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Perspective

Systems thinking and efficiency under emissions constraints: Addressing rebound effects in digital innovation and policy

Kelly Widdicks,^{1,*} Federica Lucivero,² Gabrielle Samuel,³ Lucas Somavilla Croxatto,^{2,4} Marcia Tavares Smith,¹ Carolyn Ten Holter,² Mike Berners-Lee,⁵ Gordon S. Blair,^{1,6} Marina Jirotko,² Bran Knowles,¹ Steven Sorrell,⁷ Miriam Börjesson Rivera,⁸ Caroline Cook,⁹ Vlad C. Coroamă,¹⁰ Timothy J. Foxon,⁷ Jeffrey Hardy,¹¹ Lorenz M. Hilty,¹² Simon Hinterholzer,¹³ and Birgit Penzenstadler^{14,15}

¹Lancaster University, Lancaster, UK

²University of Oxford, Oxford, UK

³Kings College London, London, UK

⁴University College London, London, UK

⁵Small World Consulting, Cumbria, UK

⁶UK Centre for Ecology and Hydrology, Lancaster, UK

⁷University of Sussex, Brighton, UK

⁸Uppsala University, Uppsala, Sweden

⁹Baillie Gifford, Edinburgh, UK

¹⁰Technische Universität Berlin, Berlin, Germany

¹¹Imperial College London, London, UK

¹²University of Zurich, Zürich, Switzerland

¹³Borderstep Institute, Berlin, Germany

¹⁴Chalmers University of Technology, Göteborg, Sweden

¹⁵Lappeenranta University of Technology, Lappeenranta, Finland

*Correspondence: k.v.widdicks@lancaster.ac.uk

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THE BIGGER PICTURE Information communication technology (ICT)'s environmental impact must be considered in digital innovation and associated policy to mitigate ICT's climate change contribution. A proposed solution to reduce ICT emissions is by improving efficiency, yet this fails to consider rebound effects where efficiency improvements offset emissions savings or increase emissions. In this perspective, we reveal insights from a transdisciplinary workshop that identified challenges for why rebound effects are difficult to include in innovation and policy. From this, we call researchers to (1) find new ways of presenting rebound effects to digital innovators and policymakers; (2) gather cross-disciplinary evidence of ICT rebound effects; and (3) transparently analyze ICT's environmental, societal, and economic impacts together. We also call for a systems thinking approach to addressing ICT's environmental impacts, whereby a solution to rebound effects becomes visible: efficiencies under emission constraints.



Concept: Basic principles of a new data science output observed and reported

SUMMARY

Innovations and efficiencies in digital technology have lately been depicted as paramount in the green transition to enable the reduction of greenhouse gas emissions, both in the information and communication technology (ICT) sector and the wider economy. This, however, fails to adequately account for rebound effects that can offset emission savings and, in the worst case, increase emissions. In this perspective, we draw on a transdisciplinary workshop with 19 experts from carbon accounting, digital sustainability research, ethics, sociology, public policy, and sustainable business to expose the challenges of addressing rebound effects in digital innovation processes and associated policy. We utilize a responsible innovation approach to uncover potential ways forward for incorporating rebound effects in these domains, concluding that addressing ICT-related rebound effects ultimately requires a shift from an ICT efficiency-centered perspective to a “systems thinking” model, which aims to understand



efficiency as one solution among others that requires constraints on emissions for ICT environmental savings to be realized.

INTRODUCTION

Global greenhouse gas (GHG) emissions, including those from the information and communication technology (ICT) sector, have been rising year after year, with ICT forming 2.1%–3.9% of total global GHGs in 2020.¹ This contribution will likely further increase with the growing range of ICT applications, accelerating demand for novel ICT (e.g., artificial intelligence [AI], Blockchain, Internet of Things, robotics), and the increasing reliance on digital technologies to support the net zero transition in other sectors (e.g., GeSI²). The efficiency gains ICT creates in these sectors, as well as its own, are usually viewed as central to reducing emissions worldwide because less energy is required for the same output.

This assumption ignores the behavioral and social responses as well as the adjustments to the wider economic system that typically occur when the efficiency of a process is improved. Efficiency improvements reduce the cost of the relevant good or service, which can encourage an increase in demand. There are many historic precedents for this. Jevons' famous observation in 1865 that increasing efficiency in UK coal use in 1865 led to increases in demand³ led to the coining of the phrase Jevons paradox. More recently, increases in land transport use were seen when more efficient transportation services were introduced, such as electric trains instead of steam trains and horses.^{4,5} As these examples show, increases in demand offset emission savings and, in some cases, can lead to an overall increase in emissions ("backfire").⁶ Emissions from the ICT industry over the last 50 years have risen from almost zero to their current level due to growing demand for digital technology despite rapid improvements in efficiency.

Across the global economy, energy efficiencies in the provision of most products and services have gone hand in hand with an average 1.8% per year growth in global carbon emissions since 1850.⁷ Emissions have continued to rise since then with little obvious deviation from that trajectory other than a small and potentially temporary dent during the COVID-19 pandemic. This does not prove that efficiency improvements lead to increased emissions, but for this not to be the case requires that emissions would have risen much quicker in the absence of efficiency gains.

