   - 8.1. System dynamics is a modelling method for complex systems (Barbrook-Johnson and Penn 2022).
   - 8.2. Feedback loops govern the dynamics of a system - its behaviour over time. Even though a model composed of feedback loops is a static representation of a system, it conceptualizes the system's dynamic behaviour over time.
   - 8.3. *Causal loop diagrams* can be used to visualize feedback loops. Relationships between variables are represented by an arrow and a polarity sign (Figure 2). The arrows or connections represent causal influence from one variable to the other. This can be either positive (i.e. they increase or decrease together) or negative (i.e. they change in opposite directions).
   - 8.4. *Feedback loops* form from closed chains of causal relationships. The polarity of a loop is determined by multiplying the polarities of individual links. A positive (reinforcing) feedback loop emerges if a change in any of the variables cascades through the loop to reinforce change in that variable in the same direction. A negative (balancing) loop returns a change in the opposite direction, hence balancing the dynamic behaviour. Positive feedback loops create exponential growth or decline. Negative feedback loops create logarithmic growth or decline.
   - 8.5. Participatory modelling involves experts and stakeholders to elicit different model components such as variables, causal relationships, and feedback loops (Vennix 1999).
   - 8.6. Participatory modelling combines scientific and expert knowledge about a system, helps stakeholders reach a common understanding of a system's structure and behaviour, and creates a shared ownership of the problem, analysis, and commitment about decisions (Andersen, Vennix et al. 2007).

FIGURE 2. REPRESENTING RELATIONSHIPS IN CAUSAL LOOP DIAGRAMS.

positive relationship: change in A changes B in the same direction	**negative relationship:** change in A changes B in the opposite direction	**delayed relationship:** change in A changes B in the same direction but with some time delay
		

Section II. Mapping digitalisation impacts.

9. Workshop participants were grouped into one of four domains based on their expertise in order to map digitalisation impact pathways using participatory system dynamics methods.

9.1. In each domain, an initial 'concept model' developed in advance by the workshop organisers introduced some basic causal relationships and helped familiarize participants with the method. The concept models are shown in the Appendix.

9.2. From these start points - which each group could extend, amend, or reject as they saw fit - workshop participants co-produced their own maps of digitalisation impact pathways, facilitated by workshop organisers.

9.3. The 'raw data' from whiteboards was post-processed by the workshop organisers into a formal representation of causal loop diagrams that enshrine the participants' understanding of the feedback loops that generate system behaviour. Example of the raw data collected on whiteboards during the workshop are shown in the Appendix.

9.4. This post-processing step was necessary to clean, clarify and refine the model diagrams to ensure coherence, avoid redundancies, and add missing factors discussed during the workshop.

9.5. In this section we present and narrate the cleaned causal loop diagrams in each of the four domains before discussing linkages and interactions.

Feedback loops are named in bold italics: R denotes reinforcing loop; B denotes balancing loop.

Society and Behaviour

10. The Society and Behaviour domain encompassed both micro-level impacts of digitalisation on individual and household behaviour and macro impacts on societal functioning.

10.1. Individual or household-level engagement with social media, e-commerce, and other digital platforms and technologies were introduced in the initial concept models and elaborated by participants. Concept models are shown in the Appendix.

10.2. How digitally-enabled (mis)information flows support or erode societal cohesion, trust, and participation are examples of the systemic dimension to digitalisation impacts in this domain.

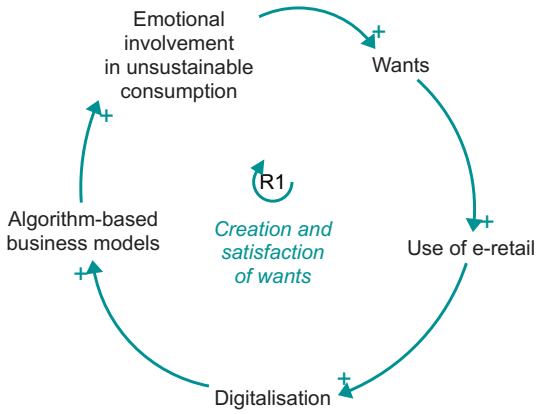
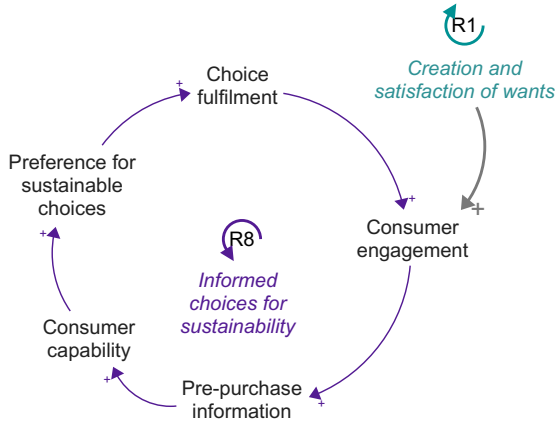
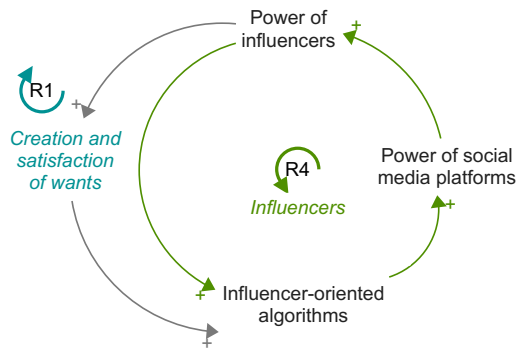
11. The basic feedback loops characterising the impact of digitalisation in the Society and Behaviour domain relate to consumer behaviour under online influence as well as (mis)information consequences for social cohesion and mobilisation.

11.1. The first three loops characterise digitalisation impacts on individual needs, wants, preferences, and behaviour with an emphasis on consumption: *Creation and satisfaction of wants*, *Informed choices for sustainability*, *Influencers*. A further set of loops show how digital platforms can drive both sustainable and unsustainable modes of consumption: *Sharing Economies*, *Product Ownership*, *Sustainability Norms*. These are shown in Figure 3.

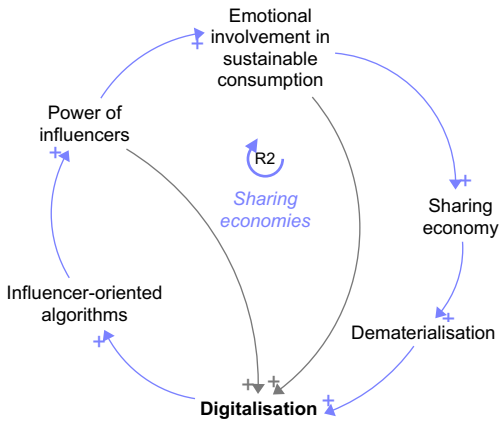
11.2. The final two loops focus on (mis)information flows through digital platforms with resulting effects on societal mobilisation and polarisation: *Misinformation and polarisation*, *Empowerment and mobilisation*. These are shown in Figure 4.

11.3. These two sets of feedback loops comprise the building blocks of the more complex interactions discussed further below.

FIGURE 3. BASIC FEEDBACK LOOPS CHARACTERISING DIGITALISATION IMPACTS ON BEHAVIOUR.

A  	***Creation and satisfaction of wants.*** Digitalisation enables *business models* that use algorithms to *emotionally engage* with users, creating '*wants*' (desires, preferences) fulfilled digitally through *e-retail.* The relative profitability and effectiveness of this business model drives further digitalisation.
B  	***Informed choices for sustainability.*** Digitalisation can boost sustainable consumption by making information about products more accessible. An increase in consumers engaging with *pre-purchase information* strengthens *capabilities* for making *sustainable choices.* Positive experiences of *choice fulfilment* interact with the ***satisfaction of wants*** loop to drive further engagement with information-rich digital platforms.
C  	***Influencers.*** The ***creation of wants*** loop is further reinforced by the *power of social media influencers* who gain increasing traction through the use of digital *platforms and algorithms* that promote and amplify their influence. ***Satisfaction of wants*** through e-retail platforms can include ***informed choices for sustainability***.

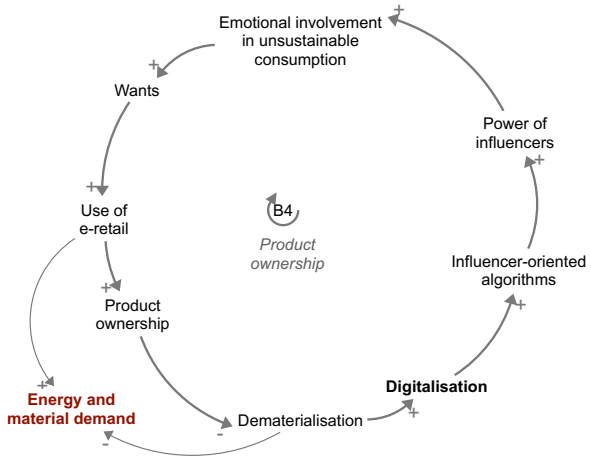
D



Sharing economies.

Digital platforms can support peer-to-peer exchange and collaborative consumption, reinforced through promotion via social media.

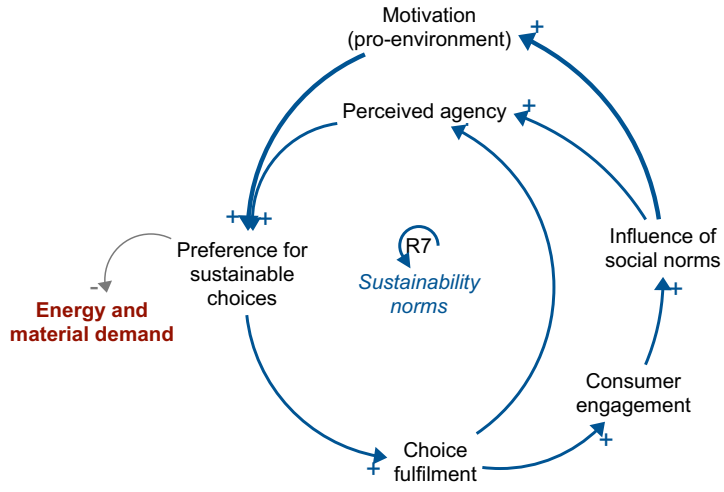
E



Product ownership.

Digital platforms and influencers create new avenues for instant gratification of material wants, leading to an accumulation of physical goods.

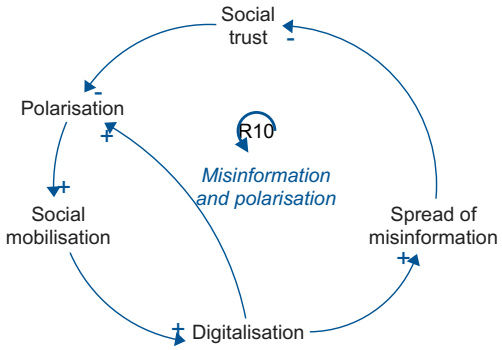
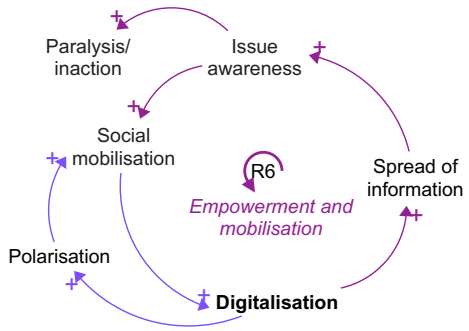
F



Sustainability norms.

Strengthening *social norms* reinforce sustainable consumption both through *perceived ability to choose* (e.g., more diverse choice sets as markets shift to cater to changing norms) and through strengthened *motivations* to act.

FIGURE 4. BASIC FEEDBACK LOOPS CHARACTERISING DIGITALISATION IMPACTS ON SOCIETY.

A  	***Misinformation and polarisation.*** The *spread of misinformation* polarises digital communities that seek affirmation through selective use of online networks, creating echo chambers that erode shared understanding and *social cohesion and trust*. Exposure to information that confirms pre-existing beliefs creates further traction for misinformation.
B  	***Empowerment and mobilisation.*** The same mechanisms of information dissemination can raise *issue awareness* and so empower and *mobilise* people to act … or lead to *paralysis and inaction* if the issue is perceived as beyond individual capabilities to act.

12. Interactions between individual feedback loops build up a more integrated systems representation of digitalisation impacts on Society and Behaviour.

12.1. The first set of interactions (Figure 5A) show how the emotional engagement targeted by influencer culture can potentially drive sharing economies and service-based business models that shift consumerist culture from owning to accessing, in turn stimulating further digitalisation.

12.2. This is evident in the increasing use of 'pre-loved' clothing platforms like Vinted as well as longer-established second-hand trading platforms like eBay and the profusion of urban mobility apps including micromobility (bikes, e-bikes, e-scooters) and mobility-as-a-service.

12.3. However, the same mode of emotionally-engaged consumption can also drive towards material consumption and the accumulation of goods.

12.4. The second set of interactions illustrate how mechanisms cut across system scales, from individual level engagement with digital platforms including e-commerce and social media to digital transformation of society.

12.5. In this example (Figure 5B), successful influencers are seen as trustworthy sources of information about specific products and services, as well as role models for 'good' or socially acceptable taste. This creates wants in a self-reinforcing dynamic as more people use affiliate links and social media platforms to purchase goods and services promoted by influencers driving the algorithms that reinforce their reach.

12.6. This dynamic related to consumption and lifestyle interacts with the polarisation and erosion of social trust in increasingly fragmented information environments for political and social discourses.

12.7. The rise of artificial intelligence influencers such as Aitana that are indistinguishable from humans and are designed by firms to manipulate consumers' perceived wants and choices further undermines social trust.

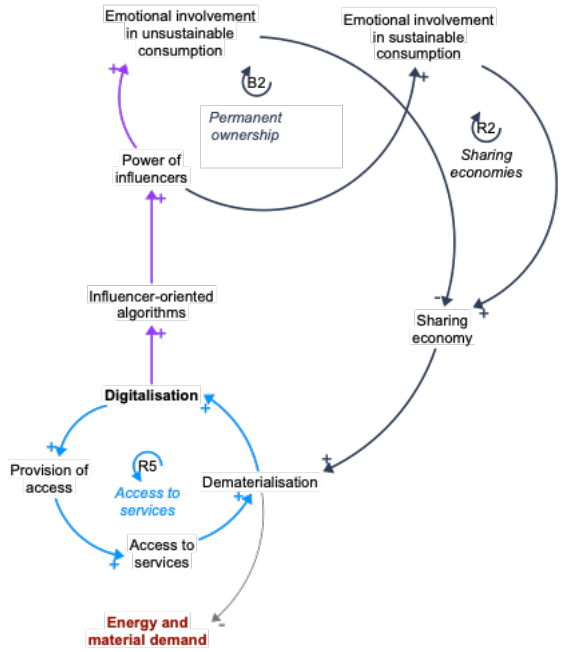
12.8. Echo chambers spread between informational and consumption domains, undermining shared understandings of appropriate wants and needs in a climate-constrained world.

12.9. This is evident in the observable tension between policy goals and measures on net-zero (e.g., low-carbon technology mandates including heat pumps and EVs) and the social resistance to normalise these measures within current lifestyles.

12.10. The third set of interactions (Figure 5C) shows how the same basic dynamic through which online information, emotional appeal, and influence draws people into self-affirming loops can also mobilise people to act - both in a political or social domain as well as through more sustainable consumption choices.

FIGURE 5. INTERACTIONS BETWEEN FEEDBACK LOOPS IN SOCIETY AND BEHAVIOUR.

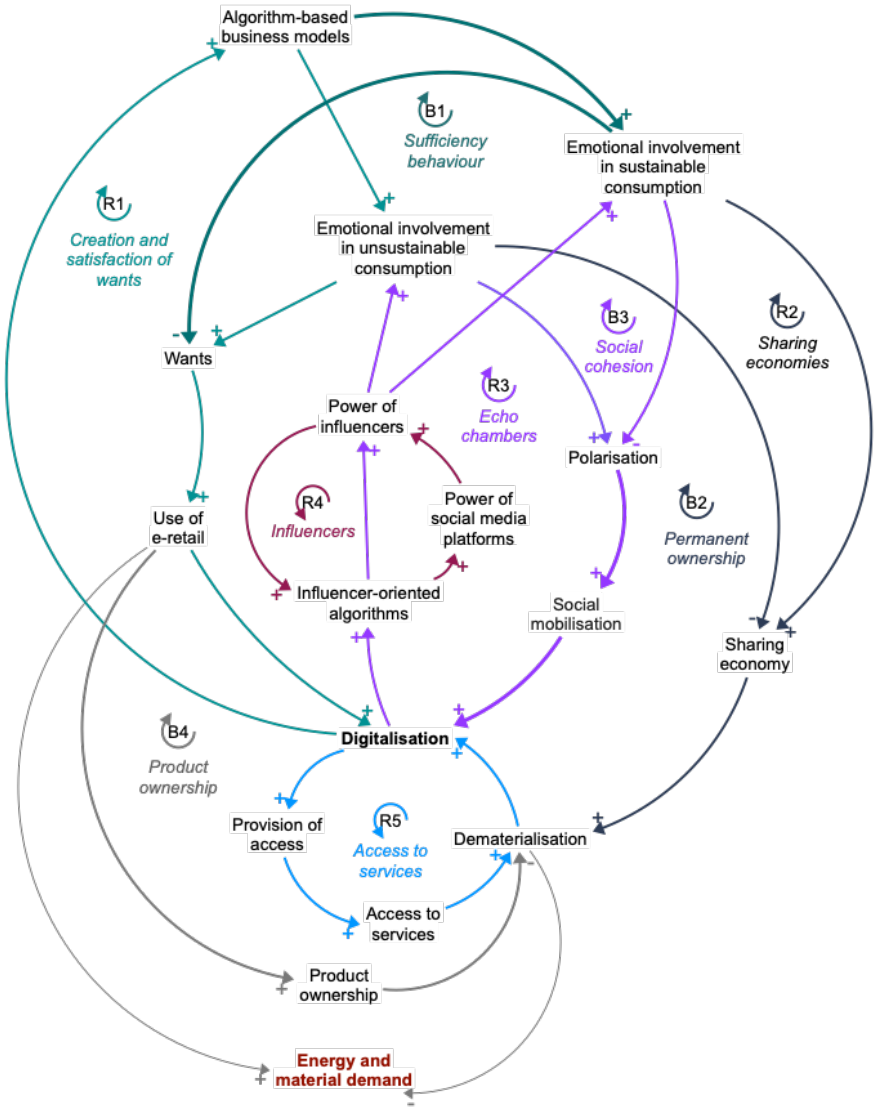
A



Influencers and Consumpion Cultures.

