THE SHIFT PROJECT

THE CARBON TRANSITION THINK TANK

ENERGY & CLIMATE

WHAT VIRTUAL WORLDS FOR A SUSTAINABLE REAL WORLD?

FINAL REPORT - MARCH 2024

Cover illustration : Virgile Bellaiche

Foreword

As part of its work programme devoted to the **challenges of digital technologies in relation to the dual carbon constraint (reducing our carbon emissions and freeing ourselves from our dependence on fossil fuels)**, The Shift Project has published five studies in recent years on the environmental impact of digital technology:

- **Lean ICT – Towards digital sobriety (2018)**
  Report assessing the environmental impact (particularly carbon and energy) of digital technology worldwide, both now and in 2025.

- **The unsustainable use of online video (2019)**
  Report tracing the links between the sociological construction of digital uses and the dynamics of our infrastructures, based on the example of online video.

- **Deploying digital sobriety (2020)**
  Methodological frameworks that public and private stakeholders should embrace to initiate operational transformations leading to a digital landscape compatible with decarbonisation goals

- **Environmental impact of digital technology - 5-year trends and 5G governance (2021)**
  An update on the trajectories to 2025 of the energy-carbon impact of digital technology. It also looks at the way in which the debate on 5G has crystallised, and the elements that make it a case study of the dynamics described in previous Shift reports: the evolution of uses and its interaction with the development of infrastructures.

- **Planning the decarbonisation of the digital system in France: specifications (2023)**
  A document providing an overview of the dynamics observed in the digital realm in France (electricity consumption, carbon), the risks and challenges faced by players involved in the country's energy-carbon planning (RTE (France's electricity transmission system operator), SGPE (French General Secretariat for Ecological Planning), etc.), and describing the categories of levers that need to be mobilised in order to make the digital sector resilient, based on its systemic description.

A host of initiatives have sprung up among digital players, who have rapidly and dramatically increased their expertise on the carbon and energy impact of connected goods and services. The aim of the work carried out in our programme is to **build a global vision of what is involved in a low-carbon and resilient digital economy, at least at European level, and to shed light on the central question of this challenge: "How can we turn digital technology into a genuine tool for rethinking production and consumption methods, rather than just a lever for optimising current methods?"**

The current phase of this work has two parallel axes:

- Our work on the relevance of virtual worlds in the light of energy-climate constraints, the aim of which is to document the way in which the promises and projections of new uses can trigger the deployment of certain trajectories in digital infrastructure development choices;

- Our work on network infrastructures, the impact of the deployment choices made, and the strategies that need to be implemented in order to make them resilient to the dual carbon constraint, of which this document is the final report.

About The Shift Project think tank

The Shift Project is a think tank working towards a carbon-free economy. As a recognised non-profit organisation operating under the 1901 French law and guided by the demand for scientific rigor, its mission is to enlighten and influence the debate on energy and climate transition in Europe.

The Shift Project establishes working groups around the most decisive issues of the transition, produces robust and quantitative analyses on these issues, and develops rigorous and innovative proposals. It runs lobbying campaigns to promote the recommendations of its working groups to political and economic decision-makers. Additionally, it organises events that facilitate discussions among stakeholders and builds partnerships with professional and academic organisations, both in France and abroad.

The Shift Project was founded in 2010 by several leading figures from the corporate world with experience in both the not-for-profit and public sectors. It is supported by a number of major French and European companies, as well as public bodies, business associations and, since 2020, SMEs and individuals. It is backed by a network of tens of thousands of volunteers throughout France: The Shifters.

Since its creation, the Shift Project has initiated more than 50 research projects, participated in the emergence of two international events (Business and Climate Summit, World Efficiency) and organised several hundred symposia, forums, workshops, and conferences. It has been able to significantly influence a number of public debates and important political decisions on the energy transition in France and the European Union.

The Shift Project's ambition is to mobilise companies, public authorities and intermediary bodies on the risks, but also and above all on the opportunities generated by the "double carbon constraint", represented jointly by the pressures on energy supply and climate change. Its approach is marked by a specific analytical perspective, based on the conviction that energy is a primary factor in development: therefore, the risks induced by climate change, closely linked to the use of energy, involve a particular systemic and transdisciplinary complexity. Climate-energy issues will determine the future of humanity, so we need to integrate this dimension into our social model as quickly as possible.