Environmental rebound effects have been well categorized in the ICT-related research literature.^{8–15} Although there is no general agreed-upon taxonomy for rebound effects, most of the literature distinguishes between direct and indirect rebound effects. Direct rebound effects occur for the same good or service that had originally become more efficient and because the efficiency gains made it cheaper and thus encouraged an increase in demand. Meanwhile, indirect rebound describes a large collection of subtler and more elusive mechanisms, which also lead to an increase in consumption but of a different good or service.¹⁶ Indirect rebound effects include, for example, the income effect (i.e., when the monetary savings achieved from more efficient production are spent on different goods and services) or the

time rebound (i.e., not energy but time is saved in the first place, time then spent on energy-intensive activities).

At the same time, sustainability and environmental impacts in general, and rebound effects in particular, are largely neglected in the design, development, or innovation processes for ICT. For example, technologists typically lack the knowledge and tools to assess environmental sustainability in software engineering practices.¹⁷ The full emissions life cycle and rebound effects are also overlooked in the greening of technologies such as 5G,¹⁸ with such "green IT" initiatives abstracting away from the social complexities that conflict with technological solutions to environmental problems.¹⁹ As consumption of ICT and the efficiencies it can create are placed at the heart of global efforts to address the climate crisis, there is a strong need for rebound effects to be included at the center of any digital sustainability agenda so that the climate benefits afforded by ICT efficiencies are not materially overestimated. To do so requires the development of digital technology innovation processes that contribute to the green agenda (i.e., "enablement" reducing emissions) while also mitigating the associated rebound effects. And further, in grappling with ICT's emissions, these processes need to consider ICT's other contributions to, and impacts on, human prosperity and the environment beyond emissions (e.g., to ecosystems and biodiversity, ICT's use of natural resources, e-waste, etc.).

The practice of "responsible innovation" offers a useful approach to achieve this, drawing on multiple perspectives to ensure transdisciplinary expertise informs such design and development processes. Although responsible innovation can be interpreted in many ways, one especially useful definition in terms of sustainability comes from the European Union's Responsible Research Innovation (RRI) Tools project:

RRI is a way to do research that takes a long-term perspective on the type of world in which we want to live. (www.rri-tools.eu)

This particular conceptualization of responsibility, a forward-looking, "care"-based approach to the future, highlights the sense of actively reflecting on current developments and seeking to shape them toward societal benefit. The approach most frequently seen in the UK context is drawn from the work of Stilgoe et al.,²⁰ whose framework for responsible innovation consists of four dimensions: anticipation—future-based thinking to pre-empt opportunities and increase resilience; reflexivity—challenging assumptions surrounding the role of science and innovation; inclusion—supporting cohesive input from stakeholders and the public; and responsiveness—changing innovation directions based on current challenges. Responsible innovation thus actively seeks to pre-empt and respond to possible outcomes, both positive and negative, and purposefully considering and reflecting on such possible outcomes is a form of anticipatory governance.²¹ Pertinent questions include not only "what could go wrong?" but "what happens if we succeed?" The outcomes of success can be just as challenging in terms of societal impacts as those of failure—for example

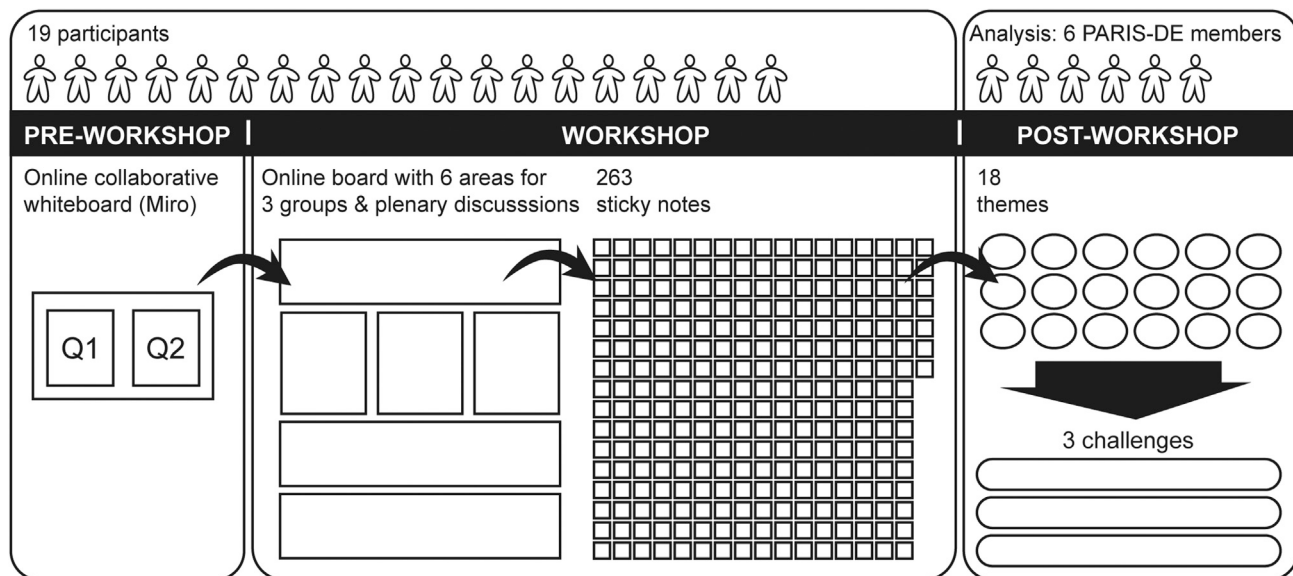


Figure 1. An overview of the workshop activities, participants, and analysis

AirBnB’s progress from a peer-to-peer sharing app to presenting serious challenges to city planners and councils.²² It is the problem of “success” that can inform work on rebound effects: ICT can indeed create efficiencies—but to such good effect that consumption increases, too.