Digitalisation has created and fed an online influencer culture: *Influencers* are promoted and trusted as tastemakers influencing the ***creation of wants*** in consumerist societies. This influence can promote sustainable choices towards ***service-based and sharing economies*** *(R2 & R5).* Conversely, influence can amplify material consumer culture and the ***ownership of goods*** (B2).

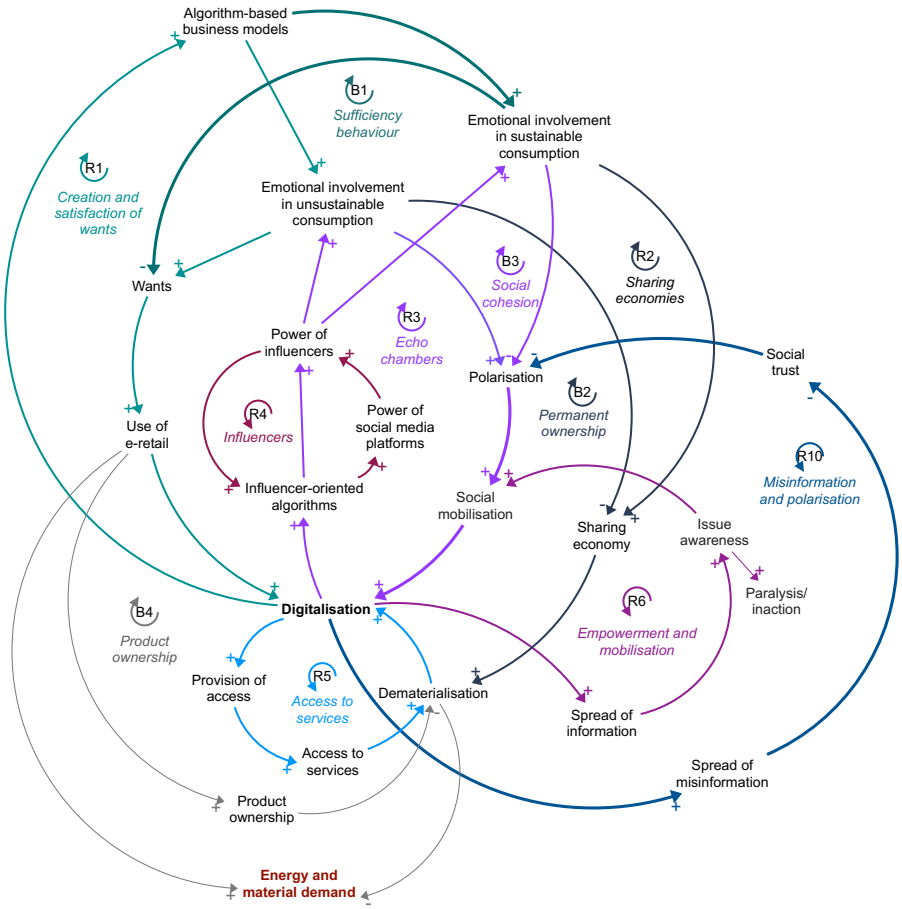
B



Influencers and Polarisation.

Social media ***influencers*** (R4) appeal to emotions and identities in distinct market segments, ***creating wants*** satisfied through *e-retail* (R1) or its antagonist, ***sharing economies*** (R2). This fragmentation in role modelling interacts with and reinforces the opinion polarisation enabled by ***echo chambers*** (R3) and social media platforms. Conversely, influencers promoting ***sufficiency behaviour*** (B1) can increase **social cohesion** (B3) by promoting lifestyles with collective benefits. Both influencer and social mobilisation loops further embed digitalisation.

C



Misinformation vs. Mobilisation.

Another major contributor to polarisation is the ***spread of misinformation*** (R10) accelerated by digitalisation. This is a downside to the easy accessibility of social media platforms with relatively low accuracy checks that influential individuals (or AI) can use to reach large groups of people. In a counteracting dynamic, these same mechanisms enable rapid dissemination of accurate and ***empowering information that can mobilise*** people to act on issues of concern (R6).

13. The full set of system interactions in the Society and Behaviour domain shown in Figure 6 integrates: (i) the reinforcing loops of influence and emotional engagement which create wants fulfilled through algorithm-driven e-retail but also, potentially, sharing economies; and (ii) the tension between reinforcing and balancing loops describing how (mis)information can both mobilise and polarise.

13.1. Also shown in Figure 6 are loops connecting the first set of consumption-oriented processes into reinforcing loops describing the potential for digitally-enabled sustainable consumption in more detail through interactions between motivations, capabilities, and social norms.

13.2. Underpinning these interactions is the ability for digitalisation to engage users in tailored, targeted, and emotional ways and to build awareness of social momentum and normalisation – including in pro-environmental directions.

14. Digitalisation impacts on Society and Behaviour are complex as they range across scales from individual consumption choices to social trust and cohesion, and across spheres of activity from retail and material needs fulfilment to political and social discourse.

14.1. The feedback loops describing these various dynamics are generally reinforcing (Figure 6). Digitalisation is an amplifier with an evident trajectory towards being ever more embedded in daily life. From a climate perspective this influence cuts both ways: competing reinforcing loops drive towards sustainable or unsustainable consumption, and towards social mobilisation or fragmentation.

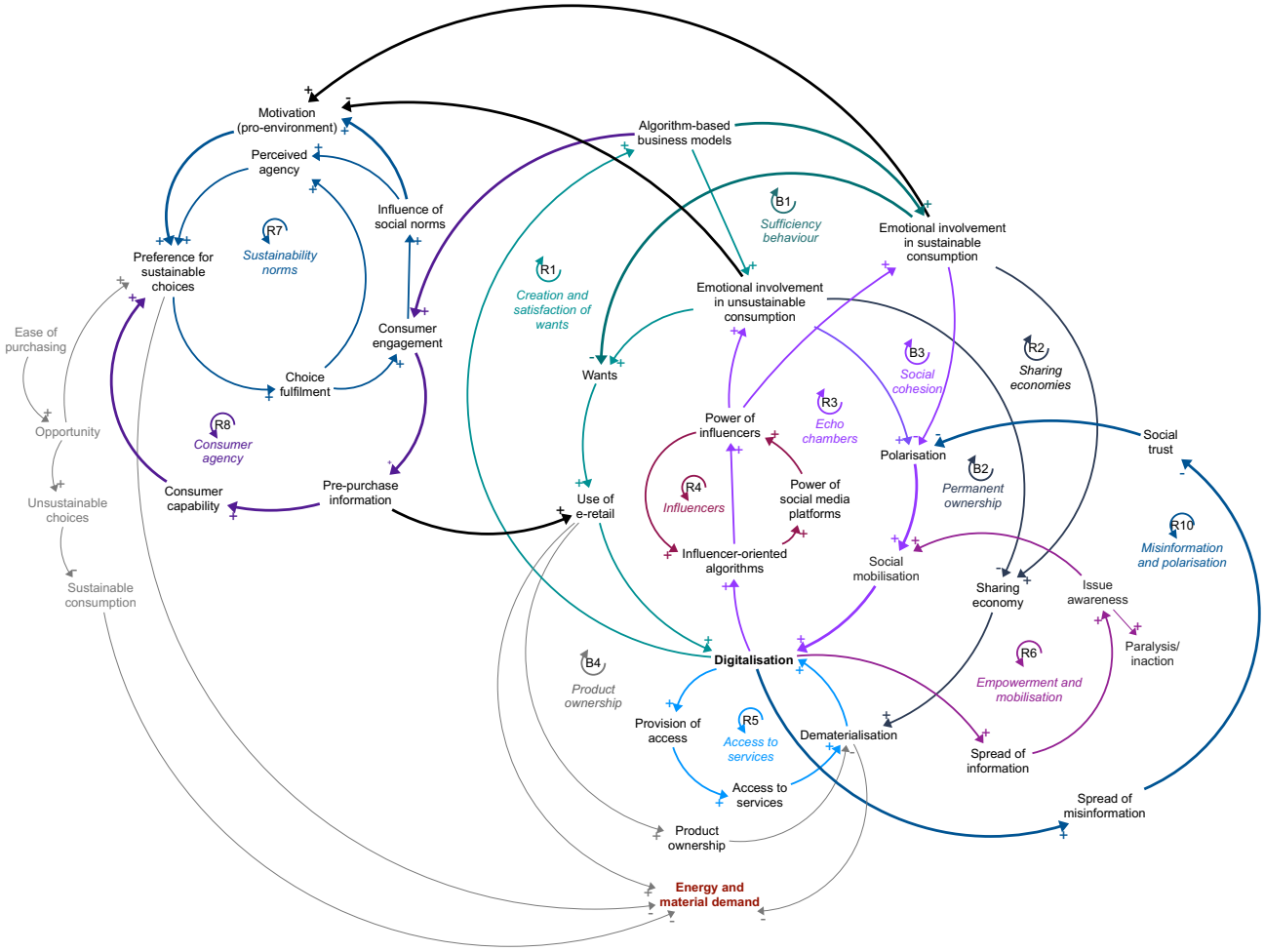
14.2. Evidence of these competing loops can be seen in e-retail growth and business model innovation (e.g., immediate delivery) alongside the proliferation of low-carbon lifestyle identities and groups.

14.3. Similarly, evidence in social discourse points clearly both to polarisation and echo chambers (particularly in large social media platforms), as well as to digitally-enabled mobilisation, activism, and communication campaigns.

14.4. An important insight from the system dynamic map shown in Figure 6 is that these competing loops in consumption and political contexts are interconnected. How influencers and algorithms harness information flows to engage with consumers and citizens is of common concern across spheres of activity.

14.5. A control strategy that follows from this insight for climate futures is to monitor and mitigate influence processes that lead to a disconnection between the need for climate action in both individual lifestyles and in wider social discourse.

FIGURE 6. FULL SYSTEMS MAP FOR DIGITALISATION IMPACTS ON SOCIETY AND BEHAVIOUR.



Economy and Firms

15. The Economy and Firms domain encompassed both micro-level impacts of digitalisation on firm strategy, business models, and skills needs, and macro impacts on jobs, market concentration and investment.

15.1. The initial concept models elaborated upon by participants included firm-level responses to the opportunities and risks created by digitalisation, particularly the differentiated impacts on workers depending on their skills and capabilities. Concept models are shown in the Appendix.

15.2. Economy-wide impacts of digitalisation discussed by participants included how the availability and distribution of jobs could fuel or retard growth and resulting reinvestment cycles in upgrading digital capabilities.

16. The basic feedback loops characterising the impact of digitalisation in the Economy and Firms domain relate to jobs and rents.

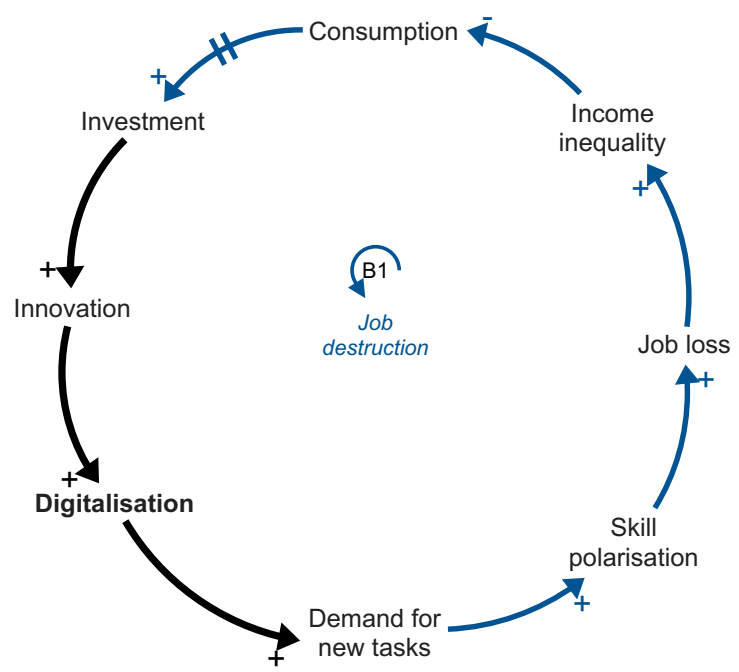
16.1. The first set of loops focus on jobs: *Job destruction*, *Job enhancement*. The second set of loops focus on rents: *Rent extraction*, *Rent suppression*. These are shown in Figure 7.

16.2. The rent extraction and suppression loops concern the economic rents ('unearned revenues', or payments in excess of the cost of production) available to a few firms in concentrated markets if they can set prices above marginal costs, to the detriment of consumers.

16.3. These two sets of feedback loops comprise the building blocks of the more complex interactions discussed further below.

FIGURE 7. BASIC FEEDBACK LOOPS CHARACTERISING DIGITALISATION IMPACTS ON ECONOMY AND FIRMS.

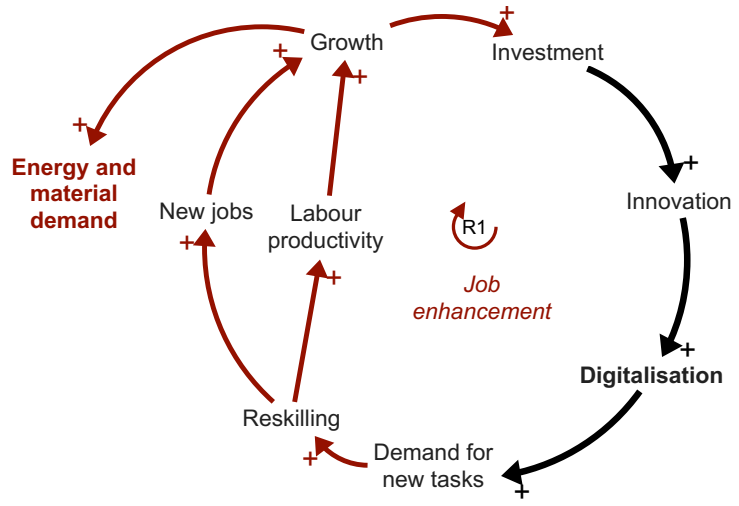
A



Job destruction.

Digital technologies require that workers perform *new tasks* and acquire digital skills rendering some skills and tasks obsolete (cf. automation). This leads to *skill polarisation*. Workers with the requisite digital skills to perform new tasks will be in high demand; those without will *lose their jobs*, leading to an increase in *income inequality*. This lowers consumption which in the long run translates into lower investment, dampening innovation and the discovery and diffusion of new digital technologies.

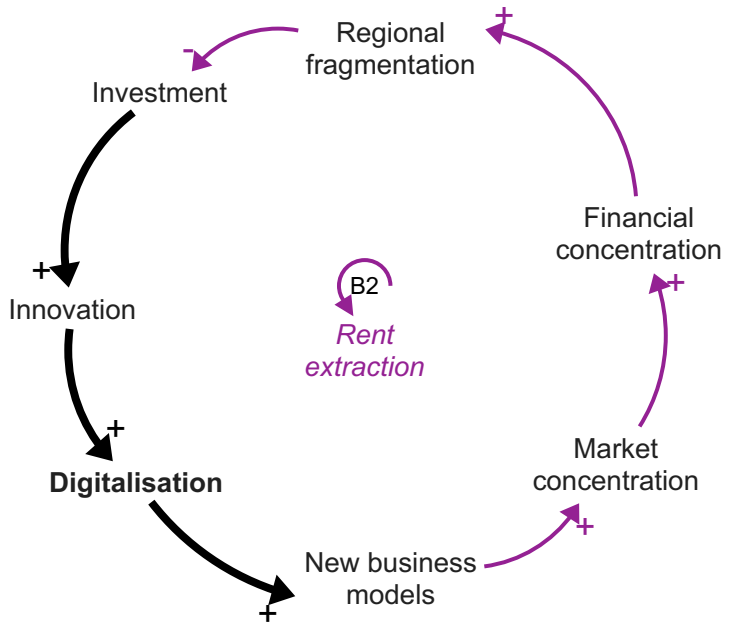
B



Job enhancement.