It is supported by a network of tens of thousands of volunteers gathered within a non-profit association: The Shifters, established in 2014 to provide voluntary support to The Shift Project. Initially designed as a structure to welcome anyone wishing to assist The Shift through research, relay, or support work, The Shifters are carrying out more and more independent work, but always with one objective: to effectively contribute to the transition away from fossil fuels at French and European levels.

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A big thank you to our sponsors who are working alongside us to promote digital sobriety and who are making it possible to publish this work:

Technical partners

The work presented in this report has also been supported by other partners, whose expertise and technical contributions have made this work possible: Cas d'Etude Pour un Immersif Responsable (CEPIR) :

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Introduction

Digital technology, both a tool and a challenge for the economy's decarbonisation

Information technologies are now central and essential to our societies, and play a crucial role in the transformation of our economy. While this digital equipment and the uses they enable and promise seem designed to meet ever greater challenges, this does not mean that they are exempt from consideration of their environmental relevance. In a world of finite resources, it's important to remember that every physical transformation, and therefore every action, requires energy. And that includes sending information. So digital technologies are not virtual tools, but physical media, even if we don't directly perceive their materiality through the actions they enable.

Digital technologies form a global system: devices (smartphones, computers, tablets, etc.) connect to each other via network infrastructures (terrestrial and submarine cables, mobile network antennas, fibre optics, etc.) to exchange information stored and processed in data centres, the beating heart of this system. But each of these elements requires energy not only to function (usage phase) but also, before that, to be produced: mining of raw materials, industrial manufacturing processes, and then delivery to consumers require substantial biotic and abiotic resources.

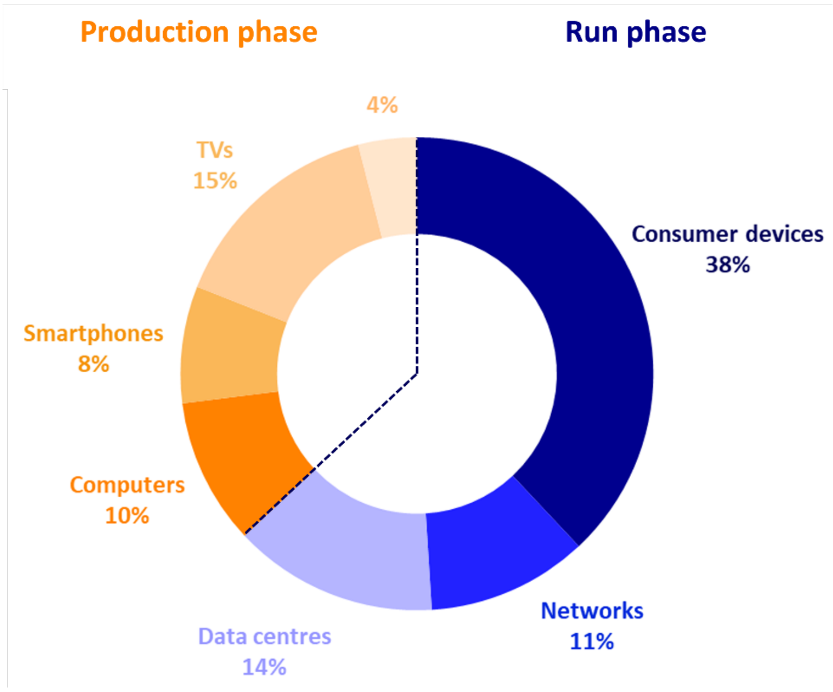

Figure 1 - Distribution of the global digital carbon footprint in 2019, by item for the production (40%) and usage (60%) phases
Source : (The Shift Project, 2021)

Each digital service relies on physical infrastructures whose resilience and relevance to the **dual carbon constraint (reducing the carbon emissions of our activities and freeing ourselves from our dependence on fossil fuels)** must be questioned. Digital technology is a catalyst: where it is deployed, it enables us to optimise, accelerate, streamline, and parallelise. Deploying it without a strategy (or rather, without a strategy designed considering this dual constraint) therefore leads to the acceleration of all dynamics, including those furthest removed from our resilience objectives. Making it a real tool for rethinking our activities, in order to make them compatible with planetary constraints, requires a systemic understanding of the impact of digital technology and an appropriate strategy.

An unsustainable trajectory that needs to be reversed

The digital sector already accounts for almost 4% of global emissions (The Shift Project, 2021), on a par with all the heavy goods vehicles in the world (IEA, 2021). In France, the digital sector accounts for 2.5% of the country's carbon footprint (ADEME & Arcep, 2023) (ADEME (French agency for ecological transition) & Arcep (French authority in charge of regulating telecommunications, postal services, and print media distribution, 2023)).