We drew on these inclusive and reflexive responsible innovation principles to design a transdisciplinary expert workshop that explored stakeholder perceptions about the nature of rebound effects, the practical challenges in accounting for rebound effects in digital technology innovation, and how these might be overcome in devising sustainable innovation processes and associated policy that meaningfully attends to wider system effects. In this perspective, we report on the key themes that emerged from the workshop. These included difficulties in communicating rebound effects, difficulties in measuring rebound effects, and the tensions between rebound effects and values. We argue that the ICT sector requires a transformation in the way it approaches efficiencies for GHG emission reductions: from unlimited increases in efficiencies and innovation to systems thinking, which accounts for efficiencies under constraints.

METHOD

To explore the complexities of rebound effects and how these can be considered in ICT innovation and associated policy, the PARIS-DE project (<https://www.paris-de.org/>) designed and ran a transdisciplinary 3-h online expert workshop in April 2022 that connected multiple disciplines and stakeholder expertise on this topic (Figure 1). Disciplinary backgrounds included carbon accounting, digital sustainability research, ethics, sociology, public policy, and sustainable business. Nineteen experts took part in the workshop; these experts were known to the PARIS-DE team or invited via snowballing, and while consideration was taken to gather a diverse set of participants in terms of disciplinary background and gender beyond the UK, the experts form

a non-probabilistic sample from the Global North. We suggest that our findings should be complemented with a workshop formed by participants from the Global South, which we aim to conduct in our future work. The workshop was conducted via Microsoft Teams using an online collaborative Miro board. Discussions were audio recorded for note purposes only, and these recordings were deleted as soon as notes were confirmed to have been captured on the Miro board.

Prior to the workshop, participants were asked to access the Miro board and use digital notes to record their answers to the questions. This permitted the workshop organizers to gather individual experiences, perceptions, and disciplinary perspectives from the experts. The questions were as follows:

- (1) In the context of your own work and experiences, what insights or examples do you have about rebound effects? For example: case studies, theoretical approaches, challenges, policy implications. This question was left open to support participants in sharing anything they deemed relevant to rebound effects and digital sustainability.
- (2) What new insights are you excited to learn regarding rebound effects? This question was chosen to help identify any gaps regarding our understandings of rebound effects.

Answers on the Miro board were arranged into initial discussion points by the PARIS-DE team, which were summarized and presented at the workshop in the first activity (see below). These included the complexity of rebound effects and the difficulty in measuring or communicating them and policy and solutions or countermeasures to rebound effects, as well as specific definitions, examples, and evidence of their existence. These shaped discussions in the workshop in the second activity (see below) and, subsequently, the findings presented in this perspective (see [challenges of rebound effects from ICT](#)).

The workshop was organized into three 45-min interactive activities, each separated by 15-min breaks.

- (1) Sharing perspectives. The PARIS-DE team welcomed all workshop participants, summarized the pre-workshop activity themes, and provided an open session for reflection and discussion based on these varying perspectives.
- (2) Breakout discussions. With our shared perspectives as a baseline, workshop participants were divided into three breakout groups to discuss what rebound effects mean for innovation processes and public policy in relation to digital technology. Each breakout group was asked to choose a member to provide feedback for the final session, with notes from their discussions added to the Miro board.
- (3) Summary reflection. Each breakout group was asked to summarize their discussions, utilizing notes on the Miro board where needed. A member of the PARIS-DE team then synthesized all group discussions into one summary, with input from all participants. The workshop concluded with a short planning session on next steps.

Following the workshop, six members of the PARIS-DE team—each with varying disciplinary perspectives from computing, design, ethics, sociology, and policy—conducted a collaborative thematic analysis of the workshop data. This involved ensuring all points from the audio recordings of the workshop were captured on the Miro board, as well as inductively identifying themes manually from the workshop notes on another Miro board during additional online meetings (see [Figure 1](#)). This exercise formed an in-depth reflection on the issues and themes that had arisen in the stakeholder group. In total, 263 digital sticky notes were created and organized into initial themes through three online sessions, forming over 7 h of collaborative analysis. These themes included definitions of rebound effects; understanding rebound effects; assessment methods; economic links; enablement; case study examples; the effect of user/people’s behavior; associated values, benefits, or positive impacts; implications (e.g., design strategies, methodological solutions); responsibility; sufficiency; policy; incentives; social and environmental justice; constraints; and communicating and framing rebound effects. Additional rounds of thematic analysis led to three overarching themes each with emerging challenges (see [challenges of rebound effects from ICT](#)), as well as underpinning themes for discussion (see [systems thinking in digital innovation and policy](#)), which together form the basis of this perspective. Thematic analysis on the Miro board as well as the draft paper were shared with all participants, who were invited to contribute to the further development and refinement of the insights through this perspective. All participants are therefore authors of the perspective and have provided consent for their discussions to be published.