Demand for new tasks pushes workers towards *reskilling* including through programs from the private and public sector. Reskilling allows workers to use digital technologies in their current job – increasing their productivity – or, alternatively, to seek new digital jobs. Both effects drive economic growth that, in turn, fosters investments in innovation and the discovery and diffusion of new digital technologies.

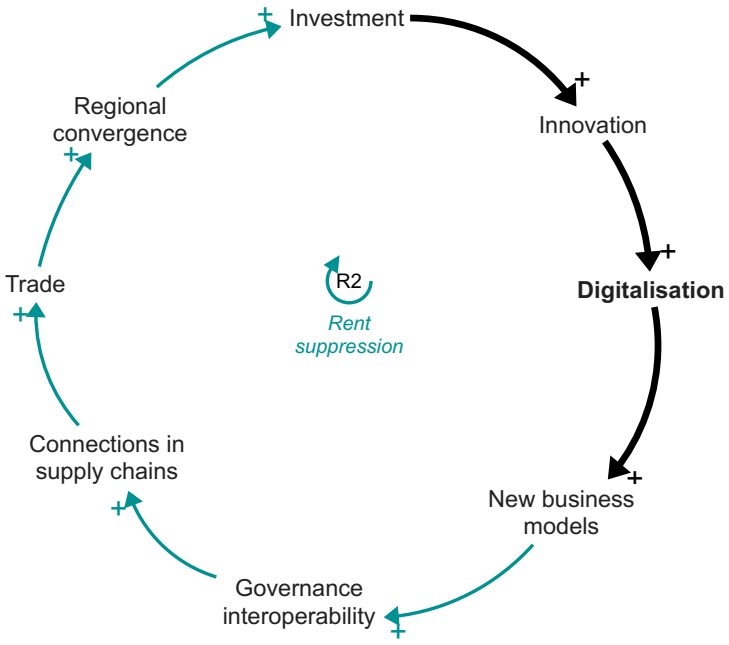
C



Rent extraction.

Digitalisation promotes *new business models* including servitisation (adding services to product offerings), but many businesses, particularly SMEs, face financial barriers to investment in requisite digital skills. Large firms with more capital disproportionately reap the benefits of digital technologies which translates into higher *market concentration* and so the *concentration of financial capital* in better resourced firms and regions. Digital solutions are not adapted to the local needs of firms and markets lagging behind. This *fragmentation* dampens aggregate *investment* in further digitalisation across all firms and markets.

D



Rent suppression.

Digitally-enabled *business models* create opportunities for multiple firms to work together to provide goods and services. This increases the demand for technical, legal, institutional and *governance interoperability* as well as the incentives to provide it. When systems successfully operate together, *connections in supply and value chains* increase, promoting *trade* and integration within and across countries. This, in turn, increases economic growth and *investment* in innovation and in the diffusion and development of digital technologies. While this dynamic tends to improve market competition (and so rent suppression), rent seeking behaviour may persist.

17. Interactions between individual feedback loops build up a more integrated systems representation of digitalisation impacts on Economy and Firms.

17.1. The first set of interactions (Figure 8A) show the tension between the job creation and job destruction implications of digitalisation. These counteracting forces are differentiated across tasks, skills, and jobs that are aligned with, or resistant to, digitally-enabled business models. This both drives and restricts firm-level investment in further digitalisation, with the net effect determined by the relative strength of the two loops.

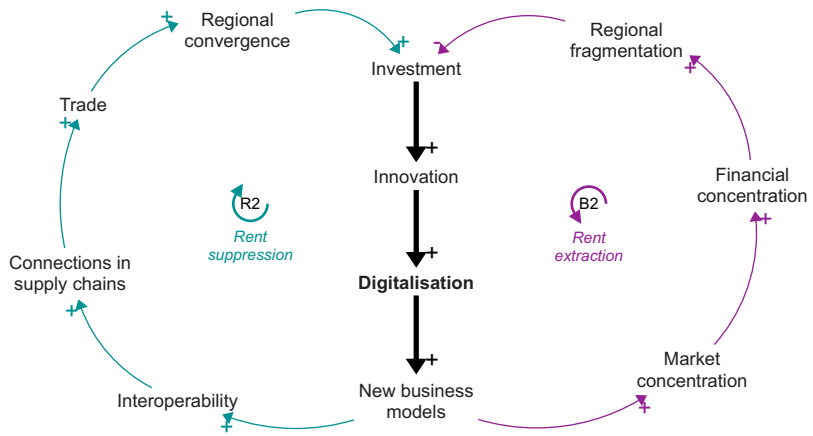
17.2. These tensions are evident in empirical studies of digitalisation impacts on labour markets which range from those emphasising net job displacement, polarisation and increasing income inequality (Frey and Osborne 2017, Acemoglu and Restrepo 2020) to those that emphasise net job opportunities and increasing digital capabilities (Santos, Barbero et al. 2023).

17.3. The second set of interactions (Figure 8B) show the tension between rent extraction and rent suppression implications of digitalisation. As with the impacts on jobs, these counteracting forces are differentiated across firm resources and strategies. The two loops interact and close by determining investment and innovation in digitalisation, with the net effect depending on the relative strength of the concentration vs. connection dynamics.

17.4. The interactions shown in Figure 8 also illustrate how digitalisation impact mechanisms cut across system scales, with firm-level strategies and business models giving rise to wider market impacts of firm interconnectivity or concentration with implications for geographic convergence or fragmentation.

FIGURE 8. INTERACTIONS BETWEEN FEEDBACK LOOPS IN ECONOMY AND FIRMS.

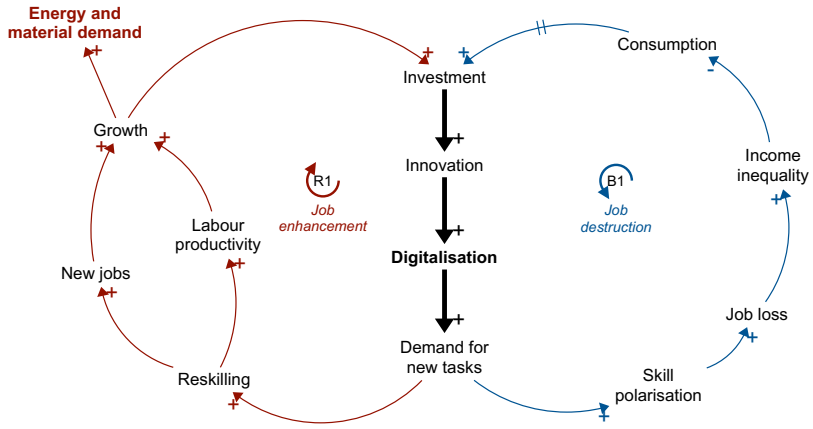
A



Counteracting effects on jobs.

Job enhancement and *job destruction* loops interact to determine investment into further digitalisation but in opposite ways. Productivity-driven stimulus and inequality-driven slowdown of consumption dampening are in tension from the labour market effects of digitalisation.

B



Counteracting effects on rents.

Digitalisation creates opportunities for new business models that can lead to both regional convergence and regional fragmentation. In the *Rent suppression* loop, digitalisation enables new types of cross-border cooperation to connect markets and supply chains. In the *Rent extraction* loop, digital business models are associated with network effects ('winner takes all'), as well as skills and capital barriers to entry that favour large firms or lead markets. Resulting concentration of market power and financial capital leads to rent-seeking behaviour and fragmentation.

18. The full set of system interactions in the Economy and Firms domain shown in Figure 9 integrates the coupled balancing and reinforcing loops that characterise digitalisation impacts on labour markets and on firm, market, or regional concentration.

18.1. Underpinning these interactions is the role of digitalisation in enabling new business models centred on data harvesting and analysis, algorithmic decision making and automation, and connectivity both within firms and between markets.

18.2. Also shown in Figure 9 is the link connecting the net effect on growth with the energy and material implications of digitalisation as antecedents of GHG emissions. Growth is not differentiated into its low or high-carbon forms, but in the absence of full decoupling, more growth scales the overall system which in turn drives up resource use.

19. Digitalisation impacts on Economy and Firms range across scales from firm-level business models with associated skills and task requirements to pan-regional market concentration or fragmentation.

19.1. The impacts of digitalisation on skills and jobs interact with the impacts of digitalisation on business models for supply and value chain integration.

19.2. Both sets of paired loops (on jobs and on rents) include both firm-level and economy-wide impacts. This cross-scale characteristic is shared with household to society interactions in the Society and Behaviour domain.

19.3. Overall system behaviour is a contingent outcome of the two sets of coupled reinforcing and balancing loops. For jobs, new skills and tasks keep net job destruction in check. For rents, supply chain interoperability keeps monopolistic rent extraction in winner-takes-all markets in check.

19.4. Evidence of these tensions is clearly visible in labour markets with some firms, sectors, and geographies facing concerns with digital capital substituting for labour and rising income inequality, while other firms and markets are sustaining strong growth and expansion into dominant market positions.

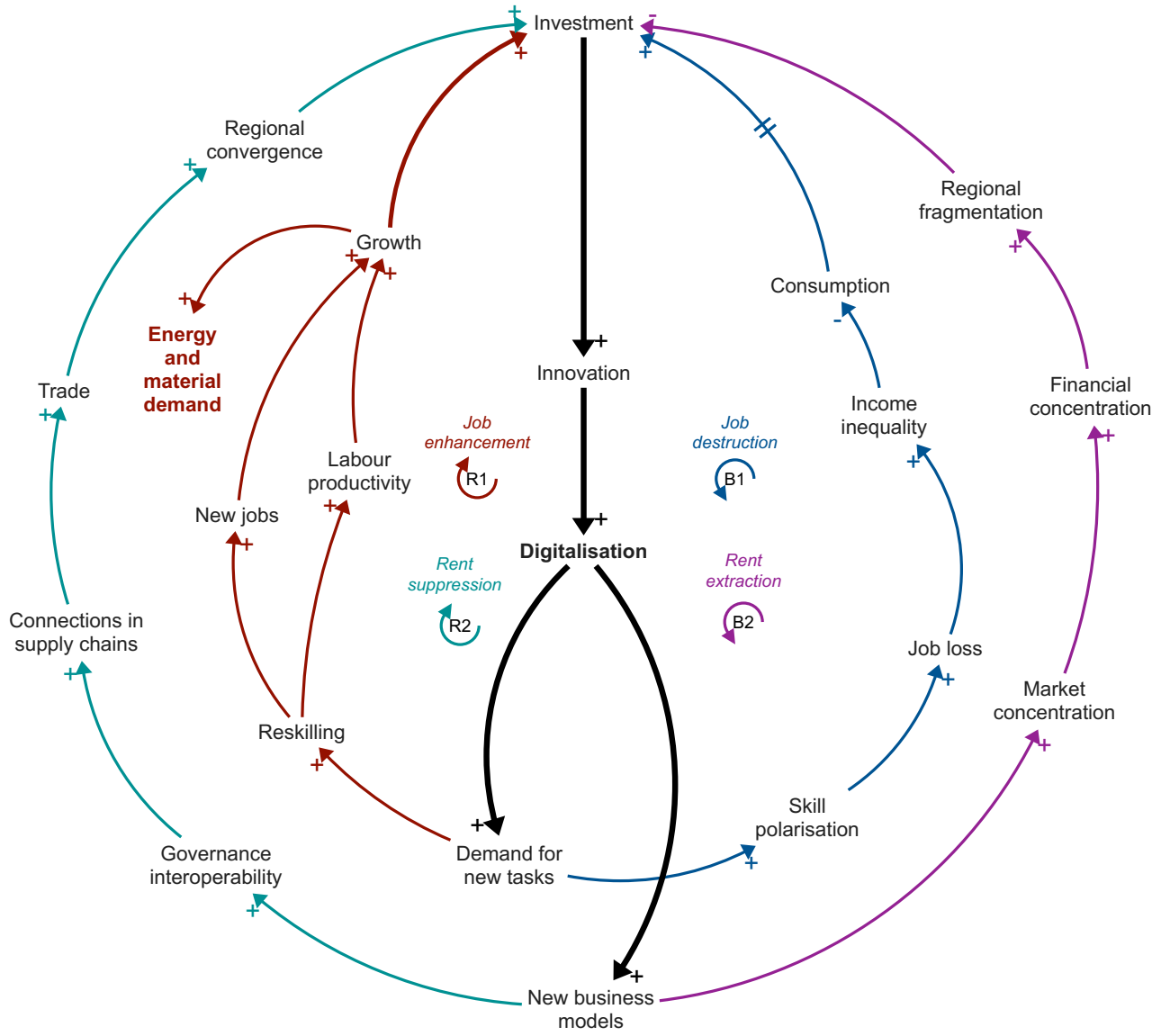
19.5. An important insight from the system dynamic map shown in Figure 9 is that the coupled reinforcing-balancing loops in labour markets and in regional convergence are interconnected. How firms' business models incorporate digitalisation affects livelihoods and economies in analogous ways with opportunities for those with requisite skills and resources and risks of being left behind for those without.

19.6. The map also helps emphasise control strategies to manage these risks.

19.7. In the jobs loops, key control variables include: (i) reskilling programmes for supporting new job creation and labour productivity in an increasingly digital workplace; and (ii) targeted measures to mitigate the income inequality effects of job destruction in task contexts exposed to automation.

19.8. In the rents loops, key control variables include: (i) effective regulations against monopolistic practices in firms and markets; and (ii) support for interoperability through, for example, technical standards, alignment between governance frameworks, cross-border digital trade, exchange of digital expertise.

FIGURE 9. FULL SYSTEMS MAP FOR DIGITALISATION IMPACTS ON ECONOMY AND FIRMS.



Governance and Markets

20. The Governance and Markets domain was mainly concerned with the institutional environments across both regulatory and market settings that shape economic and social behaviour.

20.1. Governance includes public policy and regulation and the role of government, but extends much wider into incentives, rules, norms, actor strategies and relationships. Digital governance applies these governance conditions to the ICT sector, including big tech companies, as well as to the application of digitalisation including AI in different contexts.

20.2. Digitalisation's impact on social trust and equality were introduced in the initial concept models as underpinning public support for strong climate policy – an interaction between digital and climate governance which was further elaborated by participants. Concept models are shown in the Appendix.

21. The basic feedback loops characterising the impact of digitalisation in the Governance and Markets domain relate to the interactions between digital and climate governance, and how in combination these set market incentives that steer activity in both sustainable and unsustainable directions.

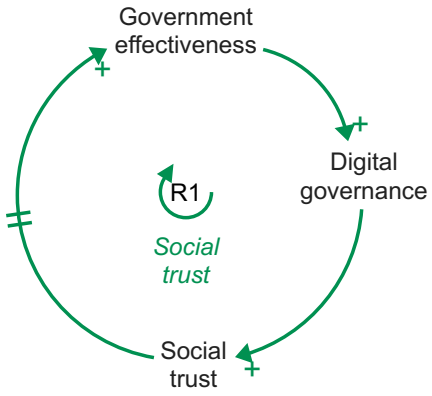
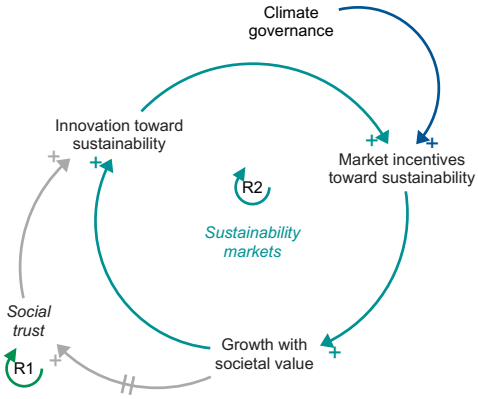
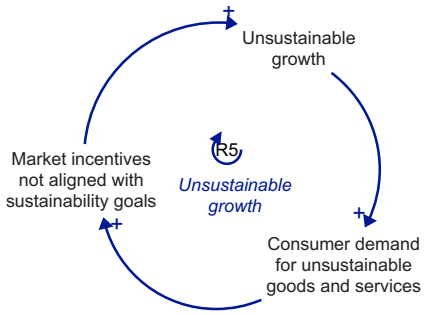
21.1. The first loop characterises digital governance impacts on social cohesion, trust, and so government effectiveness: *Social Trust*. This is shown in Figure 10A.

21.2. Government effectiveness refers to the capacity for policy formulation and implementation, and the credibility of government commitments to policies (Andrijevic, Crespo Cuaresma et al. 2020).

21.3. The other two loops characterise the basic dynamics of well-functioning markets delivering sustainable growth vs. markets delivering private but not societal value: *Sustainability markets* and *Unsustainable growth*. This is shown in Figure 10B&C.

21.4. These basic feedback loops comprise the building blocks of the more complex interactions discussed further below.

FIGURE 10. BASIC FEEDBACK LOOPS CHARACTERISING DIGITALISATION IMPACTS ON GOVERNANCE AND MARKETS.