Its particularity stems from the trends in its emissions, which are growing at a particularly rapid rate that is incompatible with its decarbonisation: +6%/year on average worldwide (The Shift Project, 2021) and +2 to 4%/year in France (ADEME & Arcep, 2023; HCC, 2020; French Senate, 2020). **Technical and operational optimisations are unable to offset the sustained growth in infrastructures, parks, and utility supplies** (ADEME & Arcep, 2023; Bol et al., 2020; European Commission, 2020; GreenIT.fr, 2019; IEA, 2022; The Shift Project, 2023b). This observation continues to hold true and has been illustrated over the last five years, although according to some studies these impacts should have levelled off thanks to technological progress (IEA, 2019; ITU-T, 2020; Masanet et al., 2020).

In France and worldwide, digital technology accounted for approximately 10% of total electricity consumption in 2022 (The Shift Project, 2021, 2023b). Against a backdrop of intense electrification of uses (mobility, buildings, industry, etc.), it is easy to see that digital energy is also at the heart of the issues involved in planning the transformation of our systems and prioritising access to resources that are now under pressure, including electricity (The Shift Project, 2023b).

Making the digital sector compatible with the dual carbon constraint therefore involves not accelerating the optimisation levers already deployed, but putting it on a fundamentally different trajectory to the one it is currently following. **In the same way as other sectors of the economy, it must achieve its decarbonisation target**, which industry players (GSMA, GeSI[1]) have set themselves through the SBTi initiative and on the basis of an ITU recommendation (SBTi et al., 2020, p. 9) of **-45% by 2030 compared with 2020 at global level**[2].

The Shift Project suggests using this target as the basis for building a national trajectory, adapting it to the specific features of the already significant decarbonisation of the country's electricity mix. **The Shift Project recommends constructing the French trajectory around this recalculated**

[1] GSMA: GSM Association, an association of international players in mobile connectivity (manufacturers, operators, etc.) | GeSI: Global enabling Sustainability Initiative, a group of international players in the digital and telecommunications sectors, whose mission is to work towards sustainable digital development.

[2] Or as part of national commitments similar to those made by French manufacturers as part of the decarbonisation roadmaps for the digital sector.

SBTi objective, aiming for a -30% reduction in sector emissions by 2030 compared to 2020, adapted to the French context.

Our digital system is built through multiple interactions between the technical system and the uses it supports. Analysing energy and the climate using a systemic approach helps us to understand that **managing the impact of our technologies will not happen without thinking about the deployment of offerings and the adoption of uses that we may or may not encourage.** A shift in device and data volumes is even **a sine qua non for keeping energy consumption under control through gains in energy efficiency (The Shift Project, 2023b).**

Why work on the energy-climate footprint of virtual worlds?

The announcement of massive investments in the metaverse in 2021 (Facebook, 2021; *L'Usine Digitale,* 2021) and the enthusiasm at national and European levels for immersive technologies (Basdevant A., François C., Ronfard R., 2022; *Direction Générale des Entreprises*, 2022; European Commission, 2023) raise questions. Virtual worlds offer new uses for a digital system already undergoing the test of energy and climate[3] constraints as a whole. The simple case of immersive technologies suggests that the **energy footprints of the three components of the digital system (devices, data centre, network infrastructure) are destined to move together in unsustainable directions:**

- **In terms of devices**, the expansion of the immersive device offerings, which are becoming increasingly energy-intensive, is designed to appeal to an ever-wider audience (Gartner, 2022).
- **As far as data centres are concerned**, immersive devices make it easier to generate and collect increasing volumes of data to be stored or exploited, which are essential for fuelling powerful business models. Added to this are other dynamics, such as the offloading of computing power to distributed data centres (edge computing) or the dedicated streaming of high-definition content to optimise interaction with immersive devices, or the deployment of generative artificial intelligence as a content creation tool available to users.
- **As far as network infrastructures are concerned**, requirements in terms of latency and download and especially upload speeds are putting pressure on network development.