CHALLENGES OF REBOUND EFFECTS FROM ICT

In this section, we provide an overview of the core themes that emerged from the workshop discussions and identify a key challenge that emerges from each of these.

Communicating rebounds

Workshop participants emphasized the need to take care when communicating issues associated with rebound effects in effi-

ciency-based solutions given how language can convey positive or negative meanings and/or feelings depending on the terms and analogies used. Language can—depending on context—be understood and used in different ways to fit different narrative purposes: a more “efficient” system is well known to support increases in production and profit, yet simultaneously, a more “efficient” system is depicted as one that decreases emissions. Danger lies in conflating these two conflicting meanings.

Participants were concerned that the language associated with rebound effects may promote a defensive response, ultimately discouraging digital innovators from engaging with the topic and creating more successful solutions. They were also concerned about how certain language could lead to a sense of doom, with digital innovators’ and policymakers’ efforts potentially feeling useless. As sustainability is often placed in opposition to growth in this debate, participants expressed that these messages can even push some digital innovators and policymakers away from engaging with rebound effects when their primary job is to deliver economic growth and prosperity to businesses and populations.

Participants discussed whether the use of a different communication strategy would promote engagement of innovators and policymakers in discussions about rebound effects: for example, by using the language of digital sufficiency.²³ Moving forward, one workshop participant suggested that drawing examples of communication strategies from other sectors, such as health and education, could help the ICT sector communicate with policymakers and influence change in policy. Utilizing imagery, diagrams, and visualizations to communicate rebound effects for easier comprehension by digital innovators and policymakers was also considered. Such images were viewed as a way to help communicate a complex issue such as rebound effects in an accessible way, highlighting relationships and interconnections between different parts of the system.^{24,25}

There was a clear consensus that current communication strategies were not working, and new ways of presenting the issue are needed to ensure they are considered in ICT innovation and associated policy.

Challenge: To find new ways of presenting rebound effects to innovators and policymakers in the digital sector to ensure they are addressed in innovation and associated policy.

Measuring rebounds

Given that ICT pervades multiple activities and sectors worldwide, the total of all environmental rebound effects (direct and indirect) includes an infinite number of possible mechanisms rippling throughout the global economy and involving complex interactions between every sector. Consequently, workshop participants emphasized that this makes environmental rebound effects extremely difficult to quantify. As these rebound effects also occur in the future, participants discussed how rebound estimates require the use of scenarios rather than measurement, adding further uncertainty.

Studies that do attempt to quantify rebound effects introduce boundary constraints for what impacts they do consider, often adding together potential individual rebound effects in order to calculate a rough overall estimate. Yet, attempts to quantify

the overall rebound effect of one efficiency improvement by adding up the effect of each rebound pathway result in an underestimate of the total effect due to truncation of myriad mechanisms at play. While some evidence of total rebound effect can be found by correlating efficiency gains with total emissions, even here, the exercise is complicated by the interactions between different sectors of the economy, and ultimately it is not possible to consider the effect of one efficiency improvement in isolation from the others that are simultaneously taking place.

Workshop participants expressed the need for new methods to anticipate rebound effects. While rebound quantification could provide clear guidance for decision-making around ICT's design and environmental impacts, more qualitative assessments were simultaneously called for, as waiting for concrete and cohesive evidence from comprehensive quantitative models and measurements would be somewhat futile. This is not only because of the urgency of the climate crisis but also because considerable uncertainty will remain, and we need to be able to digitally innovate and govern within these realms of uncertainty.^{26,27} Specific solutions included trialing methods such as the anticipatory governance approaches described above²⁸ or futures thinking and scenarios in design and innovation^{29–32} for identifying and considering potential rebound effects.

With data on ICT's environmental impacts being scarce, building a collection of rebound examples and case studies—detailing how they happen and why they occur—and then drawing on these in ICT innovation processes to explore solutions was viewed as a necessary requirement by workshop participants moving forward. One discussed example was the role of ICT—and specifically video conferencing—on the travel industry. While regional hubs connected via video conferencing can significantly reduce the emissions of a conference,³³ there is evidence that the demand for video data, and flights more generally, have increased year by year alongside ICT and aviation emissions (apart from the COVID-19 pandemic), meaning video does not substitute all flying.¹ Moreover, teleworkers have been found to travel more for business each week than non-teleworkers.³⁴ Accumulating more examples such as these, as well as others in the literature, would provide useful evidence on ICT's impacts and how and when rebound effects occur, particularly in relation to the emissions of other sectors.

Despite the suggestions for a collection of rebound examples and case studies, concerns remained among workshop participants that adopting quantitative and qualitative tools for evidencing rebound effects alongside each other requires embracing the use of mixed methods data. Specifically, drawing on well-established controversies in the social sciences, participants noted that incorporating qualitative data would make rebound effects difficult to evaluate in line with available quantitative data, meaning that evaluating rebounds could concomitantly make measuring them in digital innovation and policy even more complex.