A  	***Social trust.*** Collective trust in government aims and practices is strengthened by efforts to improve *digital governance* (e.g., curtailing misinformation and risks to personal sovereignty). In the long run *social trust* underpins government effectiveness as citizens support governments that protect common interests and institutions.
B  	***Sustainability markets.*** Alongside digital governance, *climate governance* sets *market incentives* to direct growth and innovation towards the provision of low-carbon goods and services. Functioning sustainability markets delivering *growth with societal value* recruit more firms and economic activity so are self-reinforcing.
C  	***Unsustainable growth.*** *Consumer demand for unsustainable goods and services* pulls market incentives and resulting firm activity away from *sustainability goals* and public goods like a stable climate and towards a narrower focus on delivering private value (e.g., shareholder returns).

22. Interactions between individual feedback loops build up a more integrated systems representation of digitalisation impacts on Governance and Markets.

22.1. The first set of interactions (Figure 11A) show the virtuous reinforcing interactions between good digital governance that fosters social trust and good climate governance that establishes well-functioning sustainability markets. Digital governance can also directly help set market incentives and steer digital innovation toward low-carbon applications.

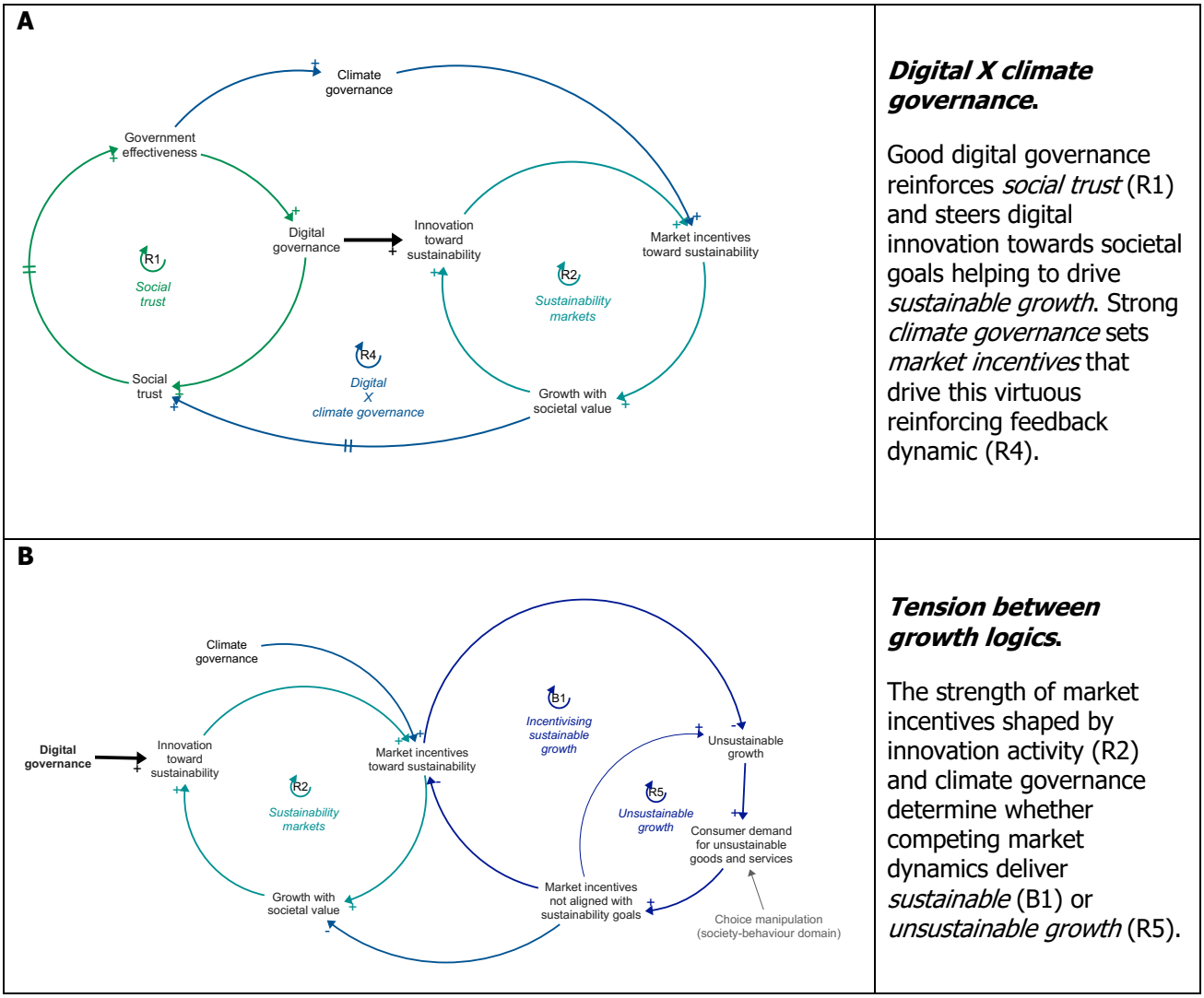
22.2. Resulting growth in sustainability markets that deliver societal value alongside private returns interacts with the social trust loop as climate governance is seen to work effectively in achieving public policy goals while delivering collective benefits.

22.3. The second set of interactions (Figure 11B) show how the two market dynamics - both aligned and misaligned with sustainability goals - are in tension. Market incentives toward sustainability benefit some firms that develop new business opportunities and digitally-enabled business models (e.g., service provision for dematerialisation). But other firms – including incumbents resistant to changing their business models – use advertising, choice manipulation, and other digital techniques to stimulate demand for unsustainable goods and services.

22.4. The relative strength of each dynamic is self-reinforcing as success recruits more firms and activity from the competing dynamic, and so pulls the market incentives further towards or away from sustainability goals. Delivering growth with societal value also delivers returns to shareholders and capital so is not incompatible with growth with private value.

22.5. Like in the Economy and Firms domain, the interactions shown in Figure 11 cross system scales, with impacts specific to actors, particularly governments and firms, but also characterising the function of institutions such as markets.

FIGURE 11. INTERACTIONS BETWEEN FEEDBACK LOOPS IN GOVERNANCE AND MARKETS.



Digital X climate governance.

Good digital governance reinforces *social trust* (R1) and steers digital innovation towards societal goals helping to drive *sustainable growth*. Strong *climate governance* sets *market incentives* that drive this virtuous reinforcing feedback dynamic (R4).

Tension between growth logics.

The strength of market incentives shaped by innovation activity (R2) and climate governance determine whether competing market dynamics deliver *sustainable* (B1) or *unsustainable growth* (R5).

23. The full set of system interactions in the Governance and Markets domain shown in Figure 12 integrates the reinforcing loops that are in tension between sustainable and unsustainable market activity with the reinforcing loop between digital governance and social trust.

23.1. The overall system behaviour in Figure 12 has both beneficial and adverse dynamics.

23.2. The beneficial dynamics see digital governance building capacity for strong climate governance to stimulate sustainable growth delivering jobs and strengthened governance capacity.

23.3. The adverse dynamics see weak incentives toward sustainability leading to unsustainable growth that recruits both consumers and workers into a reinforcing loop. However, this loop also delivers jobs which can potentially help improve social cohesion. It is the energy, material, and emissions implications of this unsustainable growth that is of concern.

23.4. Evidence of both these competing dynamics in action is clearly visible and differentiated across markets, firms and geographies. Even in countries that have peaked and declined emissions, progress still lags behind what's needed for a 1.5°C future, and the decoupling between economic activity and emission outcomes is far from complete.

24. Digitalisation impacts on Governance and Markets are more indirect than in other domains, as they are mediated by how governance institutions, including public policy, shape digital activity.

24.1. The basic premise of system behaviour in this domain is that firms driving innovation and growth in markets respond to incentives which are shaped by governance conditions (e.g., public policy, market rules, societal norms, consumer values). Climate governance not digital governance is the primary influence on whether sustainability markets function effectively and so outcompete markets geared towards unsustainable growth.

24.2. This is evident in the current policy and regulatory environments driving progress towards net-zero goals in emissions-intensive transport, buildings, industry, and energy sectors. Whether through carbon pricing, standards, transparency in emissions reporting, or consumer pressure, incentives toward sustainable activity are set by sectoral and economy-wide climate policies, not policies in response to digitalisation. This also applies to digital applications (e.g., smart building controls, mobility-as-a-service apps) whose contribution toward emission reductions is not of primary concern to digital regulators.

24.3. An exception is the current pressure to manage the energy footprint of data centres turbocharged by the generative AI boom. Otherwise, digital governance including framework policies like the EU's GDPR and AI Act have been more concerned with issues of misinformation, consumer protection, fair competition and taxation.

24.4. Strong digital governance can also direct innovation activity to align with sustainable goals.

24.5. But an important insight revealed in the full system map (Figure 12) is that digital governance's more fundamental and more indirect role is to maintain and strengthen the social trust or 'glue' necessary for strong climate governance with its important distributional impacts on winners and losers.

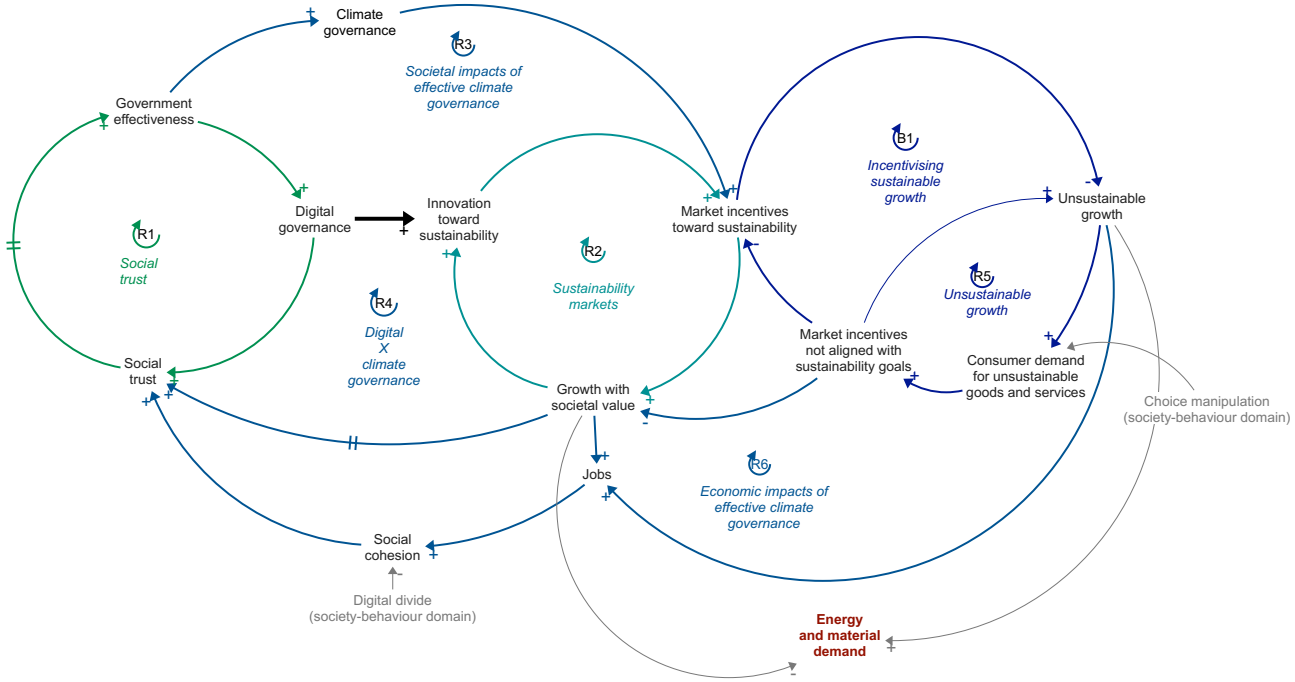
24.6. This indirect link has been demonstrated empirically for social trust in general (Creutzig, Goetzke et al. 2023) but not for the link between digitalisation and social trust in the complete loop.

24.7. Jobs provide an additional link between social trust and the competing market logics (Figure 12). Most types of growth create jobs. Whether in sustainable or unsustainable markets, jobs and incomes can help tackle inequalities and improve social cohesion, further strengthening social trust that government is working for people – across both digital and climate domains. This is not a given, however. 'Bad' jobs can reinforce inequalities or exploitative practices.

24.8. The systems map shown earlier for Economy and Firms (Figure 9) adds more contingencies to this virtuous picture in that different types of jobs (and the skills required for them) have different impacts on growth and investment.

24.9. The main control variable in the Governance and Markets domain is the incentives toward sustainability that shape innovation, investment and growth. As discussed, this control variable is manipulated more strongly by climate governance than by digital governance.

FIGURE 12. FULL SYSTEMS MAP FOR DIGITALISATION IMPACTS ON GOVERNANCE AND MARKETS.



Energy and Materials

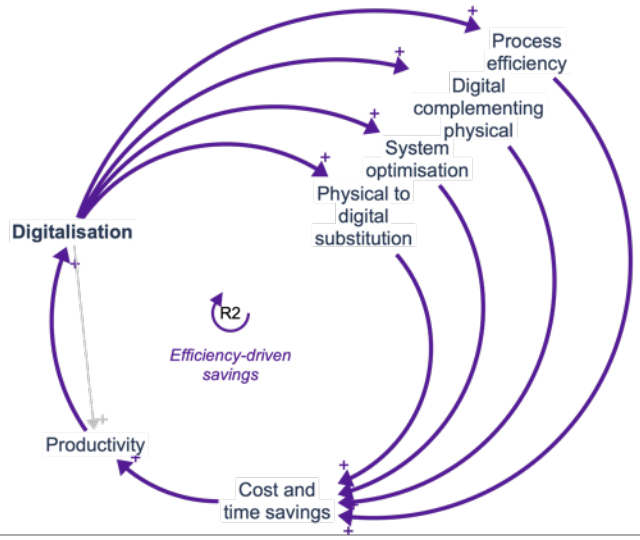
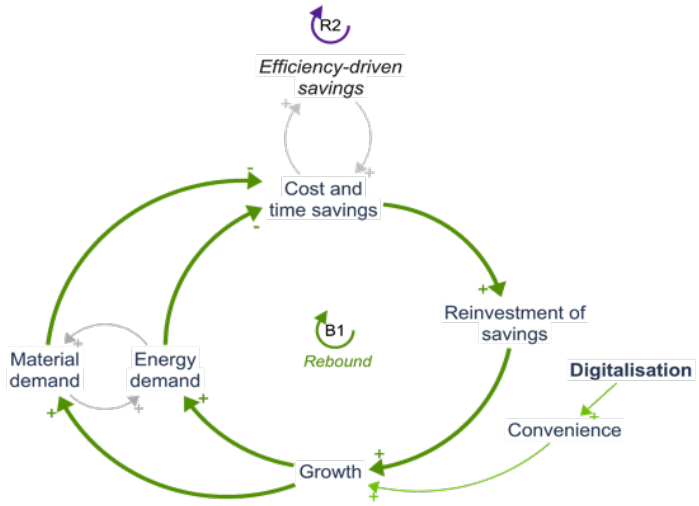
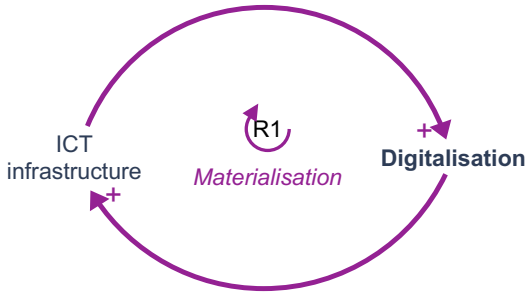
25. The Energy and Materials domain encompassed the impact pathways through which digital applications across society and the economic affect physical resource demands and so GHG emissions.

25.1. At the micro-level, impact pathways describe how digital technologies or applications affect social or economic processes or activities. Two loops characterise coupled dynamics at the activity-level: *Efficiency-driven savings* and *Rebound*. These are shown in Figure 13A+B.

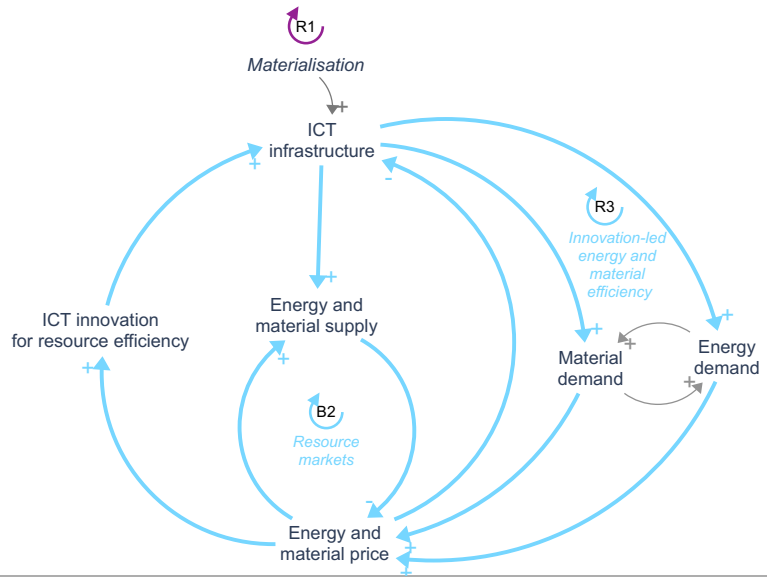
25.2. At the systems level, impact pathways describe the aggregate outcomes of digitalisation on economic and physical infrastructure. The three loops are: *Materialisation, Resource markets, and Renewable energy integration*. These are shown in Figure 13C+D+E.

