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How digital will the future be? Analysis of prospective scenarios

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Abstract

With the climate change context, many prospective studies, generally encompassing all areas of society, imagine possible futures to expand the range of options. The role of digital technologies within these possible futures is rarely specifically targeted. Which digital technologies and methodologies do these studies envision in a world that has mitigated and adapted to climate change? In this paper, we propose a typology for scenarios to survey digital technologies and their applications in 14 prospective studies and their corresponding 35 future scenarios. Our finding is that all the scenarios consider digital technology to be present in the future. We observe that only a few of them question our relationship with digital technology and all aspects related to its materiality, and none of the general studies envision breakthroughs concerning technologies used today. Our result demonstrates the lack of a systemic view of information and communication technologies. We therefore argue for new prospective studies to envision the future of ICT.

1 INTRODUCTION

In the context of climate change, many prospective studies have been proposed in the past years to envision possible futures. They describe the future in very different formats: some are purely narratives, while others rely on quantitative models. These studies help cope with uncertainties and challenges by expanding the available ideas and options ¹. Most prospective studies present multiple scenarios (see Figure 1) resulting from different societal or technical hypotheses, each shaped by many variables, such as economic growth, well-being, sobriety, low-carbon energy, population, or uncertain events. Prospective scenarios are neither predictions nor forecasts but overviews of possible future paths [Arup, 2019]. Studies often include a baseline business-as-usual scenario used as a reference.

¹<https://www.geoffmulgan.com/post/social-imagination>

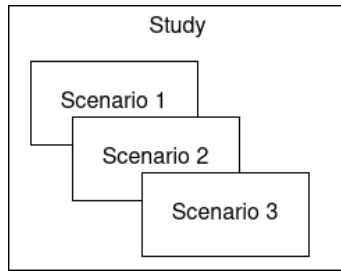


Figure 1: Each study may include several scenarios, representing alternative futures

As computer scientists, we wanted to question the place of digital technologies in these studies. Through a preliminary analysis of several scenarios, we observed that they always consider information and communication technologies (ICT) to be present in the future. However, the evolution of the ICT sector and its role in other sectors vary between scenarios. In this paper, we propose to dig further into a set of prospective studies to summarize the future of ICT they envision. More specifically, the objective of this work is to answer the following questions:

- What ICT is present in the scenarios? i.e., which infrastructure, amount of data, and technologies?
- To what extent does ICT vary among scenarios?
- What applications relying on ICT are described?
- How do the scenarios envision the role of ICT for the environmental transition?

To answer these questions, we analyzed 14 studies and their corresponding 35 scenarios, and we focused on the evolution of digital technologies and their areas of applications. We do not pretend to make an exhaustive review of existing scenarios. However, we tried to cover various scenario types, from narrations only to mainly quantitative ones, with positive or negative visions. We identified a limitation of our study, namely the selection of OECD countries-centered studies, which we discuss in Section 5.

Our contributions are to:

- Analyze digital technologies within scenarios according to a proposed set of variables organized in a comprehensive typology.
- Highlight common points and differences between scenarios.
- Identify challenges that should be addressed as research questions to enable or avoid these scenarios.
- Identify some missing aspects regarding ICT in prospective scenarios.

Section 2 presents existing work on ICT in future scenarios. Section 3, explains how we selected the studies, and discusses the variables we used to analyze the scenarios. The chosen variables are those that may influence the role of ICT in scenarios. Section 4 more specifically presents what digital technologies look like in the prospective scenarios and their area of applications. Finally, in section 5, we discuss the observations made and identify what we believe are omitted features in the studies.

2 RELATED WORKS

Only very few works exist regarding the place of digital technologies in prospective scenarios. In this section, we describe the works that are related to ours.

Several authors estimate future ICT energy consumption and carbon footprint [Andrae, 2019, Malmmodin and Lundén, 2018]. The projections depend on two main variables: ICT equipment and services efficiency, and demand for ICT (via possible rebound effects) [Freitag et al., 2021]. Our goal here is not to quantify the future consumption of ICT but rather to analyze the possible places of ICT in the future and to explicitly state the implications it could have on its direct and indirect impacts [Hilty et al., 2006] of the sector.

In [Erdmann and Hilty, 2010], the authors propose a scenario analysis of the future impacts of ICT applications on GHG emissions. ICT being a driver of new lifestyles, structural changes, and economic growth, studying its effects is complex. The authors start by reviewing existing macroeconomics on ICT and GHG emissions and conclude that, apart from a few studies, previous works show unambiguous overall reductions of GHG emissions due to ICT. The second part focuses on building specific macroeconomic ICT impact assessment models by looking at ICT's first-, second-, and third-order effects on the environment. It extends a previous study [Erdmann et al., 2004] by focusing on data uncertainty, requiring further research, and future uncertainty indicating a need for political action. The proposed macroeconomic ICT impact assessment model is applied to the three scenarios from [Erdmann et al., 2004]. These scenarios designed in 2003 describe alternative future courses of ICT until 2020. The scenario analysis from [Erdmann and Hilty, 2010] concludes with the necessity of incorporating ICT in a general macroeconomic model to quantify rebound effects of energy efficiency measures and the need for a large geographical scope for a complete impact assessment of future scenarios.