Without reaching a solution to these complexities, there was a clear demand from workshop participants to address these issues—specifically trialing different methodological approaches and bringing together rebound effect examples in practice to help the digital sector in considering and addressing rebound effects.

Challenge: To generate and collate cross-disciplinary evidence and empirical examples of rebound effects in ICT.

Tensions between rebounds and values

Not only are direct environmental rebound effects difficult to identify, confine, and measure, but workshop participants discussed how they must also be considered in tandem with social and economic dynamics. These could be perceived either positively or negatively, depending on the discipline, leading to inherent tensions between the benefits and drawbacks of different rebound effects. Economic growth that emerges from efficiency gains, and which contributes to increased employment, prosperity, and/or increased well-being, was a core example provided by workshop participants. Most economists thus view economic growth as a positive rebound that emerges from increased efficiency. On the other hand, environmentalists are concerned that such economic growth can (and will) lead to negative environmental impacts, and so the evaluation of efficiency improvements must also consider limits to material production and consumption, environmental degradation, and social inequalities.^{35,36}

In trying to disentangle some of these issues, participants questioned how best to conceptualize and actualize the relationship between economic, social, and environmental imperatives, each of which potentially brings a range of value-laden assumptions and divergent values.^{37,38} One approach is to unpack and rethink assumptions engrained in our contemporary value systems. The need for economic growth was one such assumption interrogated by participants at the workshop. The well-established alternative economic models that consider notions associated with whom economic growth is intended for (“growth for whom; whose needs are being met?”) were viewed as vital in this space (e.g., Doughnut Economics³⁹). Discussions also emphasized the need to ensure that multiple dimensions of sustainable development that go beyond GHG emissions are considered.^{40,41} For example, social well-being and the need for development worldwide need to be taken into account, including, but not limited to, issues of war, energy security, food security, access to employment, and cost of living.

In summary, and for rebound effects to be addressed in digital innovation and associated policy, experts agreed that all rebound effects (direct or indirect), as well as social and economic dynamics, need to be considered in tandem, with transparency of competing values.

Challenge: To transparently and thoroughly analyze ICT's environmental, societal, and economic impacts to account for digital technology's rebound effects.

SYSTEMS THINKING IN DIGITAL INNOVATION AND POLICY

The difficulty of communicating the mechanisms of rebound effects to non-experts, the challenges in measuring those effects, and their conflicts with differing values are all likely reasons our transdisciplinary workshop surfaced for why environmental rebound effects are often not considered in practice, and why

it is challenging to devise policy to address them. What ultimately underpins these challenges is that assessment of ICT requires balancing known impacts—such as economic growth, unemployment, and cost of living—with unquantifiable risks and uncertainties associated with social and environmental impacts. We argue that these difficulties with considering rebound effects are compounded by a current socio-political context that promotes techno-solutionist and efficiency-centric perspectives for how digital technology impacts the economy, societies, and the environment. Until we address this context, we are unlikely to get traction in addressing the challenges presented.

Techno-solutionism^{42–44} is the idea that innovations are the only solutions to global challenges and will linearly lead to positive social, economic, and environmental outcomes.^{2,45} This leads to a resultant focus on digital technology to deliver reductions in global emissions and environmental impacts, which it has so far attempted to provide through efficiency gains. Yet, as we have emphasized in this perspective, efficiency on its own cannot be relied upon to reduce environmental impact. Instead, because of rebound effects, for efficiency improvements to be environmentally beneficial, they must be accompanied by a constraint on emissions. Rebound effects thus do not fit in the techno-solution narrative, as they expose the complexities of human behavior and socio-technical interactions. In fact, rebound effects challenge the simplistic causal link between innovation and positive impacts in techno-solutionism, which takes a narrow view of digital technology and sustainability, without considering the bigger picture and accounting for all these interrelated impacts.

To account for this, systems thinking is required. Systems thinking is an approach that considers complex problems from a holistic perspective across time, taking into account the relationships and dynamics among the components of a system.^{46–48} Meadows and Wright⁴⁶ refer to systems thinking as a “different way of seeing and thinking,” one whereby a “system is more than the sum of its parts” and where emphasis is placed on interactions and feedback loops, resulting in emergent and often unexpected behaviors and surprises. This differs from analytical approaches that study complex issues by reducing systems into smaller parts. Systems thinking is a well-established area of study, having been applied in fields such as engineering, management, and computer science, as well as sustainability.^{49,50} Reasons for embracing this more concretely for sustainable ICT innovation and associated policy are 2-fold: systems thinking exposes the flaws of techno-solutionist, efficiency-driven narratives through making rebound effects visible, and systems thinking enables efficiencies to support environmental sustainability through the use of emissions constraints. This is because systems thinking requires a broadening of scope for what is important and what needs to be accounted for when considering the impacts of the ICT sector. With this widening, efficiency is only one solution among others that are needed to address digital technology’s environmental impacts—both in and beyond the ICT sector.

Specifically, a broader system thinking approach implies that efficiency gains can bring about negative impacts on environmental and social dimensions, and if they do, then it becomes reasonable to rethink efficiencies as a sole solution. Instead, ensuring efficiencies under constraints on GHG emissions forms

a completely justifiable and appropriate response. In this sense, constraints to the additional outputs from efficiency can be seen not as a limitation to economic growth but as fostering environmental sustainability or social sustainability. As we fall deeper into the climate crisis, it has never been more important to foster environmental and social sustainability, and this solid, sustainable foundation is required for any economic endeavor, e.g., productivity through efficiency, to prosper.