25.3. The initial concept model for the systems mapping is shown in the Appendix.

FIGURE 13. BASIC FEEDBACK LOOPS CHARACTERISING DIGITALISATION IMPACTS ON ENERGY AND MATERIALS.

A  	***Efficiency-driven savings.*** Digitalisation helps save resources through mechanisms that improve process or system efficiency. Resources include energy and labour inputs but also time and effort. Resulting productivity gains reinforce the incentive for more digitalisation.
B  	***Rebound.*** By making processes or systems more efficient, digitalisation stimulates growth in demand for associated social or economic activity. This offsets the *efficiency-driven resource savings* – a digital Jevons Paradox.
C  	***Materialisation.*** The physical embodiment of digitalisation in *ICT infrastructure* (data centres, networks, devices) is self-reinforcing: more infrastructure enables more applications which create demand for more infrastructure.

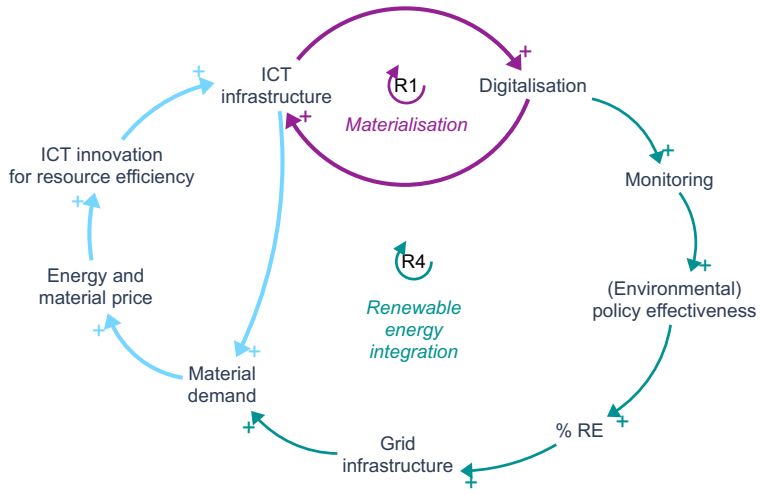
D



Resource markets.

Innovation to develop more energy and material efficient ICT infrastructure balances the reinforcing dynamic of *materialisation* and helps mitigate rising resource prices.

E



Renewable energy integration.

Digitalisation strengthens policy effectiveness and integration of intermittent renewable energy (RE) on electricity networks, further driving material demand for the entwined clean energy and digital transitions.

26. Interactions between individual feedback loops create a more comprehensive systems representation of digitalisation impacts on Energy and Materials.

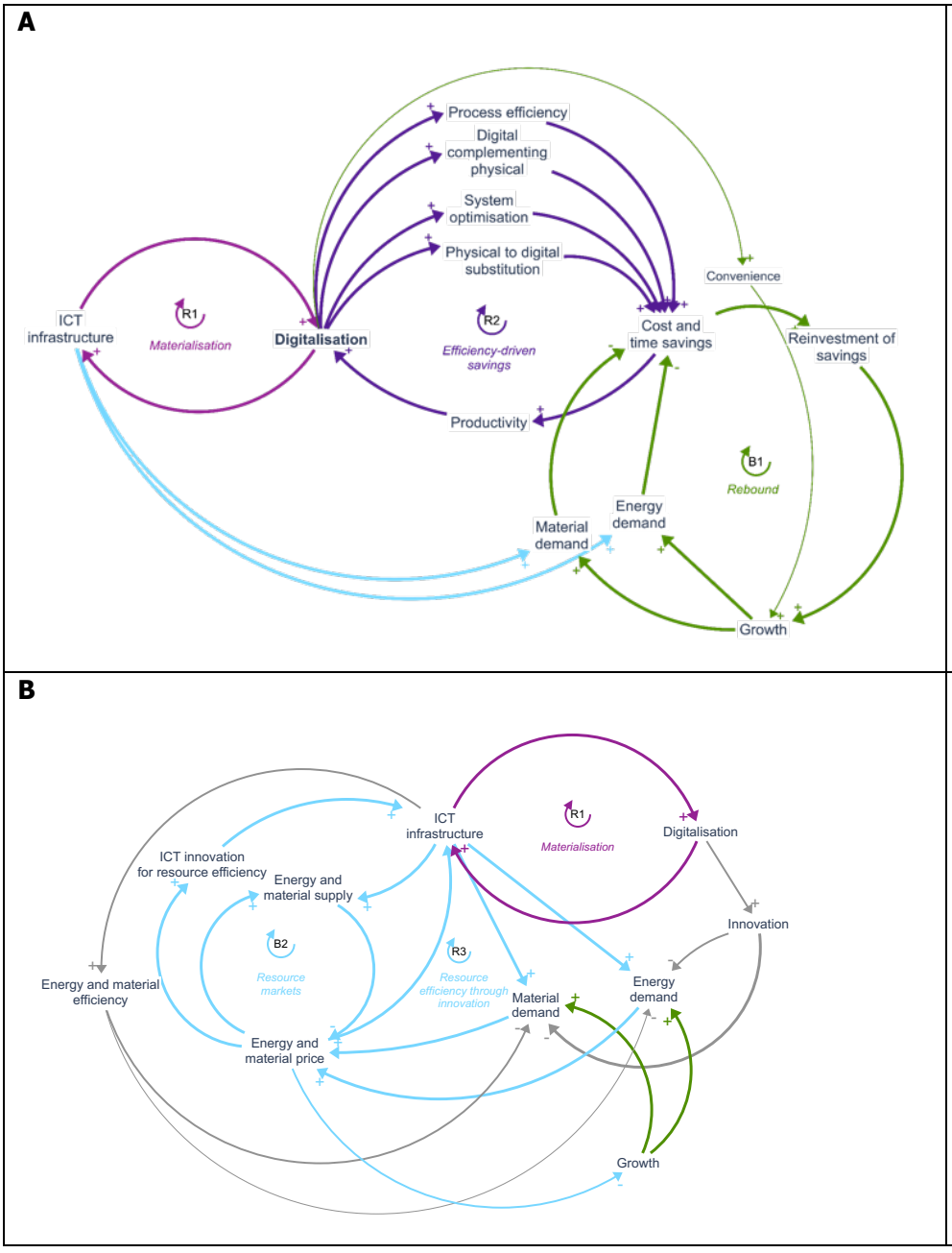
26.1. The interactions in Figure 14A show the mechanisms by which digitalisation impacts energy and material demand, both directly through the footprint of expanding ICT infrastructure, and indirectly through the substitution, optimisation, and other ways digital applications affect energy-using activity.

26.2. Rebound effects from the reinvestment of time and cost savings in more activity drive up resource demand and stimulate growth across domains.

26.3. Figure 14B illustrates the dynamics in commodity markets supplying energy and materials for the build out and operation of ICT infrastructure. Demand growth that creates scarcity and rising prices also drives innovation towards more resource-efficient infrastructure.

26.4. This market-led innovation response is also enabled by digitalisation, further strengthening the reinforcing mechanism through which digitalisation creates enabling conditions for its own proliferation.

FIGURE 14. INTERACTIONS BETWEEN FEEDBACK LOOPS IN ENERGY AND MATERIALS.



Efficiency vs. Rebound.

The overall impact of digitalisation on energy and materials is dominated by the self-reinforcing dynamic of more ICT infrastructure *materialisation* yielding more *efficiency-driven savings* balanced by offsetting *rebound* effects driving growth.

Resource efficiency through innovation.

Rising demand (and prices) for energy and materials due to digitalisation is balanced by a market-led innovation response to improve the efficiency of ICT infrastructure.

27. The full set of system interactions in the Energy and Materials domain shown in Figure 15 integrates the reinforcing and balancing loops that link digitalisation with energy and material demands, and the simple balancing dynamics in resource markets supplying those demands.

27.1. Digitalisation impacts energy and material resource demands at three related levels: (i) its own materialisation (devices, data centres); (ii) its applications and how they affect the resource-intensity of associated activities; (iii) its structural effects on aggregate levels of activity demand including rebound effects.

27.2. In combination these three levels of impact determine how the overall energy and material footprint of digitalisation, and the implications this has for scarcity and prices in resource markets.

27.3. If energy and material inputs become salient in either cost or environmental terms, innovation in hardware, software, applications, and infrastructure drive improvements in resource efficiency.

27.4. This dynamic is clearly evident in current markets for computationally-intensive (and so energy-intensive) generative AI and the new generations of energy-efficient chips and models that are now emerging. Another example is the development of more computationally-efficient cryptocurrencies (e.g. Ethereum) or generative AI models (e.g., DeepSeek) in response – at least in part – to the high energy costs of the incumbents (BitCoin, ChatGPT).

27.5. Energy and material demands are important as they cause GHG emissions. Here, digitalisation has a secondary dynamic of decoupling energy from emissions by enabling higher levels of intermittent renewable electricity to integrate on grid infrastructure.

28. The net GHG impacts of digitalisation depend mainly on the balance between efficiency gains and activity growth.

28.1. This balance applies both to digital infrastructure itself and the much larger and more diverse set of digital transformations underway across the economy and society - as captured in the system maps for Economy and Firms (Figure 9) and Society and Behaviour (Figure 6).

28.2. Which way does this balance currently tip?

28.3. Evidence that includes resource demands at all three levels, including rebound, tends to show digitalisation's net impact is to increase energy (and material) consumption (Lange, Pohl et al. 2020).

28.4. Evidence that focuses more narrowly on efficiency and productivity-enhancing applications tend to show digitalisation's net impact is to reduce energy and GHG emissions (GESI 2022). Such evidence is unsurprisingly marshalled by the ICT industry itself.

28.5. The integrated system dynamics in Figure 15 show the obvious tension between these assessments lies in whether the energy implications of digitalisation are framed primarily in relative or absolute terms.

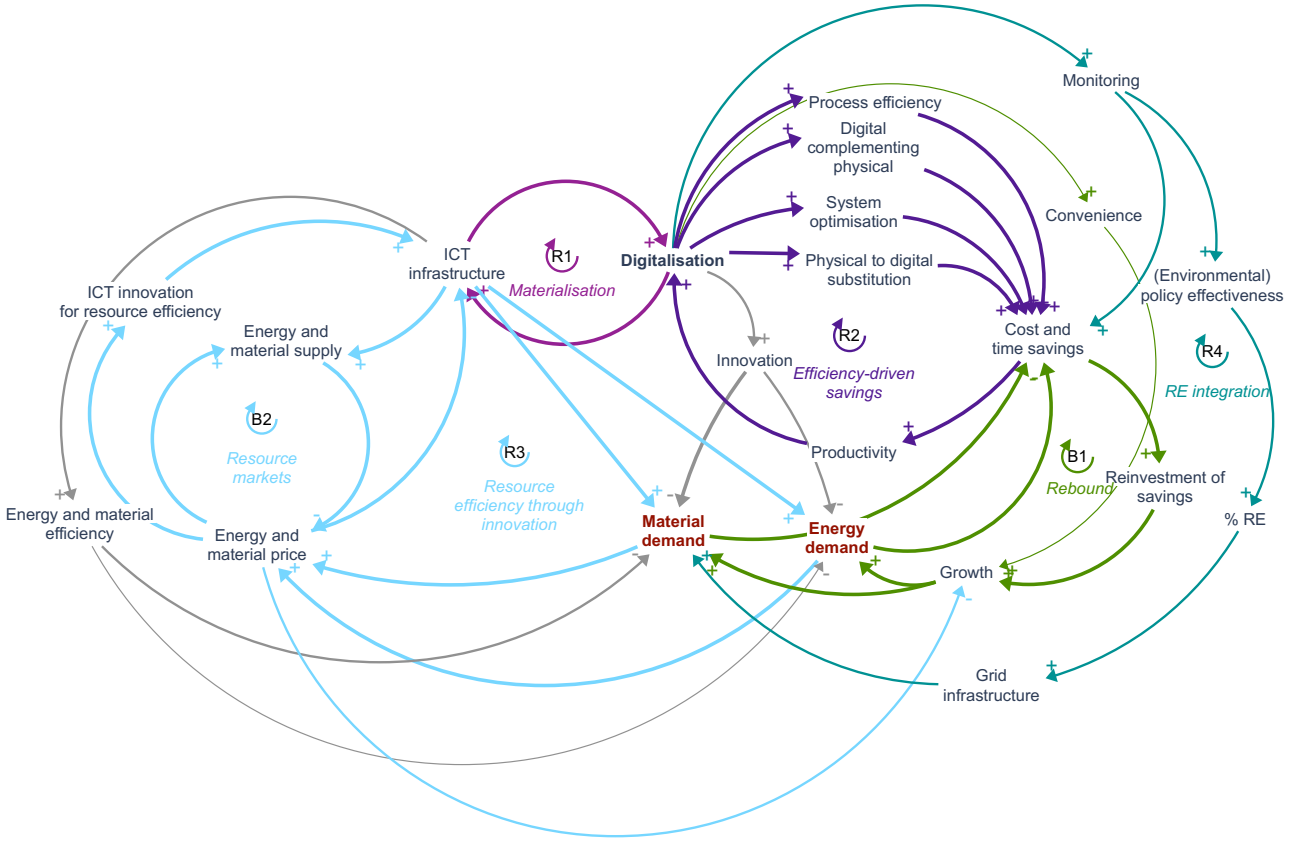
28.6. In relative terms, the *efficiency-driven savings* loop and the *resource efficiency* loop help reduce the incremental energy (and GHG) implications of digital applications and digital infrastructure respectively.

28.7. However, in absolute terms, the *materialisation* loop and the *rebound* loop drive up aggregate energy demand. Whether this absolute growth phenomena is desirable or not varies on whether the perspective taken is economic, welfare-oriented, environmental, or social.

28.8. Almost any indicator of digitalisation shows a deepening, expanding, and accelerating digital transformation still underway. Absolute growth should be expected to outweigh relative improvements. Control strategies to increase the strength of balancing loops are largely inherent to markets (e.g., in response to high energy costs or material scarcities). Regulatory interventions can add further momentum (e.g., data centre efficiency standards).

28.9. Ultimately the GHG impacts of digitalisation both within the ICT sector itself, and across all the application domains, will be subject to increasingly strong incentives to decarbonise on the pathway to net-zero.

FIGURE 15. FULL SYSTEMS MAP FOR DIGITALISATION IMPACTS ON ENERGY & MATERIALS.



Linkages and Integration Across Domains

29. The maps of digitalisation impact pathways in each of the four domains can be inter-linked both implicitly and explicitly to show the full, complex set of system dynamics.

29.1. Each of the system maps shown for the four domains provide a rich picture of the reinforcing and balancing loops characterising digitalisation dynamics, but in isolation for discrete impact domains.

29.2. Impact pathways are linked between domains in both implicit and explicit ways.

29.3. Explicit cross-domain links are between variables mapped in more than one domain during the workshop.

29.4. Implicit cross-domain links are ones evident in literature or real-world observations but that were not mapped as shared variables across domains in the workshop discussions.

29.5. An example of an explicit link across domains is through '*innovation*' that impacts investment activity in the Economy & Firms domain and also impacts market incentives in the Governance & Markets domain (discussed further below).

29.6. Some of these explicit links were prompted in the workshop mapping exercise as they appeared in more than one concept model (see Appendix) or because they are important elements of the Shared Socioeconomic Pathway (SSPs) framework for climate mitigation analysis (see Section IV. Digitalisation in Climate Mitigation Futures.).

29.7. An example of an implicit link across domains is through household preferences which influence how digital applications are used for substitution, optimisation, or dematerialisation in the Energy and Materials domain, and whether consumption choices are oriented more toward sustainable or unsustainable goods and services in the Society and Behaviour domain. Household preferences also influence participation in online networks and so exposure to (mis)information flows in the Governance and Markets domain.

29.8. Including these explicit and implicit cross-domain links introduces further system complexity as the indirect consequences of a change in any given variable both increases in scope and amplifies in effect.

29.9. These cross-domain links are important for understanding the potential indirect and systemic impacts of digitalisation across emissions, society, markets, and governance.

29.10. However, it is challenging to find easily interpretable visualisations for these inter-linked system maps across domains given that even within a domain the impact pathways are complex. This is a challenge for further research.

30. Growth, innovation, and social trust are all shared variables that explicitly link digitalisation impact pathways across domains.

30.1. Digitalisation's impact on growth is central to many of the system maps.

30.2. Growth drives new job creation as well as investment in further digital innovation. Growth drives resource consumption and the materialisation of further digital infrastructure. Competing growth engines in sustainable and unsustainable markets are influenced by climate and digital governance regimes that set market incentives and the direction of firm behaviour.

30.3. Innovation is also an integral part of the digitalisation narrative, whether applied to new business models, new consumer offerings, or firms' investment strategies.

30.4. Innovation can improve the efficiency with which energy and material resource inputs are converted into useful digital services. Innovation directed toward sustainable goods and services can drive well-functioning sustainability markets delivering societal value (including lower GHGs). Innovation depends on the investment that is stimulated by trade and regional convergence but undermined by inequality and financial concentration in fragmenting markets.