Also focusing on assessing future scenarios, authors in [Fauré et al., 2017] review methods for assessing future scenarios' environmental and social sustainability impacts. They consider three types of scenarios according to the classification of [Börjeson et al., 2006], i.e., predictive, explorative, and normative scenarios. A particular focus is put on sustainability assessments of scenarios in the ICT sector, an example of a rapidly developing sector. The study concludes that the topic of assessment requires further attention if scenarios are to be used to support policy and guide action towards sustainability. In this paper, we do not question the environmental and societal impacts assessment of the scenarios but rather compare scenarios based on the imaginaries and research questions they may drive.

[Andok, 2022] proposes an analysis of the evolution of digital futures in European Union reports. The author reviews three EU reports on digital futures. The first one, [European Commission, 2014], published in 2014, is very techno-optimistic in every aspect of the society. The second (post-COVID pandemic) report [European Commission, 2021] from 2021 is slightly less optimistic and mentions vulnerabilities and disinformation. It also discusses sustainability, mentioning how digital technologies can contribute to EU Green Deal objectives. The third report [Polona and Stefano, 2022] gives short-term objectives regarding cyber-security after the beginning of the Russian-Ukrainian war. From this analysis, Andok highlights the shift from opportunities only to dangers and threats, and from 40 years perspective visions to shorter ones (10 years or even less).

3 METHODOLOGY

This section describes the 14 studies (section 3.2) we chose to analyze. We also present the features we use to classify them, which can influence on the evolution of ICT within the different scenarios (section 3.1).

3.1 Typologies describing the studies and scenarios

Each study has its way of designing possible futures, so capturing the diversity of the scenarios is complex [Van Notten et al., 2003]. Several works have proposed scenario typologies (e.g. [Ducot and Lubben, 1980, Van Notten et al., 2003, Crawford, 2019]) to capture this diversity. These typologies aim to categorize scenarios by answering the questions of why (project goal), how (process design), and what (scenario content) [Van Notten et al., 2003]. However, more analysis is needed to understand more deeply why scenarios end up being so similar or different. Scenarios result from hypotheses and parameters evolutions regarding economy, lifestyles and governance, which are not always explicit.

In this work, we focus on the place and role of ICT in future perspectives. We are therefore interested in comparing the different scenarios according to features that influence the place of ICT. Authors [Erdmann et al., 2004, Erdmann and Hilty, 2010] distinguish external variables that include GDP, population, labor demand, electricity prices, and other variables that may influence first-, second-, and third-order impacts of ICT. Examples of variables impacting first-order impacts are technological trends from large to small devices, household internet penetration, or energy efficiency. Variables for second-order impacts include energy efficiency or materials potentials for other sectors of activity. Finally, variables for third-order impacts are elasticity of demand, average personal transport time, or some economic behavior. The authors use all these variables to analyze the three scenarios from [Erdmann et al., 2004].

Following these works, we propose our own typology and variables to analyze ICT in prospective scenarios. We differentiate three levels of features to characterize every scenario (Table 1).

Typology	Level:	Study
	Objective:	General overview of the study
	Features overview:	Project goal, content and complexity
	Reference:	[Van Notten et al., 2003]
Societal variables	Level:	Scenario
	Objective:	non ICT-specific variables that influence scenarios
	Features overview:	Economy, lifestyle, demography, governance
ICT variables	Level	Scenario
	Objective	ICT-specific variables present in scenarios
	Features overview	Infrastructure, Applications, Technologies

Table 1: Overview of typology and parametric variables used to compare scenarios

The first one is the general typology from [Van Notten et al., 2003]. It enables to view how the study was conducted and its perimeter quickly. The second one is

Societal variables, which concern hypotheses for society pathways regarding lifestyle, economy, governance, demography, and equality. We propose variables freely adapted from [Ademe, 2021]. When analyzing the scenarios, we observed that the variables of economic growth, sobriety, the importance of the state, and the collaboration between countries were discussed in all general studies and drive scenarios. We here refer to general studies as the ones that regard all areas of society. These societal variables impact the kind of ICT envisioned; for example, a scenario with solid states implies centralization of digital infrastructure and services.

Finally, we considered ICT-specific variables to characterize the ICT infrastructure and usage types. We distinguished three types of ICT-specific variables, the first being general ICT characteristics, with variables about the evolution of usages, about equipment (lifetimes, quantity of equipment, data center locations, use of cloud,...), and about usage (energy efficiency, data flows and data center consumption). All these characteristics directly impact equipment and infrastructures, and we call them *infrastructure* variables. The second type, called *applications*, addresses the kind of applications of ICT considered in the scenarios (teleworking, smart mobility, robots for manufacturing in industry,...), and the third type, *technologies*, the digital technologies present in the scenario (data analytics, AI, cloud and edge computing,...).