Furthermore, systems thinking changes the role of efficiency as a solution. When constraints are placed on digital technology and its environmental impacts—such as through the use of caps on GHG emissions—the dynamics of growth from efficiency would be changed completely. In this scenario, the rebound effect would be eliminated because emissions would be fixed at the level of the GHG constraint, and efficiency gains would become the sole means by which output growth would be possible. We therefore emphasize that efficiency gains rely upon GHG emission constraints to make emission reductions possible, and thus efficiencies under constraints are the only true efficiencies for emission reductions (Figure 2). Moreover, with systems thinking, efficiencies under constraints are not antagonists of growth and innovation but rather provide the friction needed to drive effective progress in innovation and support wider opportunities for good for our environment, societies, and economy. Constraints therefore inspire creativity in digital innovation and associated policy to fully support the green transition. While we have focused on GHG constraints in this first instance, it is worth pointing out further constraints (e.g., on material depletion) will also be relevant for sustainable digital technology innovation to thrive and, especially, to provide a collective approach to address interconnecting rebound effects.

In summary, rebound effects represent clear challenges that the digital sector needs to address in digital innovation processes and associated policy. Systems thinking offers a sector-wide perspective change that can account for such challenges, enabling an understanding that efficiencies are one solution among others that need constraints to offer emissions savings. We urgently need to embrace this approach for digital sustainability to be realized and suggest that transdisciplinary and responsible innovation research, like this workshop, is one prerequisite to embracing systems thinking and its broader lens in order to consider the varying disciplines and stakeholder views that surface the systems and tensions between them. The economic opportunity for the ICT sector offered by embracing the significance of rebound effects and the consequent requirement for a global GHG constraints is that under those constraints, efficiency improvements, including those offered by ICT to the whole economy, will become more valued than ever as the only means by which output growth can be possible.

CONCLUSION

In this perspective, we have drawn on transdisciplinary analysis of an expert workshop to explore the issue of environmental rebound effects that emerge from ICT. We have summarized key challenges surrounding why rebound effects are difficult to include and assess within digital technology innovation processes and associated policy, specifically regarding communicating rebound effects, measuring rebound effects, and the

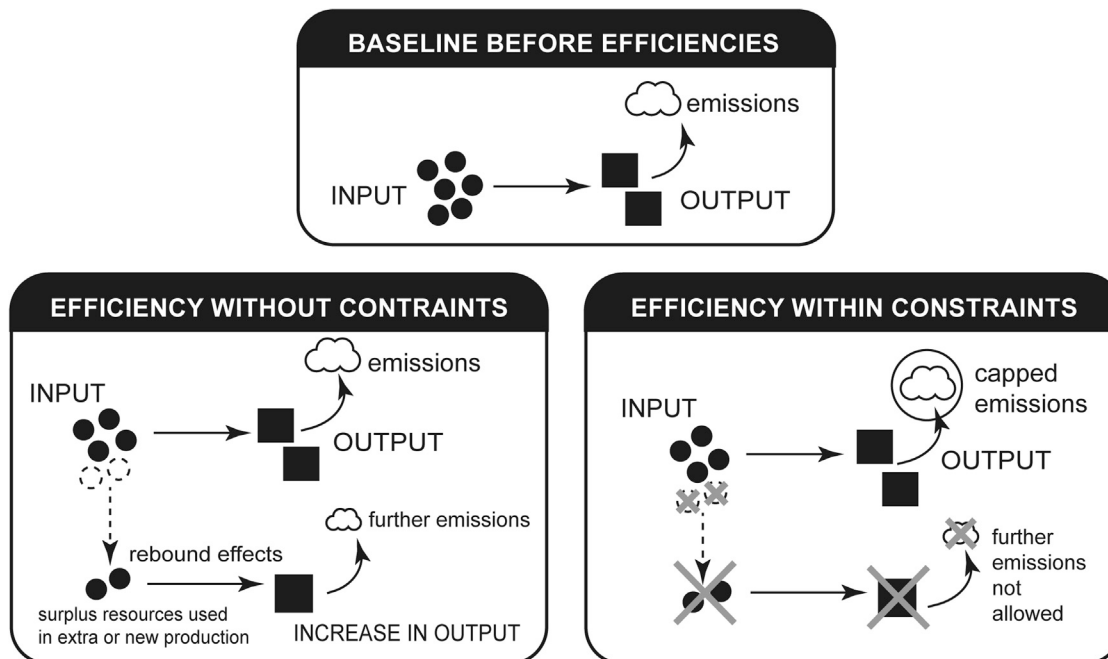


Figure 2. A visualization of rebound effects from efficiency and efficiency under emissions constraints

tensions between rebound effects and values. Our call for action for researchers moving forward is to (1) find new ways of presenting rebound effects to innovators and policymakers in the digital sector to ensure they are addressed in innovation and associated policy; (2) generate and collate cross-disciplinary evidence and empirical examples of rebound effects in ICT; and (3) transparently and thoroughly analyze ICT’s environmental, societal, and economic impacts in tandem to fully account for digital technology’s rebound effects. Furthermore, we recognize that these challenges relate to limitations in current techno-solutionist and efficiency-centric perspectives for how digital technology impacts the economy, societies, and the environment. Systems thinking exposes the flaws of these perspectives: efficiencies under GHG emission constraints are the only way in which efficiencies for true emission reductions can be realized. This urgently required change in approach, underpinned by transdisciplinary and responsible innovation research, is what will enable an ICT sector-wide drive for digital technology’s negative rebound effects to be assessed and overcome—enabling improvements in digital innovation for the good of our environment, societies, and economy.