Supply and usage effects intertwine at various levels and co-build a dynamic that, if it were to become entrenched in the digital ecosystem under the influence of public policies (or, conversely, the absence of public policies) and the economic strategies of dominant players (the Big Tech), would lead to an **exacerbation of the current trend's incompatibility with the carbon dual constraint.**

After setting up an analysis framework including both usage and technical issues, several analyses were proposed: a qualitative analysis allowing a consequential visual representation of the induced (direct) effects on the digital system depending on the use of virtual worlds, followed by a quantitative analysis assessing the environmental impact of a widespread and undifferentiated deployment of virtual worlds. An in-depth analysis is conducted on mobile

[3] The ADEME-Arcep business as usual scenario indicates a 45% increase in greenhouse gas emissions between 2020 and 2030 (Weinberger M. & Gross D., 2023). The ITU recommendation is -45% between 2020 and 2030. (SBTi et al., 2020).

networks using our methodology and tools documented in our "Energy and climate: Lean networks for resilient connected uses” report (The Shift Project, 2024a). This is done to strengthen our understanding of the effects of supply and usage on our network infrastructure, by seeking to answer the question: "What impact do virtual worlds have on the deployment of our mobile network infrastructure?" The final section focuses on the "metaconferencing" use case, with a methodological approach to identifying conditions of relevance to achieve net energy-climate benefits and on the arbitration of virtual world modalities to identify technological development options and "use cases" consistent with a lean and resilient digital system.

Virtual worlds' technological directions and energy-climate trajectories

The metaverse and virtual worlds: context

The past infatuation with the development of virtual worlds by the digital industries can be seen in the "hype" cycles for emerging technologies published by Gartner, the consultancy and analysis company, between 1995 and 2023: These include "virtual reality" (3 instances), "augmented reality" (12 instances), "telepresence" (2 instances), "virtual worlds" (3 instances), "public virtual worlds" (3 instances), "virtual reality" (5 instances) and "mixed reality" (1 instance) (Gartner, 1995-2023) ("Appendix – Context and history"). In particular, the 2016-2019 period saw an intensification of virtual reality headset technological developments by commercial companies (see graphs in "Appendix – Context and history").

At the same time, **popular culture and video games and films** such as Tron (1982, 2010), Snow Crash (1992), Matrix (1999), Avatar (2009), Ready Player One (2018), The Sims (2000), Second Life (2003), Grand Theft Auto (2003), Roblox (2006), or Pokémon Go (2016) **illustrate the strong presence of virtual worlds in the developments of creative industries and cultural sectors, both in their imaginaries**[4]**, representations, and content, as well as in their form.**

In October 2021, the enthusiasm for virtual worlds increased following the **resounding announcement by renowned company Meta of the structuring of a generalised virtual world, the "metaverse"** (Meta, 2021a, 2021b). Rather than the promise of a disruptive new service being made available in the short term, **this announcement undoubtedly should be interpreted more as a signal sent to the digital ecosystem to structure technological directions and regulations in a manner that paves the way for the eventual emergence of a metaverse.** While consumer communication and marketing typically revolve around a revolutionary service or equipment, this is not the disruption of a single player but rather the continuation of the incremental approach of the previous three decades ("Appendix – Context and history"), where several industries (creative, software and hardware, infrastructure) each bring their own technology to the table, with the desire to converge (as seen with Disney and Epic

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[4] Conversely, the proliferation of fictions and narratives facilitates the socialisation of techniques by commercially promoting uses, giving them meaning or embedding imaginaries associated with these techniques on a large scale (Musso P. et al., 2014).

Games in 2024 (*L'usine digitale*, 2024) or Apple, Pixar, Adobe, Autodesk, and Nvidia *(L'usine digitale*, 2023)).

The signal was taken seriously in France and Europe (Basdevant A., François C., Ronfard R., 2022; *Direction Générale des Entreprises*, 2022; European Commission, 2023) **with a surge of announcements, investments, business start-ups, and structuring around immersive technologies and on a European Union scale with the intention that 6G will enable the advent of these types of virtual worlds** (European Commission, 2023; European Parliament, Committee on the Internal Market and Consumer Protection, 2023; *L'usine digitale*, 2023a).

The vision of what these technologies offer in concrete terms is blurred in particular because it is heterogeneous for several reasons: Meta is developing multiple technological components simultaneously[5], adopting an incremental approach, suggesting multiple possible applications[6], and designing various environments with different artistic directions[7]. The only distinct point is the promise of a "metaverse" as the "next chapter of the internet" or the "internet of the future" (Meta, 2021b), culminating in the staging of complete dematerialisation in Meta's marketing videos. In addition to this vision, other players are entering the scene, each producing their own definitions, visions, speculations, and products[8] ("Appendix - A multitude of definitions for virtual worlds").