Even if digital technologies exist in all scenarios, the studies rarely mention these variables. We observed that they are only discussed explicitly in quantitative studies that calculate energy consumption and greenhouse gas emissions (e.g., [Ademe, 2021, négaWatt, 2021, RTE, 2022]) and in prospective studies specifically targeting ICT as main topic (e.g., [Creutzig et al., 2022, CNIL, 2021, Deron and McDonald, 2022]). In fact, as previously observed by [Creutzig et al., 2022], no current conceptualization of decarbonization pathways explicitly accounts for the impacts of digitalization in the Anthropocene.

Figure 3 gives the complete list of variables.

3.2 Studies selection

In this section, we present how we chose the 14 studies and how we categorized them according to a subset of features that we found to be relevant. We give a short overview of the considered studies in Appendix A. We also provide a complete classification of all scenarios according to the typology and variables described in the previous section in the supplementary material.

We first selected studies we already knew, then searched for others online. We tried to find studies with various: spatial perimeters (which countries are considered), domains considered (ICT -specific or not), and methodologies (narratives vs quantitative studies). Other variables, such as those of the typology (section 3.1), also help differentiate scenarios but were not our main starting points. The last criterion we used, which is not part of the typology from [Van Notten et al., 2003], is the publication year.

Publication year We limited ourselves to recent studies. The oldest one in our deep analysis was published in 2018. We found very few notions of digital technologies in the oldest general scenarios. For example, in [OECD, 2011], we found only one mention of data access, smart metering, and a suggestion to make chemical information widely

available through the Internet thanks to the development of new and innovative computer models. Another example of a scenario that we purposely did not include in this work is the ICT-specific from [Erdmann et al., 2004]. It aims to explore (qualitatively) and assess (quantitatively) how ICT will influence environmental sustainability between 2003 and 2020.

Spatial scale As we are located in France, we naturally started our review with the most recent prospective works made in this country: [Ademe, 2021, négaWatt, 2021, Ministère de la Transition écologique et solidaire, 2020, RTE, 2022, The Shift Project, 2020, Millot et al., 2018, CNIL, 2021]. We then opened to studies targeting the future of EU: [European Commission, 2019, European Environment Agency, 2021]. Finally, we selected studies for the entire world: [IPCC, 2022, Arup, 2019, Danish Design Center, 2020, Creutzig et al., 2022]. One ICT-specific study focuses on Quebec [Deron and McDonald, 2022]. The studies chosen thus mostly target OECD countries, which is a limitation of our work.

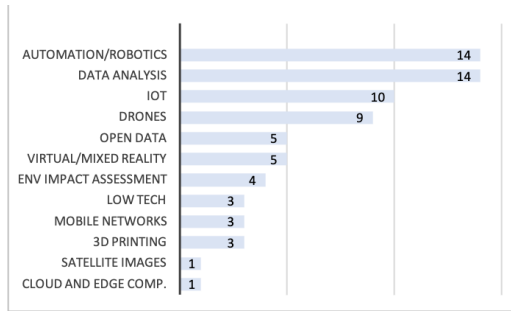
Data With this criterion, we differentiate qualitative only from more quantitative studies. Within qualitative, we include some entirely narrative studies: [European Environment Agency, 2021, Arup, 2019, Danish Design Center, 2020]. They include stories of people living in 2050 enabling us to look at what life could more concretely look like, and resemble science fiction. The study [Danish Design Center, 2020] is in the form of a future scenario toolkit. Many other toolkits² exist but were not studied here as none are ICT-centered, and we considered these toolkits to be redundant with the ones already studied. Conversely, some studies are much more quantitative and try to estimate GHG emissions by 2050 (e.g., [RTE, 2022] is mainly based on numerical models).

Topic All studies build upon climate change context. General prospective studies concern all societal areas (e.g. [Ademe, 2021, IPCC, 2022, The Shift Project, 2020, Arup, 2019]). Additionally, we selected two studies focusing on energy in France in 2050 [RTE, 2022, Millot et al., 2018]. Finally, obviously, we have included in our work studies that specifically target information and communication technologies: [Creutzig et al., 2022, CNIL, 2021, Deron and McDonald, 2022].

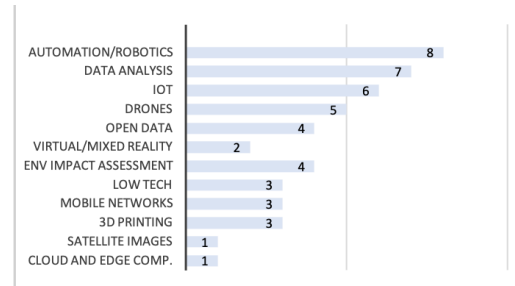
4 RESULTS

We now present which digital technologies (section 4.1) can be found in prospective studies (section 4.2). All studies consider that ICT will be present in 2050 at different scales. In some scenarios, digital technologies are central in every aspect of society, but not in all of them. Here, we only present more frequent or surprising findings and refer the reader to supplementary material for complete details. Figure 2 presents a summary of our findings.