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AUTHOR CONTRIBUTIONS

Conceptualization, K.W., F.L., G.S., L.S.C., M.T.S., C.T.H., G.S.B., M.J., and B.K.; methodology, K.W., F.L., G.S., L.S.C., M.T.S., C.T.H., G.S.B., M.J., and B.K.; investigation, K.W., F.L., G.S., L.S.C., M.T.S., C.T.H., M.B.-L., G.S.B., M.J., B.K., S.S., M.B.R., C.C., V.C.C., T.J.F., J.H., L.M.H., S.H., and B.P.; data curation, K.W., F.L., G.S., L.S.C., M.T.S., and C.T.H.; writing – orig-

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DECLARATION OF INTERESTS

M.B.-L. is the founder and principal consultant of Small World Consulting. C.C. works at Baillie Gifford, which is a commercial entity. G.S.B. is a member of the *Patterns* advisory board.

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About the author

Kelly Widdicks is a lecturer in computer science at the School of Computing and Communications at Lancaster University. Her research focuses on understanding and mitigating the negative impacts of digital technology on the environment and society, using a socio-technical approach and mixed method studies to develop sustainable and responsible designs of devices and services. She is a co-investigator on the EPSRC-funded PARIS-DE project for which she currently leads work focused on incorporating rebound effects into digital technology design and policy formation.

Federica Lucivero is a senior researcher in ethics and data at the Wellcome Center for Ethics and Humanities and the Department of Population Health. In her research, she explores ethical and social aspects of the increasing introduction of IT (online portals, wearable sensors, mobile apps) in care pathways, individual health practices, and biomedical research. She has been writing on the environmental sustainability of big data initiatives and received a British

Academy/Leverhulme grant to conduct an exploratory study on “digital sustainability.” She is a co-investigator on an EPSRC collaborative project PARIS-DE (Design Principles and Responsible Innovation for a Sustainable Digital Economy).

Gabrielle Samuel (Gabby) is a social scientist whose main research interests relate to the ethical issues associated with big data and AI in the health arena. Gabby is particularly interested in exploring how environmental sustainability values intersect big data and AI technologies, particularly as they pertain to health research. Gabby currently holds a Wellcome Fellowship, which is exploring the environmental sustainability of data-driven health research using a case study of genomics and digital phenotyping in the UK. She is also a co-investigator on a EPSRC collaborative project PARIS-DE (Design Principles and Responsible Innovation for a Sustainable Digital Economy).

Lucas Somavilla Croxatto is a research associate at the Responsible Technology Institute at the University of Oxford. He applies a variety of lenses to understanding the role of responsible science, technology, and engineering innovation in decision-making, particularly in the application of knowledge systems and climate governance. Relevant themes in his work include futures, uncertainty, sustainability transformations, and responsible anticipatory science and technology governance. Lucas holds an MSc in anthropology, environment, and development (UCL) and a PhD in science, technology, engineering, and public policy (UCL). He is a fellow at the Earth System Governance Program and a research fellow at UCL STEaPP.

Marcia Tavares Smith is a senior research associate at the School of Computing and Communications at Lancaster University who is working on the EPSRC-funded PARIS-DE project. Her research interests include co-design and other participatory approaches to design, digital innovation, HCI, and sustainability and the role of design and designers in innovation.

Carolyn Ten Holter is a researcher at the Responsible Technology Institute investigating responsible innovation in novel technologies, including autonomous vehicles and quantum computing. With a background in law, information organization, and industry, her expertise is in interdisciplinary approaches to socio-technical problems. She works with policymakers, commercial organizations, and academia to draw together cross-sector understandings of challenges in novel technologies and is particularly interested in interactions between the “triple-helix” model of academia, industry, and policy in the governance of novel technologies.

Mike Berners-Lee consults, thinks, writes, and researches on sustainability and responses to 21st century problems. He is the author of acclaimed books, including “There is No Planet B: A Handbook for the Make or Break Years” and “How Bad Are Bananas? The Carbon Footprint of Everything.” He is a professor at Lancaster University, where his research includes supply chain carbon modeling, sustainable food systems, and the environmental impact of ICT. He has made numerous speaking, radio, and television broadcast appearances to promote public awareness of sustainability and climate change issues.

Gordon S. Blair is head of environmental digital strategy at UKCEH and is also a distinguished professor of Distributed Systems at Lancaster University. He is co-director of the Center of Excellence in Environmental Data Science (CEEDS), a joint initiative between UKCEH and Lancaster University, and is principal investigator of the PARIS-DE project, looking at design principles and responsible innovation for a sustainable digital economy. His current research interests focus on the role of digital technology in supporting environmental science, including new forms of environmental monitoring and associated digital research infrastructure and new forms of analyzing and making sense of these data.