30.5. A third shared variable between digitalisation impact pathways across domains is social trust.

30.6. Social trust underpins the capacity of governments to lead on climate action through strong climate policy and governance institutions that in turn set incentives for firms aligned with decarbonisation goals. Social trust can be undermined by misinformation and polarisation enabled and amplified through digital platforms and influencers.

30.7. This means that the social dynamics associated with digitalisation and online information flows pose systemic risks to climate governance.

31. Linking the dynamics of digitalisation across domains shows that almost any impact pathway will impact GHG emissions, even if very indirectly.

31.1. Energy and material demand is a precursor to GHG emissions and so climate mitigation challenges. (Decarbonisation of the energy supply through substitution of fossil fuel inputs is a distinct process which was not covered in depth in this digitalisation workshop).

31.2. The impacts of digitalisation on energy and material demand both directly – through the manufacturing and operation of ICT infrastructure – and indirectly – through digital applications in buildings, transport, industry and other sectors – was primarily captured in the Energy and Materials system map (Figure 15).

31.3. However, digitalisation impacts on growth in the Economy and Firms and Governance and Markets domains also influence energy and material demand as a growing economy increases absolute demand for energy and material impacts in the absence of full decoupling between energy and emissions (which has not been achieved).

31.4. Essentially these cross-domain links mean that any and all of the impact pathways shown in the system maps will ultimately affect GHG emissions, even if this is a very diffuse or indirect effect.

31.5. The challenge with integrating system maps across domains is to identify and focus on the most influential or counterintuitive causal pathways that are only observable from a full systems perspective.

Section III. Future Narratives for Digitalisation

32. Mapping digitalisation impact pathways provides a structured approach for thinking through alternative possible futures for digitalisation.

32.1. Workshop participants in each of the four groups (one per domain) were asked to consider what the future would look like if specific feedback loops identified in their system dynamic maps were to dominate.

32.2. All groups focused on at least two possible futures exploring a wide future possibility space, bounded by best- and worst-case assumptions about whether digitalisation would lead to positive or negative societal outcomes.

32.3. Data collected during these discussions were analysed across the four domains to identify the main elements of the future narratives for digitalisation.

33. A future in which digitalisation supports positive societal outcomes highlights its role in driving sustainable economic growth aligning with climate mitigation targets through improved energy and material efficiency, sustainable infrastructure, and supportive policies.

33.1. Energy and material efficiency increase, rents are distributed from firms to workers, regions converge reducing economic and social inequalities globally.

33.2. Digitalisation promotes social cohesion and social verification of information by educated users, as well as sustainable consumption practices.

33.3. Table 1 summarizes the dominant dynamics discussed (from the system maps showed earlier), their main drivers, and the main conditions under which this future narrative will materialize. It also details the strategies put in place by the main actors in this best-case scenario.

34. This best-case scenario has positive outcomes for each of the four domains used to structure the system mapping.

34.1. *Energy and material use*. Digital innovations promote increased efficiency in energy and material use. This, coupled with interventions on the demand side to avoid overconsumption and rebound effects, leads to lower energy consumption, reduced waste, and more sustainable resource use.

34.2. *Society and behaviour*. As well as improved quality of life through better access to services, enhanced convenience, and more opportunities for education and employment, digital technologies also promote social inclusion and reduce inequalities through purposeful and informed participation in decision-making (i.e., empowerment and agency). They also promote social trust (and reject free riding): people and nations believe others are doing their share to reduce adverse societal impacts.

34.3. *Economy and industry*. Economic growth driven by increased productivity, new business models, and job creation. Workers are skilled and upskilled; gains from digital technologies are passed through from firms to workers and individuals. Industries become more competitive and innovative, contributing to overall economic resilience, while engaging to achieve sustainability.

34.4. *Governance and markets*. Strong governance frameworks ensure digital markets function efficiently and fairly, protecting consumer rights, ensuring fair competition, and promoting sustainable business practices, while being aligned with sustainability objectives.

35. A future narrative for digitalisation that has positive societal outcomes can be easily aligned with climate mitigation targets.

35.1. In any future, digitalisation has both direct and indirect implications for energy and material demand, and so GHG emissions. In a best-case scenario these implications are strongly net beneficial.

35.2. *Energy efficiency, and lower energy and material demand*. Digitalisation drives significant improvements in energy efficiency, reducing overall energy consumption and supporting the transition to renewable energy sources. Smart grids, IoT, and AI optimize energy usage, lowering carbon emissions. Advances in digital technologies lead to more efficient use of materials, reducing waste and the need for raw materials. Circular economy principles are embedded in digital practices, promoting recycling and reuse.

35.3. *Sustainable infrastructure*. Investment in sustainable digital infrastructure, such as energy-efficient data centres and green computing technologies, supports climate goals.
35.4. *Climate-smart digital policies*. Governments implement policies that integrate digitalisation with climate objectives, such as incentives for green technologies, and regulations that promote sustainable digital practices. Policies encourage the development and use of low-carbon technologies by firms and consumers. International cooperation ensures these policies are harmonised globally.

TABLE 1. 'BEST CASE' SCENARIO IN WHICH FUTURE DIGITALISATION LEADS TO POSITIVE SOCIETAL OUTCOMES.

Dominant Dynamics	***Main Drivers***
• *Efficiency and sustainability*. Digital technologies lead to more efficient use of resources, resulting in reduced energy consumption and material waste. Digitalisation and ICTs enable sharing, decreased demand for ownership as affordable services become available. • *Inclusive growth*. Equitable access to digital services reduces inequalities and promotes social inclusion. • *Economic resilience*. Integration of digital technologies promote new business models, which in turn drive sustainable economic growth by increasing productivity, creating new business models, generating jobs, and fostering connectivity in supply and value chains.	• *Strong digital governance.* Effective regulations and policies that promote innovation, efficiency, and equitable access to digital technologies. • *Technological innovation.* Continuous advancements in ICT drive efficiency and create new opportunities for economic growth and societal benefits. • *International cooperation and regional convergence.* Global collaboration and harmonization of policies enhance the effectiveness of digitalisation efforts and promote social and environmental principles for continuing investment. • *Investment in education, digital skills and literacy.* Programs to boost digital skills and broader literacy are available, accessible to citizens and workers.
Main Conditions	***Main Actors and Strategies***
• *Robust regulatory frameworks* that promote innovation while ensuring data privacy, security, and equitable access. Policies incentivise sustainable and efficient use of resources. Regulators are able to obtain insights faster and adapt to needs. • *Investment in digital and physical infrastructure* to support widespread adoption and integration of digital technologies, including high-speed internet access and smart grids. • *Education and skill development* programs to ensure the workforce is equipped to use and benefit from digital technologies.	• *Governments and regulators* enforce regulations that ensure social trust and equitable access to digital technologies. They invest in public infrastructure and services that leverage digital innovations. • *Firms* innovate and adopt digital technologies to improve operational efficiency, reduce costs, and create new market opportunities. They collaborate with governments through private-public partnerships and with other stakeholders for responsible digital practices. • *Consumers and civil society* invest in the development of digital skills and in education. They use digital technologies and platforms to actively engage. Access to data and digital technologies fosters the creation of social trust. • *International institutions* facilitate global cooperation and harmonization of digital policies and standards, address cross-border challenges and promote the sharing of best practices. • *The financial sector* directs investment towards digitalisation projects with the highest social returns.

36. A contrasting future in which digitalisation leads to negative societal outcomes is characterised by rapid innovation and change that drives fast but unequal growth and hinders economic and social sustainability.

36.1. This negative outlook makes it less likely that climate targets will be achieved; or if they are, it is at the expense of societal and economic well-being.

36.2. Table 2 summarizes the dominant dynamics discussed, their main drivers, the main conditions under which this scenario will materialize, and the strategies of the main actors.

37. This worst-case scenario has negative outcomes for each of the four domains used to structure the system mapping.

37.1. *Energy and material use*. Increased energy consumption and material waste due to inefficient digital infrastructures and the constant need for hardware upgrades. This results in higher environmental impacts and resource depletion.

37.2. *Economy and industry*. Economic disparities widen as digital monopolies consolidate power and wealth, stifling innovation and competition. Traditional industries decline, leading to job losses and economic downturns. No compensation measures are put in place to support workers or small businesses.

37.3. *Society and behaviour*. Social inequality and exclusion worsen as access to digital technologies and skills remains uneven. Trust in institutions and democratic processes erodes due to misinformation and digital manipulation, leading to social unrest and polarization. The rule of law and government effectiveness are undermined.

37.4. *Governance and markets*. Ineffective governance structures fail to regulate the digital economy adequately, leading to market failures and increased systemic risks. Regulatory capture by powerful tech corporations undermines public trust and government effectiveness.

38. A future narrative for digitalisation that has negative societal outcomes is strongly misaligned with climate mitigation targets.

38.1. If governance of digital technologies is weak, it is unlikely that strong and coordinated climate regulations, such as carbon pricing and taxes, would be implemented to drive progress towards mitigation goals.

38.2. Regional fragmentation undermines international cooperation necessary to promote decarbonization strategies.

38.3. Green technology investment can still be fostered, particularly if aligned with the business interests of large tech (digital) companies. (This is evidenced by current investment flows into small modular reactor, renewable electricity, electric vehicles and other low-carbon technologies).

38.4. However, wider digital and economic divides hamper widespread uptake of climate solutions or the phase out of high-emitting technologies.

TABLE 2. 'WORST CASE' SCENARIO IN WHICH FUTURE DIGITALISATION LEADS TO NEGATIVE SOCIETAL OUTCOMES.

Dominant Dynamics	***Main Drivers***
• *Inefficiency.* Low energy and material prices, coupled with the absence of limits on resource extraction, lead to increased energy and material use. Resources are used inefficiently, leading to low sustainability and societal benefits. The infrastructure required for digital services contributes significantly to energy consumption and material waste. Overall, there is a large, unregulated increase of ICT energy, material and water footprint. Overall proliferation of digital interfaces due to lack of interoperability. • *Deepening inequality and polarization.* Uneven access to technology and digital literacy deepens social and economic divides, including in the labour market, increasing exclusion of marginalised communities. Misuse of digital technologies increases misinformation and distrust in public institutions, promoting populism. • *Economic disruption and regional fragmentation.* Traditional industries and small and medium size enterprises face significant disruption due to rapid digital shifts. They lack the financial and human capital resources to reap the benefits of digitalisation, which are concentrated in large firms and corporations. This results in widespread job losses and economic instability, particularly in those countries which are not at the technological frontier.	• *Rapid and ungoverned technological advancement*. Unchecked technological progress without ethical considerations exacerbates inequality and social divisions. Ineffective governance and lack of stringent regulations enable the misuse of digital technologies, particularly by the few who are digitally literate, leading to negative societal impacts. These are exacerbated by weak data privacy protections and insufficient cybersecurity measures. • *Market and financial concentration*. Increased concentration of market power among a few large digital corporations leads to monopolistic practices, increases rents, reduces the pass through of benefits to workers and consumers. Competition is stifled, and so too are innovation and economic equity.
Main Conditions	***Main Actors and Strategies***
• *Poor regulatory frameworks*: Insufficient regulations and weak enforcement mechanisms fail to address the negative impacts of digital technologies. • *Lack of public investment*: Insufficient investment in public infrastructure and digital literacy programs leads to inefficiencies and increased costs. • *Economic and social instability*: Rapid technological changes create economic and social instability, exacerbating inequality and reducing social cohesion.	• *Firms* focus on profit maximization with minimal regard for social and environmental impacts. They engage in lobbying against regulations, aggressive market expansion, and prioritization of shareholder over societal value. • *Governments and regulators* fail to keep pace with digital advancements, resulting in weak and fragmented regulatory responses to rapid technological change. • *Civil society and activists* try to advocate for digital rights and ethical use of technology but are underfunded and have weak influence against powerful corporate interests.

39. These two extremes ranging from best to worst case outcomes show how emphasising different dynamics and impact pathways give rise to competing future narratives for digitalisation.

39.1. Each extreme is the result of self-reinforcing dynamics with weak balancing loops to keep the trajectory of path-dependent change in check – whether towards desirable or undesirable futures.

39.2. Workshop participants emphasised that in reality, outcomes were not a stark binary between best and worst case. Rather, digitalisation futures will include both positive and negative elements. The system dynamic maps make these countervailing forces explicit.

39.3. By identifying enabling conditions and actor strategies, the two scenarios also highlight ways to help plan for good while mitigating risks of bad.

39.4. Common themes include: (i) effective digital governance alongside climate governance to set incentives for firms; (ii) regulatory frameworks to avoid market concentration; (iii) concerted action to tackle income, livelihood, and access inequalities to avoid social trust and cohesion being eroded.

Section IV. Digitalisation in Climate Mitigation Futures.

40. Alternative digital futures have widely different implications for GHG emissions and climate governance.

40.1. Narratives like the EU's twin green digital transition emphasise synergy and enablement, but misalignment and exacerbation is also possible.

40.2. Mapping digitalisation futures into climate change mitigation pathways makes these interactions explicit and so more analytically tractable.

40.3. One of the workshop aims was to identify links between alternative digitalisation futures and the 'SSPs' – a widely used framework of long-term global development scenarios used to analyse climate change mitigation (and adaption) challenges.

41. The Shared Socio-economic Pathways (SSPs) describe plausible alternative futures for global development based on different assumptions about how demographic, economic, technological, social, governance and environmental factors will change into the future.

41.1. The SSPs include both narrative storylines describing broad trends over large world regions as well as a quantification of key variables that can serve as inputs to integrated assessment models as well as climate impact models and vulnerability assessments (O'Neill, Kriegler et al. 2016).

41.2. There are five SSPs defined along two dimensions of socio-economic challenges: challenges for adaptation and challenges for mitigation.

41.3. A figure provided as part of the pre-workshop material to participants - shows the five SSPs and how they vary in terms of specific assumptions regarding the economy and society, policies and institutions, technologies, and the environment and natural resources (see Appendix).

41.4. Quantitative SSP variables include a small set of fundamental drivers, and a larger set of elements characterising the dynamics of change in energy, land use and other systems.

41.5. More recently, these SSP elements have been extended along several socioeconomic dimensions including gender and income inequality, government effectiveness, and the rule of law (see: https://ssp-extensions.apps.ece.iiasa.ac.at).

42. Digitalisation is not represented explicitly in the SSPs - neither in the narrative storylines nor in the quantitative elements.

42.1. This makes it hard to identify the unique enabling or exacerbating effect of digitalisation in analyses of climate mitigation futures including those used to inform the achievement of national net-zero commitments under the Paris Agreement.

42.2. Table 3 provides a summary of the five SSP narratives taken from O'Neill, Kriegler et al. (2016). These narratives barely mention digitalisation as a storyline element.

42.3. In the righthand column, we suggest an initial interpretation of each SSP narrative through the lens of digitalisation.

TABLE 3. SUMMARY OF THE FIVE SSP NARRATIVES WITH INDICATIVE LINKS TO DIGITALISATION AS A DRIVER, CHARACTERISTIC, OR OUTCOME OF CHANGE.

SSP	SSP description: quoted from O'Neill, Kriegler et al. (2016)	Indicative links with digitalisation.
SSP1: Sustainability—Taking the green road	"Commitment to achieving development goals, increasing environmental awareness in societies around the world, and a gradual move toward less resource-intensive lifestyles, constitutes a break with recent history in which emerging economies have followed the resource-intensive development model of industrialised countries."	Management of the global commons to respect planetary boundaries extends to the digital sphere, aligning digitalisation with climate governance including through cooperative global institutions and an emphasis on de-materialisation and less resource intensive lifestyles.
SSP2: Middle of the road	"A development pathway consistent with typical patterns of historical experience observed over the past century. For example, emerging economies grow relatively quickly and then slow as incomes reach higher levels. This growth, along with income inequality that persists or improves only slowly, continuing societal stratification, and limited social cohesion, constrains significant advances in sustainable development."	Digitalisation's historical role as an amplifier and accelerator of economic and social change continues with both positive aspects (e.g., productivity gains) and negative aspects (e.g., inequality of access, digital divide) remaining in tension.
SSP3: Regional rivalry—A rocky road	"Concerns about competitiveness and security push countries to increasingly focus on domestic issues. This trend is reinforced by comparatively weak global institutions. Countries focus on achieving energy and food security goals within their own regions at the expense of broader-based development. Several regions move toward more authoritarian forms of government with highly regulated economies. Investments in education and technological development decline."	Digitalisation is more tightly focused on national champions and policy goals with a gradual de-globalisation of the digital economy and slower overall rates of digital transformation.
SSP4: Inequality—A road divided	"Highly unequal investments in human capital, combined with increasing disparities in economic opportunity and political power, lead to increasing inequalities and stratification both across and within countries. Over time, a gap widens between an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour intensive, low- tech economy."	Digitalisation amplifies the high-growth global knowledge economy with rapid structural change among 'winning' countries and population segments, but with strong negative effects on job losses, skills displacement, and income polarisation as well as the concentration of power undermining political agency. [*1]
SSP5: Fossil-fuelled development—Taking the highway	"Global markets are increasingly integrated, with strong investments in health, education, and institutions to enhance human and social capital. The push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyles around the world. All these factors lead to rapid growth of the global economy."	Digitalisation enables accelerated globalization and rapid development of emerging economies through new opportunities in the knowledge economy, and increasing global integration and convergence of platforms, social media networks, and consumption patterns. [*2]

*1: The SSP4 narrative alludes to but does not mention digitalisation: "rising inequality is assumed to arise from a number of factors including skill-biased technology development (where technology replaces many low-skill jobs)."
*2: The SSP5 narrative is the only one that makes explicit reference to digitalisation: " the digital revolution enables a global discourse of a significant and increasing fraction of the global population for the first time in human history which may lead to a rapid rise in global institutions and promote the ability for global coordination".