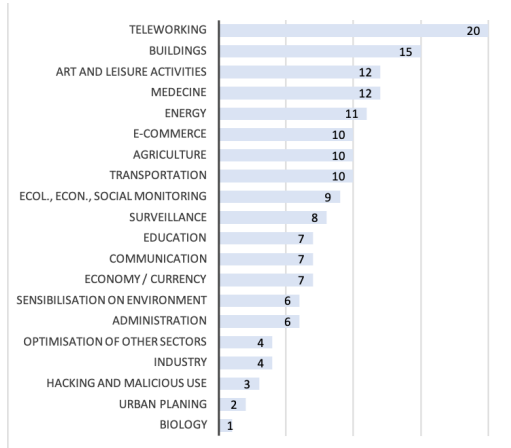
²https://oecd-opsi.org/toolkits/?_toolkit_discipline_or_practice=futures-and-foresight



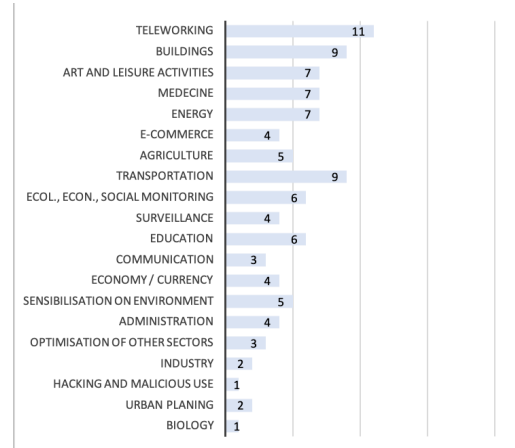
a) Digital technologies by scenario



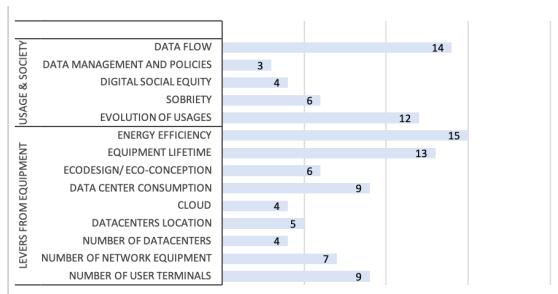
b) Digital technologies by studies



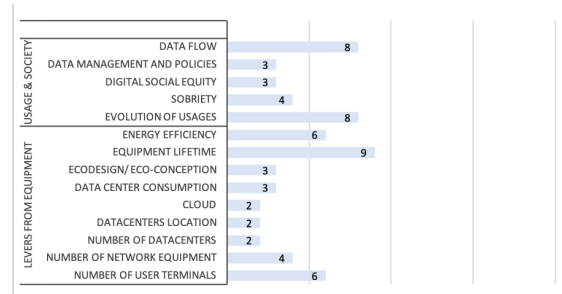
c) Applications by scenario



d) Applications by studies



e) Infrastructures by scenario



f) Infrastructures by studies

Figure 2: Summary of our scenario analysis for ICT. a),c),e): Number of scenarios among the 35 explicitly mentioning an ICT variable. b),d),f): Number of prospective studies among the 14 explicitly mentioning an ICT variable. For complete details, we refer the readers to our complementary material.

4.1 Digital technologies and ICT characteristics

Digital technologies that are the most present in scenarios are artificial intelligence (AI), robotics and automation, the Internet of Things (IoT), drones, and data analytics. Most studies explicitly mention AI and robotics for at least one scenario. On the opposite, virtual and mix reality for working remotely and leisure can only be read in the stories of some narrative scenarios. Remark that technologies are not always directly named; we can only assume that this technology is used in a given application. For example, precise agriculture might be mentioned as an application but with no mention of AI and robotics within the scenario. In the complete table given in the supplementary material, we have

tried to avoid making our assumptions. A technology is marked as present in a scenario only if explicitly mentioned.

As a consequence of the use of data by digital technologies, 5 scenarios mention open data in four studies: (in studies [Ademe, 2021, Arup, 2019, European Commission, 2019, Creutzig et al., 2022]). Open data is essential in the "Deliberate for the good" scenario of the ICT-specific study [Creutzig et al., 2022]. It comes with the idea that sustainable ICT requires more equity and collective data management.

Concerning the environmental impacts of digital technologies, four scenarios specifically mention mandatory life-cycle assessments of all new services and equipment (in studies [Arup, 2019, The Shift Project, 2020, European Commission, 2019, Deron and McDonald, 2022]).

4.2 Applications of digital technologies

As already said, digital technologies are present in every scenario we have read. Here, we present the applications for which these technologies are deployed. These applications are driven by general variables such as economic growth, demography, or lifestyles.

Note that scenarios are not entirely exhaustive regarding applications. It is not because an application is not explicitly mentioned that it does not exist in the future that is described. Similar to what we did for technologies, we avoided making assumptions about omissions in the paper and supplementary material.