Marina Jirotko is professor of human-centered computing at the Department of Computer Science at the University of Oxford. She leads an interdisciplinary research group that combines both social and computer science approaches to the design of technology—developing methods and approaches for building and evaluating technology responsibly in ways that may enhance individual autonomy and well-being and promote and protect human values. Marina is an EPSRC Established Career Fellow conducting a 5-year investigation into Developing Responsible Robotics for the Digital Economy. She is director of the Responsible Technology Institute at Oxford and co-director of the Observatory for Responsible Research and Innovation in ICT (ORBIT), which provides RI services and training to ICT researchers and practitioners. She is also co-investigator on the EPSRC Paris-DE project.

Bran Knowles is a senior lecturer at the Data Science Institute and School of Computing and Communications at Lancaster University. Her research explores social and ethical considerations surrounding data systems, with a particular focus on what makes these systems “trustworthy.” She leads the ACM Europe Technology Policy Committee working group on climate change and is co-investigator for the EPSRC-funded PARIS-DE project.

Steven Sorrell is an energy and climate policy specialist with 30 years of experience in academic and consultancy research. He is currently professor of energy policy in the Science Policy Research Unit (SPRU) at the University of Sussex and co-director of the Digital Society theme of the Center for Research into Energy Demand Solutions. Steve worked as an electrical engineer before joining SPRU in 1991. Since then, he has undertaken a range of applied, problem-oriented research on energy and climate policy, with particular focus on energy demand and resource depletion.

Miriam Börjesson Rivera is a postdoctoral researcher at Uppsala University in the intersection of everyday life and digital technologies. Her main research interest is to explore how people’s everyday practices can become more environmentally sustainable and the role digital technologies could play in this transition. Börjesson Rivera holds a PhD in planning and decision analysis with specialization in environmental strategic analysis and has extensive experience working in transdisciplinary research projects with researchers from other scientific disciplines, such as design research, future studies, human-computer interaction, and sustainability assessments.

Caroline Cook works at Baillie Gifford, a global investment manager based in Edinburgh. Baillie Gifford aims to invest for clients in companies that have the potential to generate enduring growth and, through that, attractive returns for shareholders. Caroline coordinates the approach to climate and environment issues, working across the firm with investors, clients, and companies.

Vlad C. Coroamă is a lecturer of smart energy and digitalization and sustainability with the TU Berlin, Germany. Convinced that the climate crisis is one of the greatest challenges ever faced by humankind, his research revolves around the relation between digitalization and the environment. He contributed both methodologically and with concrete assessments to understanding the environmental impact of ICT, in particular the Internet. Today, his main research interest lies in exploring the mechanisms through which digitalization can save resources, energy, and emissions and how to best exploit this potential while understanding and avoiding the counteracting rebound effects.

Timothy J. Foxon is professor of sustainability transitions at SPRU (Science Policy Research Unit), University of Sussex. His research explores the technological and social factors relating to the innovation of new energy technologies, the co-evolution of technologies and institutions for a transition to a sustainable low carbon economy, and relations and interdependencies between energy use and economic growth. He is a co-investigator of the UK Center for Research on Energy Demand Solutions (CREDS) and has published 2 books, over 60 academic articles, 15 book chapters, and over 20 research reports. His book “Energy and Economic Growth: Why we need a new prosperity” was published by Routledge in 2018.

Jeffrey Hardy is currently a senior research fellow at the Grantham at Imperial College London, where he leads a team in the UK Energy Revolution Research Consortium examining the policy and regulation of smart local energy systems. He is also a non-executive director of Public Power Solutions, deputy chair of the UK Power Networks Customer Engagement Group, and director of Sustainable Energy Futures, Ltd.

Lorenz M. Hilty is a full professor at the Department of Informatics at University of Zurich with a research focus on digital transformation and sustainable development. He is the sustainability delegate of his university and director of the Zurich Knowledge Center for Sustainable Development. Before, he was head of the Technology and Society Lab at the Swiss Federal Laboratories for Materials Science and Technology. Lorenz initiated the ICT4S (Information and Communication Technologies for Sustainability) conference series with ICT4S 2013 in Zurich. He is a member of the Steering Committee of TA-Swiss, the Foundation for Technology Assessment at the Swiss Academies of Arts and Sciences.

Simon Hinterholzer is a researcher at the Border-step Institute for Innovation and Sustainability. At Border-step, he has been researching the climate and environmental impacts of digital technologies, especially data centers, for

several years. In this large topic area, he has both implemented and measured positive effects of digitalization through building automation and energy savings in projects such as WindNODE. He also prepares studies and research on how much energy and materials digitalization requires, which has been done, for example, in research projects such as TEMPRO or a study on energy-efficient cloud computing for the EU Commission.

Birgit Penzenstadler is a professor for software engineering in sustainability at Chalmers University of Technology, Göteborg, Sweden, and Lappeenranta University of Technology, Finland, as well as an embodied mindfulness coach and yoga teacher. In her research, she combines both to bring well-being and resilience to the IT community so that we can develop systems that support sustainable development and a lifestyle in alignment with our planet.