43. The workshop identified further explicit links between alternative digitalisation futures and the SSP framework.

43.1. To facilitate this, selected SSP elements were introduced as 'prompts' for participants to consider as possible variables to include in the causal loop diagrams characterising digitalisation impact pathways.

43.2. These elements with definitions are shown in the Appendix. They were only included as variables in the pathways if participants agreed on their relevance.

43.3. There are many other variables included in the pathways that may have a direct or indirect link to SSP elements, but these were not prompted.

44. Certain SSP elements – including growth, innovation, government effectiveness, and regional convergence - were linked into the digitalisation impact pathways mapped out by workshop participants.

44.1. Table 4 summarises how 'prompted' SSP variables were linked into the digitalisation impact pathways.

44.2. These linkages tended to be made towards the end of the participatory mapping process, so are more ex-post than integral: many are either the end of 'outward' relationships with no onward connections, or the beginning of 'inward' relationships with no antecedent connections. As such, these should be treated as an initial exploratory set of links only; they are far from exhaustive.

45. Digitalisation can be both the cause and the effect of change characterised in SSP storylines.

45.1. These are captured by the direction of the causal links included in the impact pathways and are distinguished in Table 4.

45.2. SSP elements cause digitalisation impacts: e.g., education (an SSP element) enhances digital skills reducing the digital divide and the corrosive effects of misinformation.

45.3. Conversely, digitalisation impacts SSP elements: e.g., productivity gains and digital innovation activity drive economic growth (an SSP element).

45.4. As a result, elements of the SSP narratives can both be *the result of*, be caused by, be enabled by digitalisation impacts ... and SSP elements can *lead to*, cause, or result in digitalisation impacts.

TABLE 4. SUMMARY OF HOW SSP ELEMENTS WERE LINKED INTO DIGITALISATION IMPACT PATHWAYS, EITHER AS AN OUTCOME OR AS A DRIVER OF DIGITALISATION.

Prompted SSP elements	**SSP elements can be *the result of*, be caused by, be enabled by digitalisation impacts … or SSP elements can *lead to*, cause, or result in digitalisation impacts.**				**General link between SSP element and digitalisation impacts, plus *alignment with SSP1,3,4,5 storylines.* ***
Domain ⇒ SSP element ⇓	**society & behaviour**	**economy & industry**	**governance & markets**	**energy & materials**	
Education	*leads to*: weaker effect of misinformation on polarisation undermining social trust *leads to*: stronger digital skills and accessibility, reducing digital divide	*leads to*: more digitalisation in knowledge economy			Education and skills as an enabler of digital skills and knowledge economy and to overcome the digital divide. *aligns with:* SSP5, and in inverse form with SSP4
GDP (Economic growth)		*is the result of*: productivity improvements & new job/skills opportunities (supported by retraining) … otherwise is constrained by inequalities	*is the result of*: innovation activity in both directed (towards sustainability) and undirected markets	*is the result of*: cost & time savings, and lower transaction costs (more convenience)	Generally positive effect of digitalisation on economic growth via productivity and innovation. *aligns with*: *SSP1, SSP5*
Inter-national trade		*is the result of*: data-driven business models, interoperability & supply chain connectivity across geographies	*leads to*: more global distribution of digital infrastructure		Digitalisation both enables and is enabled by economic globalisation. *aligns with:* SSP1, SSP5
Regional converg-ence	*is the result of*: digital platforms spreading information & influence	*is the result of*: digitally-enabled trade, and digital services *is the result of*: market concentration in global tech firms	*leads to*: more global distribution of digital infrastructure		Digitalisation reduces regional variation via both infrastructure and information flows but with risks of power concentrating in lead firms or markets. *aligns with:* SSP1, SSP4, SSP5
Techno-logical change		[the synonym "innovation" was used in the discussions]	*leads to*: both directed digital innovation towards		Digitalisation is part of technology development,

		is the result of: economic growth *leads to:* more digitalization and the diffusion of new business models	sustainability and undirected innovation		transfer, and change processes. *aligns with:* SSP1, SSP5
Income inequality		*is the result of*: job losses, skills polarisation & market concentration	*leads to*: undermining of social trust and so government effectiveness		Exacerbating effect of digitalisation on income and gender inequality via labour markets, with knock-on risks for social cohesion. *aligns with*: *SSP3, SSP4*
Gender inequality	[see under education & digital divide]	*is the result of*: job losses, skills polarisation	*leads to*: undermining of social trust and so government effectiveness		
Global institutions		*are the result of*: digital governance needs and capabilities *lead to*: stronger interoperability and standardisation of digital protocols & practices	*lead to*: stronger & more digital governance for directing innovation activity		Digitalisation both requires and enables effective global institutions. *aligns with:* SSP1, SSP5, and in inverse form with SSP3
Govern-ment effective-ness	*leads to*: strengthened disclosure & transparency of supply chain data (inc. on carbon emissions) *is the result of*: social trust … otherwise is constrained by polarisation		*leads to*: stronger & more digital governance for directing innovation activity *is the result of*: social trust … otherwise is constrained by inequalities		Digitalisation can either enable government effectiveness and rule of law (e.g., via enhanced transparency, individual data rights & sovereignty) or undermine them (e.g., via surveillance, digital divide, and private capture of public goods). *aligns with:* SSP1 (enabling effect), SSP4 (undermining effect)
Rule of law			*leads to*: stronger & more digital governance for directing innovation activity		
Other elements include demography, structural change, and urbanisation were not selected for inclusion in the digitalisation impact pathways.					

* Excluding SSP2 for which all identified linkages are relevant to some extent. (SSP2 is a 'middle of the road' scenario broadly a continuation of historical trends).

46. In general, we found strong consistency between the digitalisation impact pathways mapped out in the workshop, and the dynamics of change characterised by alternative SSP storylines … even though these storylines do not mention digitalisation.

46.1. As a general-purpose technology, digitalisation interacts with economic, societal, and institutional aspects of the SSP storylines.

46.2. The positive effects of digitalisation on productivity, innovation, growth and global trade and cooperative global institutions align most closely with SSP1 and SSP5 storylines.

46.3. The negative effects of digitalisation on market concentration and power align most closely with SSP4, and on labour market, skills and access inequalities most closely with SSP3 and SSP4.

46.4. All effects, both positive and negative, have relevance for SSP2 as they are all evident in the recent history of digitalisation for which SSP2 is the closest continuation.

47. Linkages between digitalisation impacts and future global development storylines used in climate mitigation analysis emphasise how digitalisation acts as an amplifier of both beneficial and adverse changes throughout the socioeconomic system.

47.1. Workshop discussions did not suggest digitalisation has a fundamentally disruptive effect on the drivers and dynamics of global development described by alternative SSP storylines.

47.2. However, Carlsen, Nykvist et al. (2024) have recently argued that AI may represent one such disruption that challenges the fundamental assumptions on which the SSPs are based.

Section V. Digital Governance.

48. The workshop was designed to explore connections between digitalisation impacts and climate mitigation outcomes to strengthen scenario and modelling analysis of these entwined issues.

48.1. No consensus was sought on policy insights or messages.

48.2. Indeed, the workshop was not designed to set out principles or guidelines for governing digitalisation to help ensure it delivers on public policy goals across society and the economy.

48.3. The pre-workshop report cited various publications that set out just such an agenda (TWI2050 2019, WBGU 2019, Santarius, Dencik et al. 2023).

48.4. Although not tasked with developing an agenda for digital governance, certain themes clearly emerged from different groups at different points during the workshop, in particular: (i) in mapping digitalisation impact pathways in the governance & markets domain; (ii) in characterising digital futures in the context of AI; (iii) in concluding plenary discussions.

49. The breakout group on governance and markets explicitly considered digitalisation impact pathways relevant to both digital and climate governance as both affect the direction and speed of innovation, economic growth, and value creation in markets.

49.1. The full impact pathways are shown earlier in the report.

49.2. In mapping out these pathways, there was broad consensus that steering markets to deliver societal value was primarily the responsibility of climate governance.

49.3. Digitalisation does not change the primary importance of strong climate policy for driving emission reductions, including by ensuring firms' incentives are aligned towards low-carbon innovation, strategies, and business models.

49.4. However, opinion varied in the extent to which digital governance was additionally required.

50. Digital governance for climate mitigation can be narrow or broad, but no consensus was reached on which was necessary.

50.1. The narrow view argues that climate governance establishes direction; digital governance should 'just' tackle issues unique to the sector: (1) the energy and material footprint of expanding ICT infrastructure; and (2) societal risks related to trust, agency, inequality, child safety, and security that could result from the inappropriate use of digital media, (mis)information, surveillance, and other applications.

50.2. In addition to these issues unique to the sector, the broad view argues that digital governance should additionally tackle: (3) the indirect impact of digital applications on greenhouse gas emissions through substitution, productivity, growth, rebound and other effects evident at both micro and systems levels: from individual consumption choices on e-retail platforms up to labour productivity gains throughout industry and the economy.

51. Alternative framings of digitalisation as 'saviour' or as 'demon' reveal competing interpretations of its alignment with climate mitigation.

51.1. An optimistic reliance on 'digitalisation as saviour' is consistent with the EU's narrative around a 'twin green digital transition'. This risks creating a moral hazard that could undermine the political will for strong climate governance.

51.2. The inverse framing of 'digitalisation as demon' emphasises energy-hungry infrastructure, unchecked market power of tech firms, data capture for private gain, and threats to political agency and social cohesion from misinformation. Digitalisation as a threat to emission-reduction efforts could strengthen the case for strong climate governance while weakening the social and political institutions on which such governance relies.

52. The speed and scope of AI developments pose particular digital governance challenges - a cross-cutting theme throughout the workshop.

52.1. One group explicitly considered the regulatory challenge posed by very fast-moving AI developments given the much slower responsive capacity of governance institutions including regulators.
52.2. Like the digitalisation as 'saviour' vs. 'demon' discussions, this 'fast-slow' tension in AI governance was not resolved but flagged as a pressing concern; see also (Bengio, Hinton et al. 2024, Luers, Koomey et al. 2024).
52.3. Unlike climate governance, AI governance currently involves very few actors (firms and states). But both climate and AI governance similarly depend on robust cooperative institutions, brokering, political agency, and the integration of justice and equity considerations into governance approaches.
52.4. How these shared underpinnings will play out in the future is uncertain. The alternative SSP storylines used in climate mitigation analysis systematically explore the implications of these governance uncertainties for climate policy, including through quantitative measures of government effectiveness and rule of law (see Section IV. Digitalisation in Climate Mitigation Futures.).

53. As the risks of adverse impacts are high, digitalisation needs steering to deliver societal value and avoid undermining climate goals.

53.1. A final roundtable set of recommendations for elements of a digital governance regime reflected a diversity of views among participants. The premise of these final discussions was that digitalisation acts as an amplifier and accelerator of change, both for better and for worse.
53.2. Recommendations included the use of digitalisation to monitor emissions, improve the quality of low-carbon services, shape consumer behaviour, support agency and citizenship, boost social cohesion and trust in the state, and enhance the transparency of sustainability indicators.
53.3. The scope of these recommendations is consistent with the broad view of digital governance: not just ICT energy footprints and misinformation, but also the impacts of digitalisation on economic and social activity responsible for GHG emissions.
53.4. Both climate and digital governance are cross-cutting issues that require coherence and interaction between traditional policy departments, knowledge domains, and business objectives. Effective integration is a major challenge for skills, organisations, and assessments.
53.5. Another common digital governance theme related to the digital divide, skills, inequalities of access and opportunities.
53.6. Although workshop discussions primarily oriented around participants' experiences in the Global North, the unequal geographies of digitalisation with respect to ICT infrastructure, labour markets, and economic opportunities risks a new wave of exploitative practices that need mitigating through effective digital governance.

Section VI. Conclusions.

54. This report highlights the key insights from an Expert Workshop on Digitalisation Narratives and Climate Change Mitigation held in May 2024 at IIASA.

54.1. Over 1.5 days of structured activities and discussions the 35 participants mapped out digitalisation impact pathways in four different domains, explored the drivers and dynamics of digitalisation in best- and worst-case futures, and considered what this current and future understanding meant for climate mitigation efforts.

54.2. The workshop was motivated by the weak representation of digitalisation in global scenarios and modelling of climate mitigation pathways.

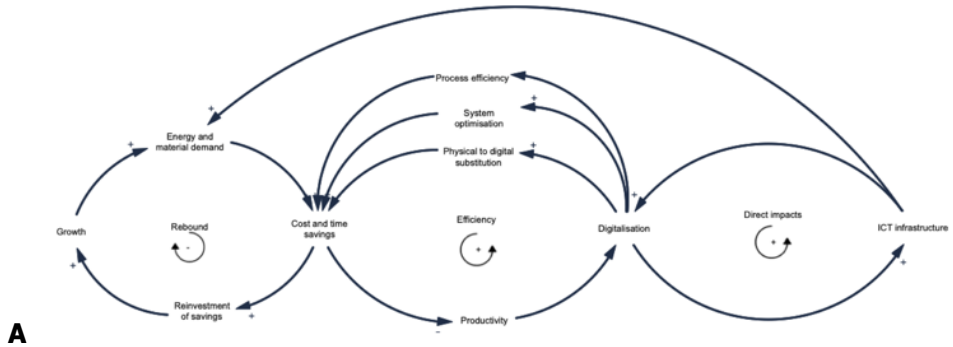
54.3. In this synthesis report from the workshop we were able to:
- *map out* the complexity and pervasiveness of digitalisation impacts across society and the economy;
- *demonstrate* how digitalisation is a double-edged sword with both positive and negative effects on jobs, on sustainable growth, and on user engagement and empowerment;
- *counter* a naïve perception that rapid digital transformation is necessarily aligned with climate goals;
- *show* how firm and household-level digitalisation impacts have wider systemic consequences;
- *reveal* how impacts in one domain can indirectly outcomes in other domains;
- *identify* common areas of understanding including on the importance of tackling the digital divide, fast paced AI developments, and societal risks from misinformation;
- *expose* fault lines in opinion between the need for broad vs. narrow digital governance, and between digital-climate interactions as being enabling vs. exacerbating.

54.4. These and other insights point to the contingency of possible digital futures for climate mitigation. Digitalisation can enable emission reductions and effective climate governance, but also exacerbate energy intensive activity and undermine governance capacity and the social cohesion on which it relies.

54.5. Making digitalisation more explicit as a driver and outcome of change in low-carbon futures, including those explored in the SSPs, is a necessary step towards harnessing it as a force for climate good.

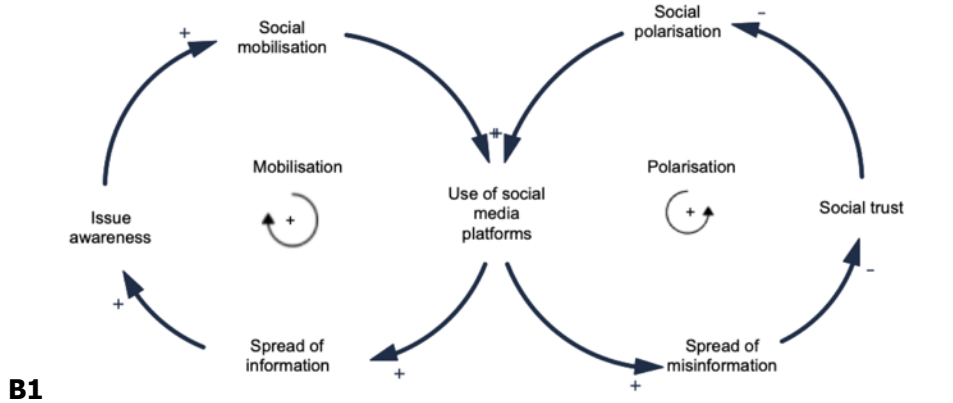
Appendix.

FIGURE A1. INITIAL CONCEPT MODELS IN FOUR DOMAINS, USED FOR CATALYSING WORKSHOP DISCUSSIONS & PARTICIPATORY SYSTEM DYNAMIC MAPPING.