4.2.1 Main applications

Almost all studies consider remote working, precise medicine and smart transports to be natural ICT applications. To a lesser extent, applications in farming, economy, and buildings are widely present. These applications are a natural extension of today's current development and funding of ICT.

ICT is also considered in several scenarios for ecological, economic, and social monitoring. In particular, it enables tracking the state of the planet for forecasting and information on extreme events.

4.2.2 Applications only discussed in a few scenarios

Some applications that already exist today are not discussed in all scenarios:

- e-commerce: We only saw e-commerce in four studies ([The Shift Project, 2020, Ademe, 2021, Danish Design Center, 2020]) with an increase (in particular for business-as-usual scenarios) or a decrease (for more sober scenarios). Supply chain management is mentioned in [IPCC, 2022] but not specifically for e-commerce.
- Information on climate change: ICT is important in some scenarios to raise awareness of climate issues and guide citizens. Digital media can be used to promote a culture of sustainability [Ministère de la Transition écologique et solidaire, 2020, IPCC, 2022, European Commission, 2019] and to inform about one's own emissions and carbon quota [European Environment Agency, 2021, Arup, 2019].

- **Social media:** ICT is also still used for communication and social media and explicitly mentioned as such in the Regional Cooperations scenario of [Ademe, 2021], in the Ecotopia and Technocracy scenarios of [European Environment Agency, 2021], and in [CNIL, 2021]. In these scenarios, digital technologies enable citizens to interact continuously.
- **Leisure:** Leisure relying on digital technologies is discussed in several studies, with different visions in different scenarios. In [Ademe, 2021], the frugal scenario assumes less digital leisure, while the Restoration Gamble one assumes more and more digital leisure. Conversely, the [négaWatt, 2021] scenario, which is a relatively sober scenario, supposes that digitalization continues for leisure activities. Even more surprising, the Ecotopia scenario of the study [European Environment Agency, 2021] scenario, which is, in essence, closer to nature, considers an increased presence of the digital sphere.

Digital technologies can also be used to improve the living environment, as in the Humans Inc. scenario of [Arup, 2019], which mentions digital walls displaying images of a clean waterfront to protect residents from unpleasant views.

- **Surveillance:** In general studies, surveillance was only found in the Extinction express scenario of [Arup, 2019] with the use of micro-drones by the police and in centralized scenarios from [Danish Design Center, 2020], with AI or autonomous units. Naturally, it is discussed more deeply in [CNIL, 2021], the main topic being data protection and individual privacy. As such, data surveillance is a central variable of this study.

Furthermore, while digital technologies are widely used in scientific domains (e.g., biology or physics) today, they are only mentioned in one study.

4.2.3 Sobriety in digital technologies

Some scenarios call for sobriety and therefore, bring sobriety within the digital sector inherently. This is visible, for instance, in the sufficiency scenario of [RTE, 2022] with less digital leisure and less digital advertising. In the Frugal Generation scenario from [Ademe, 2021], digital sobriety implies no new data center development and a stop of data growth. Another aspect of this sobriety concerns equipment reparability by users, which is discussed in many scenarios to increase equipment lifetime. In [Deron and McDonald, 2022], a reduction of the number of pieces of equipment is also possible with the development of equipment sharing in companies.

Some sober scenarios [négaWatt, 2021, The Shift Project, 2020] consider digital sobriety from a digital technologies usage angle. The proposal is to control usage and limit data flows. In the scenario from [The Shift Project, 2020], digital sobriety includes reducing video resolutions or cloud gaming, or bounding equipment rate per person. But, on the contrary, this same scenario assumes an increase in the use of ICT in many sectors (such as higher education or defense). [Creutzig et al., 2022] propose an extensive application of ICT to match sustainable development goals.

5 DISCUSSIONS

The first observation of our survey was that there is no scenario little or no ICT. Due to the increasing environmental impacts of digital technologies [Freitag et al., 2021], it is essential to think about their place in an environmentally-constrained world. The role of digitalization in the anthropocene was also the starting point of [Creutzig et al., 2022]. In addition, ICT is related to significant physical, resilience, and environmental challenges that should drive its future developments.

In the following, we discuss how the studies considered these challenges and what is currently missing when considering ICT in prospective studies.

Lack of systemic view of ICT All scenarios admit a digital world quite similar to that of today. It can be more minimalistic or developed, sometimes with sobriety and efficiency, but no significant change exists. Many scenarios give a central place to IT for Green applications (smart farming, smart building, ecological monitoring). Some structural changes come from innovations in ICT, such as teleworking or autonomous driving.

As our goal was to study the place of digital technologies in future scenarios, we defined general ICT-specific variables to analyze if some scenarios consider them as the starting point. These variables encompass the growth of data, location of data centers, or sobriety usage. ICT variables (section 3.1) can be seen as parameters that can be changed to achieve different scenarios. They could indeed serve as central hypotheses to design general scenarios, i.e. being one of the causes in the scenario. An example is the following: because there will be much efficiency in digital technologies in the future, these technologies will be more deployed. Or, because of a limitation on the number of data centers, digital technologies have stopped being applied to some sectors of society. However, no general study has built upon these considerations. ICT variables remain only consequences of other aspects of these scenarios. While ICT-centered studies [Creutzig et al., 2022, CNIL, 2021, Deron and McDonald, 2022] build upon these ICT variables, their scenarios hardly mention the application of ICT in various areas of society.

Scenarios rarely look at ICT with a comprehensive perspective. The studies often provide a citizen’s point of view on ICT more than companies, organizations, or society one. Not having a more systemic view of society implies that ICT is very application-oriented, omitting all the interconnection with infrastructures and technologies. For example, [The Shift Project, 2020] offers a specific plan for the future of digital technologies, but separated from other sectors of activities and with few interactions. While digital sobriety is encouraged, ICT’s place in other sectors is hardly discussed, even when it is already deployed.

Resilience and missing applications In addition, ICT is related to significant physical, resilience, and environmental challenges: ICT infrastructures, for example, are very vulnerable to extreme climate events. This vulnerability is only very rarely evoked in the scenarios. Only [The Shift Project, 2020] states that ”The ubiquity of digital technology makes its resilience crucial to many aspects of society”, and this variable is absent from all scenarios. Not considering the interaction of digital technologies with other sectors of activities may lead to inconsistent scenarios. Furthermore, digital technologies are often seen as crucial for decarbonization. Its central place in some decarbonization strategies

with regard to its vulnerability is never discussed.

Of course, it is difficult for a prospective study to cover all areas of society. Nevertheless, those that serve essential needs such as drinking, eating, housing, or health care might be the ones that are the most important to develop imaginaries and make the right decisions. Many of these essential areas already depend on ICT today. But no study mentions them all. We can think for example, about all supply chains or water supply and management. We can, therefore, only guess that these areas may also follow business-as-usual or sobriety tendencies. This lack of details raises questions regarding the transformations that an increase or decrease in digital technologies may imply for these applications and people working in these fields. No study questions the resilience of society towards these digital technologies.

Another aspect that is rarely tackled in scenarios is cybersecurity. Another aspect that scenarios rarely tackle is cybersecurity. The capacity of the technologies to resist cyber-attacks is essential, especially in scenarios with more fragmentation of the world.

Questions related to ICT materiality Developing ICT in many sectors of activities, as proposed in some scenarios, would likely necessitate the installation of a significant amount of new digital infrastructures. Only some scenarios mention the availability or criticality of resources, pure water, energy, or land (e.g., with resource colonies on the moon and deep sea mining in Extinction express of [Arup, 2019], or in [RTE, 2022] scenarios for energy production). This physical reality behind digital technologies is most often forgotten.

Relying on ICT in the future requires looking at energy and resources supply, which geopolitical tensions, collaborations between countries, or changes in governance may hinder. These tensions are discussed in French National studies (e.g. RTE and negaWatt) and in the narrative study Arup, but do not seem to influence their integration of ICT. The Extinction express scenario of the latter describes resource colonies on the moon and in the deep sea.

To the best of our knowledge, no study, however, mentions the geopolitical aspects related to the location of data centers and the installation of ICT infrastructures (e.g., underwater cables or satellites).

New technologies Surprisingly, many technologies that have started to receive attention and funding today are not mentioned in any of the studies, which build upon existing technologies only. For example, there is very little about 6G, and nothing on quantum informatics, intermittent computing, or DNA data storage. It is difficult to imagine how these innovations in ICT could be integrated in the scenarios. An example of studies where disruptive technologies (e.g., cyborg botany or olfactory notifications) are considered in scenarios has been presented by French designers³. Note that we did not include this work in our analysis because of a lack of details on the methodology. Significant changes in the use of technology, by using low-tech solutions for example, are also mostly absent from scenarios.

In [Erdmann and Hilty, 2010], the authors argued that forthcoming macroeconomic studies on ICT should account for first-, second-, and third-order effects, reflect error

³<https://b-com.com/actualite/immersion-dans-le-numerique-responsable-de-2040>

margins resulting from data uncertainty and use scenario techniques to explore future uncertainty. However, the studies we analyzed generally do not, even when ICT-centered. Some studies point to possible rebound effects of digital technologies, but indirect effects of ICT and their assessment are never included in the scenarios.

Disruption In continuity with the previous point, very few general scenarios are peripheral, i.e., include unlikely and extreme events and consider a discontinuous path to the future. Generally, disruptive scenarios are narratives. When looking specifically at ICT in general scenarios, it is pretty similar to today's. Our relationship to digital technologies is not deeply questioned, which may be why ICT is present in all scenarios without breakthrough innovations.

Other environmental aspects The studies were all made from a climate change perspective, omitting biodiversity losses and other planetary boundaries and focusing on human futures only without considering other species. These environmental problems may have other consequences on future scenarios. One that is directly related to ICT is water scarcity. Indeed, the manufacturing of ICT equipment and data center cooling have a substantial ecological footprint in terms of water use. Prospective studies on ICT should, therefore, broaden their narrations.