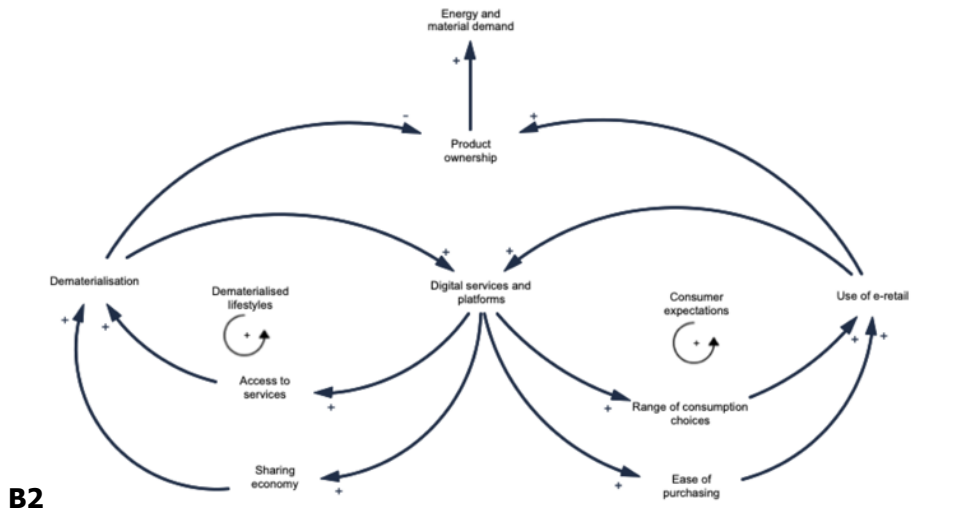


A

Concept model: Energy and Materials.



B1



B2

Concept model: Society and Behaviour.

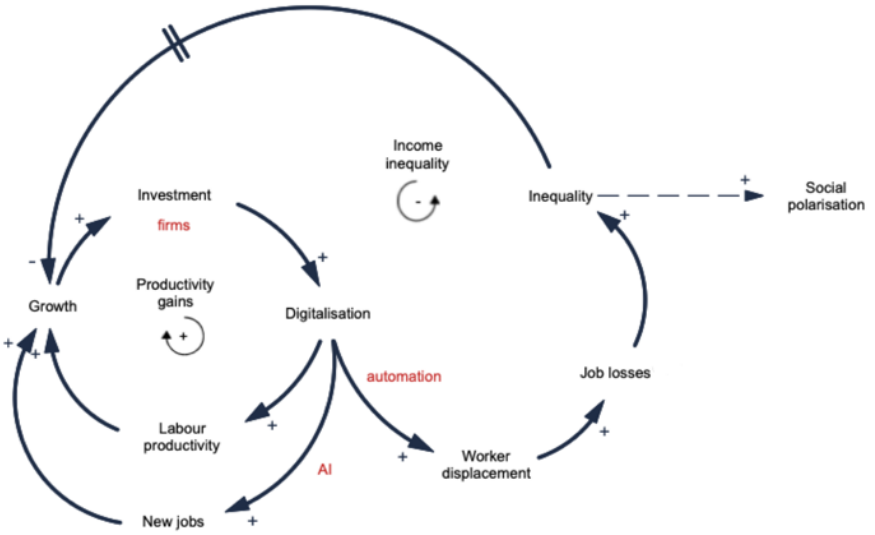
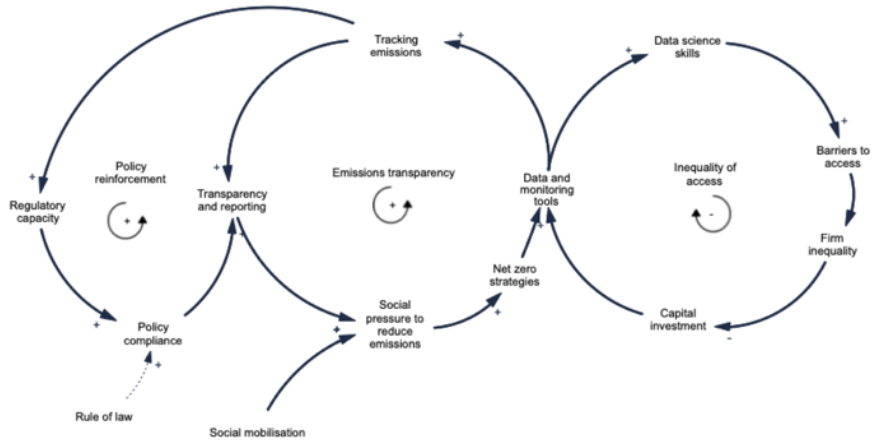
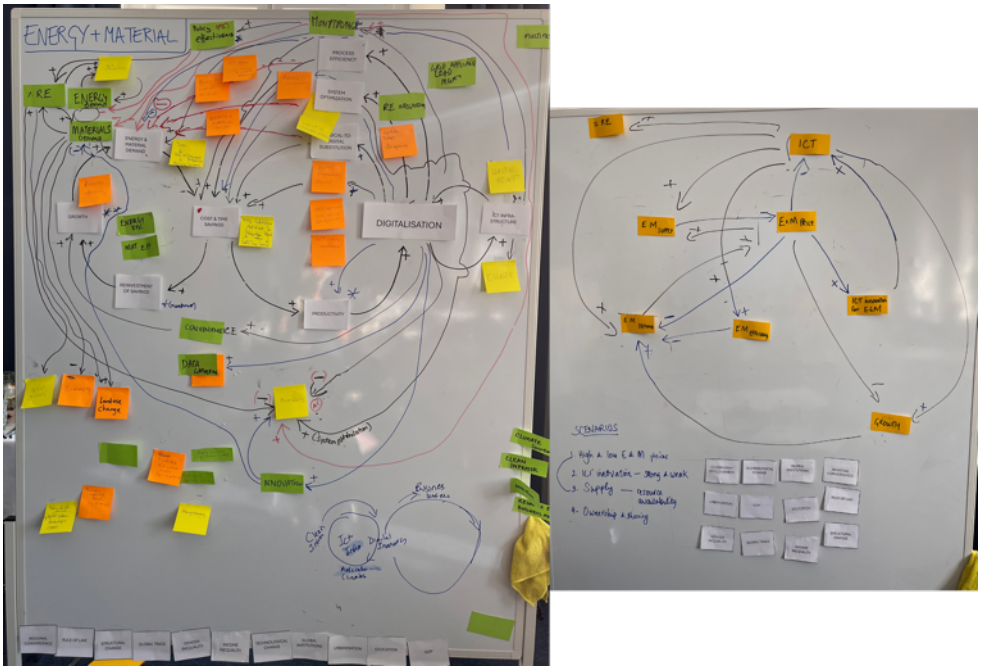
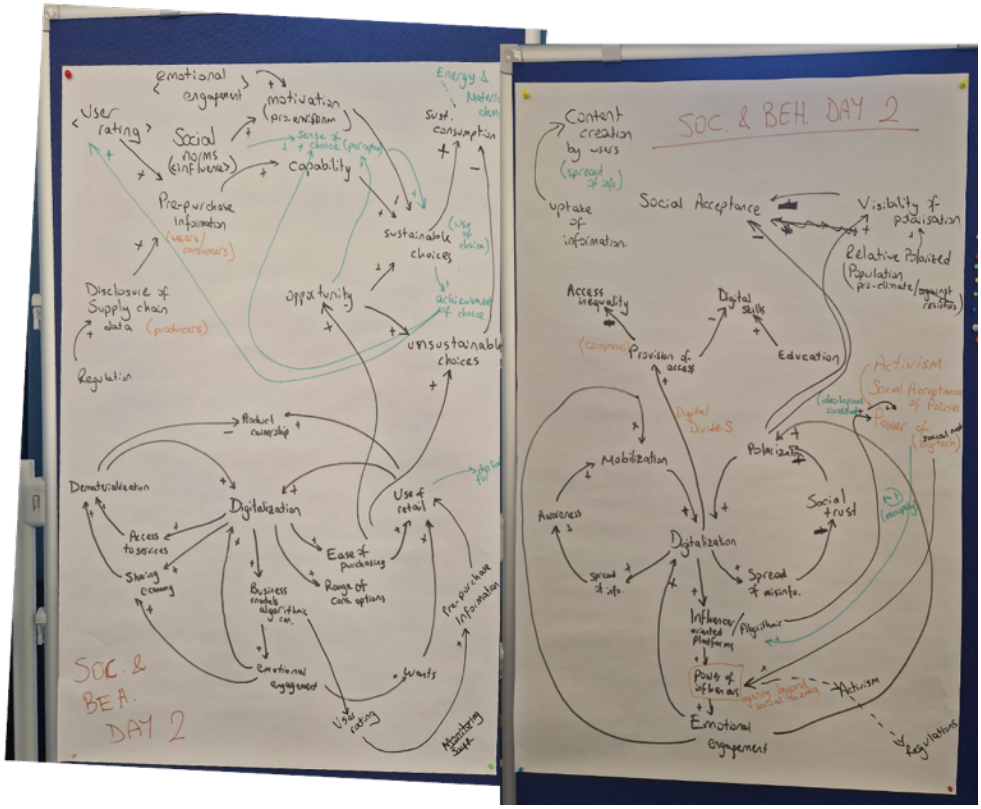
C  	**Concept model: Economy and Firms.**
D  	**Concept model: Governance and Markets.**

FIGURE A2. 'RAW DATA' FOR SYSTEM MAPS CO-CREATED DURING WORKSHOP.

A 	**Co-created model (pre-cleaning): Energy and Materials.**
B 	**Co-created model (pre-cleaning): Society and Behaviour.**

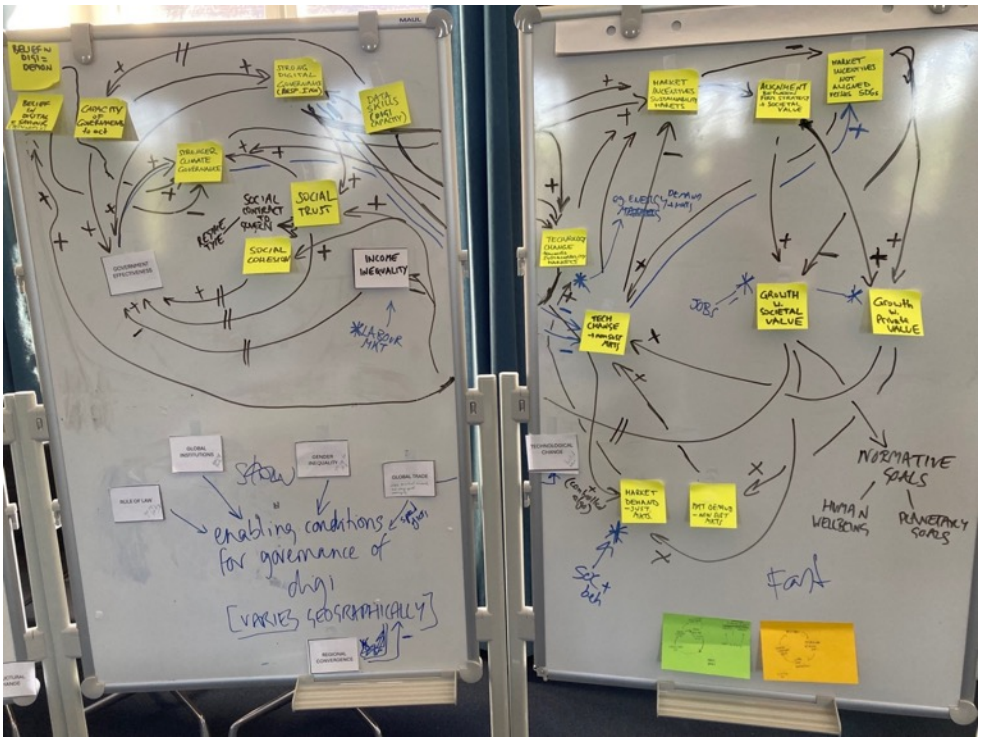
C 	**Co-created model (pre-cleaning): Economy and Firms.**
D 	**Co-created model (pre-cleaning): Governance and Markets.**

FIGURE A3. NARRATIVE ELEMENTS OF FIVE GLOBAL SOCIOECONOMIC DEVELOPMENT SCENARIOS USED IN CLIMATE CHANGE MITIGATION ANALYSIS – THE SHARED SOCIO-ECONOMIC PATHWAYS OR SSPS. REPRODUCED FROM (BAUER, CALVIN ET AL. 2017).

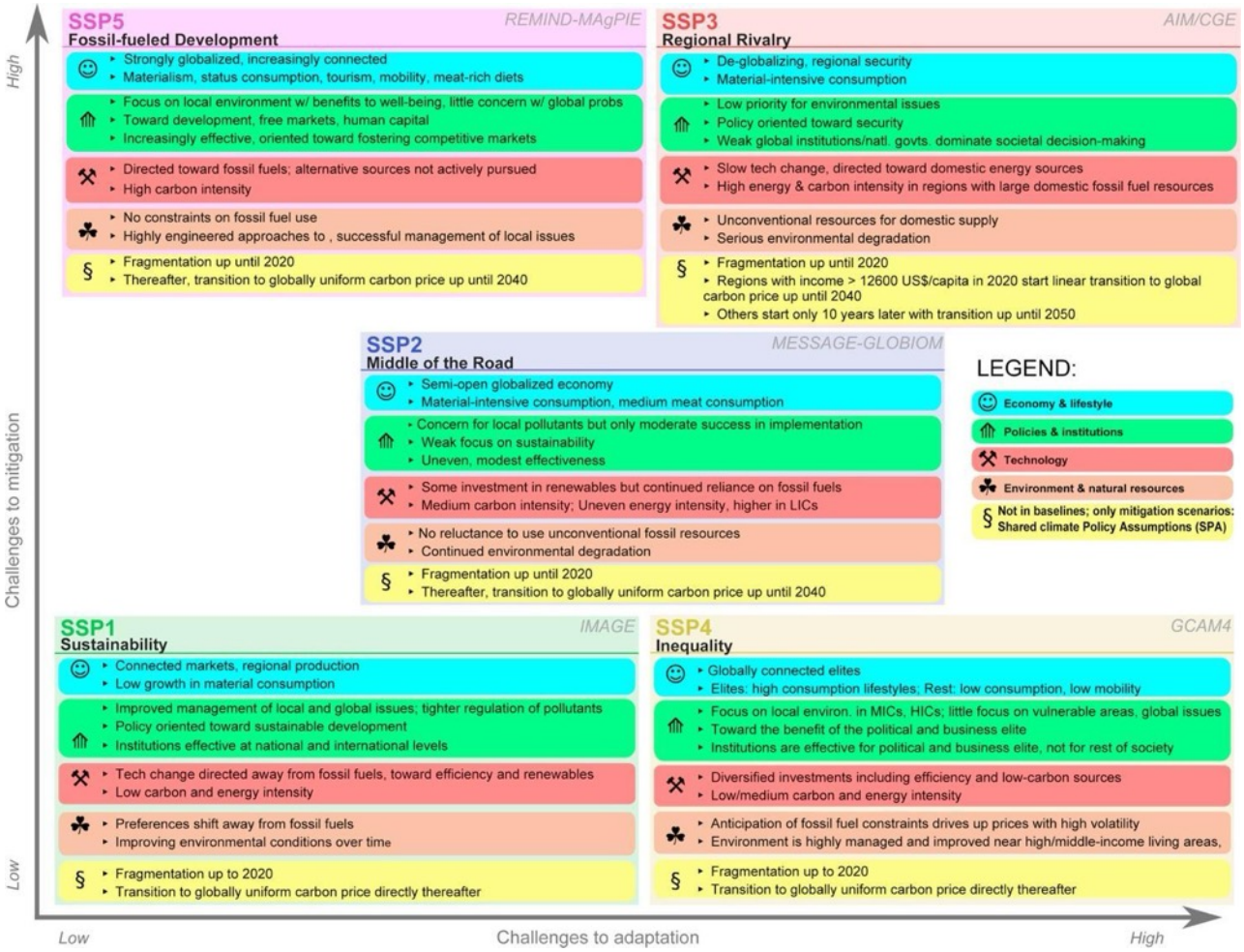


TABLE A4. SSP STORYLINE ELEMENTS INCLUDED AS PROMPTS FOR POSSIBLE INCLUSION IN THE PARTICIPATORY MODELLING.

SSP elements	role in SSP framework	Definition
Demography	Driver	e.g., population growth, fertility & mortality rates
Education	Driver	e.g., % of population completing secondary education
GDP	Driver	economic growth
Structural change	Extension variable	sectoral shares of employment and value added (GDP) moving from agriculture to manufacturing to services
Urbanisation	Driver	% of population living in urban area
International trade	Other element	global interconnectedness through trade, markets, and technology transfer
Regional convergence	Other element	rate of economic convergence between world regions (inc. income and living standards)
Technological change	Other element	rate of innovation and turnover (substitution) in key technologies - could be digital, energy, or other
Income inequality	Extension variable	within-country Gini coefficient
Gender inequality	Extension variable	composite of reproductive health (e.g., maternal mortality), empowerment (e.g., education, parliament), and labour force participation
Global institutions	Extension variable	global interconnectedness through institutions
Government effectiveness	Extension variable	quality of public services, policy formulation & implementation, and credibility of government commitment to policies
Rule of law	Extension variable	individual liberty, equality before the law, and strength of governance institutions
Other SSP elements not included as prompts for inclusion in the causal loop diagrams		
Category: Economy & lifestyle	Other element	Globalisation, consumption & diet
Category: Policies & institutions	Other element	International cooperation, environmental policy, policy orientation
Category: Technology	Other element	Technology transfer, energy technology change, carbon intensity, energy intensity
Category: Environment & natural resources	Other element	Fossil constraints, environment, land use, agriculture

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