Global North centered Most innovations in the ICT sector and major industries of the domain are from Global North countries. As a consequence, the studies we have chosen were made in OECD countries, and this clearly has an influence on scenarios. Some studies (e.g., Arup) provide visions within the world and have been designed with people from several countries worldwide. Nevertheless, our work is more likely not representative of visions from Global South studies, and future works should consider how to imagine ICT for the future in Global South countries.

6 CONCLUSION

In this paper, we have analyzed the place of ICT in prospective scenarios. We have highlighted some variables that influence the development of digital technologies and the areas of applications where ICT might be essential in the future. Our analysis demonstrates that the feasibility and consequences of the increasing development of digital technologies are not sufficiently considered. Through our discussions, we have shown that the studies hardly question our relationships to digital technologies or the applications of ICT in the context of the Anthropocene. This shortcoming limits the possibility of imagining more diverse plausible futures for the ICT sector. There is, therefore, a need to design prospective studies that could offer this more diverse and systemic view of ICT and highlight which undone science [Hess, 2015] should receive more attention. Prospective studies with a sustainability perspective for ICT can i) offer a more diverse and systemic view of the future of digital technologies; ii) highlight the need for discussing, structuring, or funding. As an example, [Deron and McDonald, 2022] indeed demonstrate that, from prospective co-design workshops, it is possible to find milestones to reach a desirable future of digital technologies. The milestones show samples of undone sciences [Hess, 2015] for which

social and industrial movements, funding, and research are needed for a desirable and sustainable ICT.

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A SUMMARY OF STUDIES REVIEWED FOR THIS PAPER

Study	Summary & Scenarios
<i>IPCC</i> 2022	Report from IPCC Group III. This document does not correspond to a unique scenario, but describes the mitigation options. <i>IPCC</i>
<i>Ademe</i> 2022	This study from French Agency for Ecological Transition ADEME proposes five coherent and contrasting paths leading France towards carbon neutrality by 2050. <i>Business-As-Usual; Frugal Generation; Regional Cooperation; Green Technologies; Restoration Gamble</i>
<i>négaWatt</i> 2021	Scenarios for France made by the négaWatt association to achieve carbon neutrality by 2050 while reducing the extraction of raw materials. This scenario is also compatible with the -55% greenhouse gas target set at European level for 2030. <i>négaWatt</i>
<i>EU green deal</i> 2019	This communication sets out the strategy to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. <i>EU green deal</i>
<i>Eionet</i> 2022	This study produces a set of imaginaries offering engaging, plausible and contrasting images of what a sustainable Europe could look like in 2050. The imaginaries were developed through a participatory process, involving European Environment Agency staff, experts from the Eionet group on foresight, and external stakeholders. <i>Great decoupling; Ecotopia; Unity in adversity; Technocracy</i>
<i>Arup</i> 2019	Study made by an international multi-disciplinary team of consultants, designers and scientists. In the study, Climate considerations come third, subordinate to economic development and societal wellbeing. Scenarios are narratives and accompanied by a story told from the perspective of a person within that world, a timeline of events, and the achievement of the 17 UN SDGs.

	<i>Greentocracy; Post Anthropocene; Extinction Express; Humans Inc.</i>
<i>DDC</i> 2020	The Danish Design Center (DDC) designed the Living Futures: Scenario Kit for understanding, discussing, and shaping the future. The kit is built around a set of four alternative futures set in the year 2050 explored through narrated stories by fictive people living in them. <i>Centralised Market-driven; Centralised Society-driven; Distributed Market-driven; Distributed Society-driven</i>
<i>SNBC</i> 2020	The National Low Carbon Strategy (SNBC) describes a roadmap for France on how to steer its climate change mitigation policy. The SNBC is based on a reference scenario developed through a modelling exercise also used in the Multi-annual Energy Programming. The scenario details the public policy measures, in addition to those already in place, which will allow France to meet its short-, medium- and long-term climate and energy objectives as best it can. <i>Baseline</i>
<i>RTE</i> 2022	Study on the technical conditions necessary for a power system with a High Share of Renewables in France Towards 2050, under the RCP 4.5 trajectory from IPCC 5th report. <i>Baseline; Extensive Reindustrialisation; Sufficiency; Acceleration 2030</i>
<i>Shift</i> 2020	The Shift Project published a plan for transforming French economy in 2022 for each sector of the economy. A preliminary report was published in end 2020 and this is the one we review here. <i>PTEF</i>
<i>France 2072</i> 2018	This research work models two contrasting lifestyles for France in 2072, to answer the question: To what extent do lifestyles influence the energy system's capacity to achieve carbon neutrality?; And among other, is a digital world compatible with the need to decarbonize the energy system, as usually thought? <i>Digital society; Collective society</i>
<i>D&A</i> 2022	This Digitalization & Anthropocene research study presents the past, present, and future of digitalization. It presents three illustrative future pathways that span the possibility space for digitalization and decarbonization in the Anthropocene. The authors conclude by identifying leverage points that shift human-digital- Earth interactions toward sustainability <i>Planetary destabilization; Green but inhumane; Deliberate for the good</i>
<i>CNIL</i> 2021	This study proposes new narratives and imaginaries regarding the protection of personal data in 2030 to help thinking regulatory practices. Throughout the process, highlights have been made on the use of technology in different social groups and at different times of digital life, as well as the resulting risks to individual and collective freedoms. <i>Renewed; Meddling; Home Sour Home</i>
<i>Digit. Challenge</i> 2022	The Université de Montréal and Espace pour la vie propose Chemins de transition ("Paths for transition"). This project combines a participative approach with major systemic challenges on a provincial scale. It combines different methodologies (backcasting, change-oriented approaches, transition management, etc.) and addresses 3 challenges: food, digital, territory. We here focus on digital challenge only. <i>Quebec 2040</i>

Table 2: Summary of studies reviewed for this paper

B SCENARIO VARIABLES

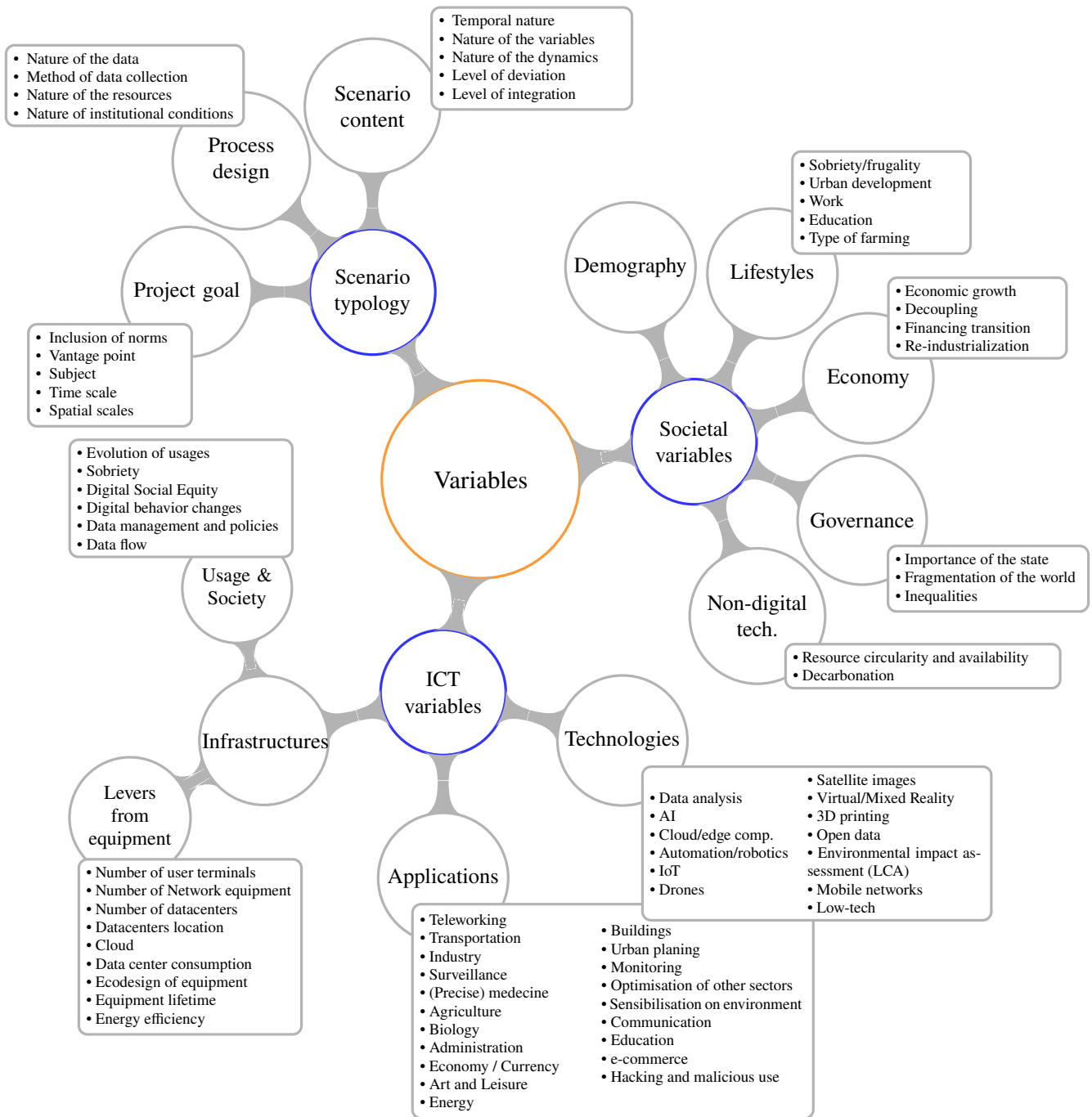


Figure 3: Mindmap of variables describing the scenarios