The resulting blurred, multiple, and heterogeneous vision not only makes environmental assessment complex but also complicates the refutability (in the epistemological[9] sense) of statements such as "the metaverse is compatible with the Paris Agreement". In the absence of a clear definition of the concrete object "metaverse" or "virtual worlds", consideration of its implications may lead only to relativistic debates on the potential services that the metaverse could provide, or on the types of metaverse that would be less emissive than others. Such an approach would eliminate the questioning of the role of virtual worlds in a sustainable digital environment that aligns with the dual carbon constraint.

It is precisely to avoid this pitfall that The Shift Project is proposing a double definition, both based on technological characteristics and on use cases. The aim is to provide the best possible overview of the continuum of virtual worlds and describe their energy and climate implications. It also aims to, based on the specific technological directions chosen, identify the relevance conditions of virtual world modalities by considering them within their deployment and usage context.

The term "metaverse" is rarely used in the remainder of this report, except in the title given to our scenario "Meta-metaverse" of undifferentiated deployment and widespread adoption of virtual worlds. Instead, it is replaced by the term "virtual worlds" or "virtual world continuum", encompassing all the proposed forms of virtual worlds, whether already existing or not, in order to move towards technologically segmented approaches.

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[5] Virtual reality headsets, smart glasses, online virtual reality video games, collaboration applications and work environments, photorealistic avatar, 3D reconstruction, AI (Meta, 2024)

[6] Social links, entertainment, games, fitness, working better and doing more, education and retail (Meta, 2021b).

[7] For example, the Meta environments Horizon Workrooms, Horizon Worlds and the (Meta, 2021b) communication video have different artistic directions.

[8] Like the vision presented by Apple with its Apple Vision Pro headset.

[9] Concept in epistemology introduced by Karl Popper, which characterises hypotheses or statements that can be contradicted by logical reasoning based on experience, observation or empirical reality.

It should be noted that while the metaverse and virtual worlds have been forced onto the collective agenda[10] (economic, media, political[11]), this report does not consider them to be a must. Environmental considerations, including the **energy and climate considerations we are looking at here, must play a key role in decisions on the development and deployment of these technologies and services,** either upstream or in parallel with the mobilisation of the ecosystem of players on strategic choices.

Qualifying the energy-climate impact of the virtual world continuum on the digital system

In the digital ecosystem, subject to various influential visions and trends (including that of Meta), several ranges of technologies and products are being put in place, with the aim of complementing each other to give rise to **multiple modalities of virtual worlds**. It is precisely because the modalities of virtual worlds are and could be diverse that the **qualification and quantification of their energy and climate impacts require appropriate characterisation.** Two complementary lines of analysis enable this:

- **“Use cases",** which characterise the variety of possible uses and applications;
- **An approach based on the diversity of technological directions and the level of progress of each technological direction.**

This dual approach resonates on several levels:

- It is similar to the approach proposed by think tank *Renaissance Numérique* in its publication “Governing the Metaverse and tomorrow’s internet" (R*enaissance Numérique,* 2023), as it **describes both the uses and representations and their continuous connection and interaction with technical systems**. The Metaverse is characterised as a **boundary object** (similar to the concept of a promise, as established by Meta in 2021), i.e. "a catalyst for diverse and varied representations, which set in motion and gather around it ecosystems of heterogeneous players who initially evolve in different worlds” (*Renaissance Numérique*, 2023);
- It is **dual** in nature, encompassing both **"uses"** and **"technologies"**, in the same way as on each of the three levels of the object approach by (Musso P. et al., 2014) reproduced in (Figure 2);

[10] As will be demonstrated by the references considered in the construction of narratives (aimed at describing trends in the digital ecosystem) in the following section: "Approaching virtual worlds through 'use cases'." This part can be completed by “Appendix – ‘Use cases’ and narratives” and “Appendix - Bibliographic analysis of the construction of virtual world offerings with a bibliographical focus”.

[11] (Basdevant A., François C., Ronfard R., 2022; Direction Générale des Entreprises, 2022; European Commission, 2023, European Commission, 2023; European Parliament, Committee on the Internal Market and Consumer Protection, 2023; *L’usine digitale*, 2023a).

- In the field of engineering sciences, needs analysis and functional analysis are stages in which uses are specifically taken into account, before being translated into technical specifications.

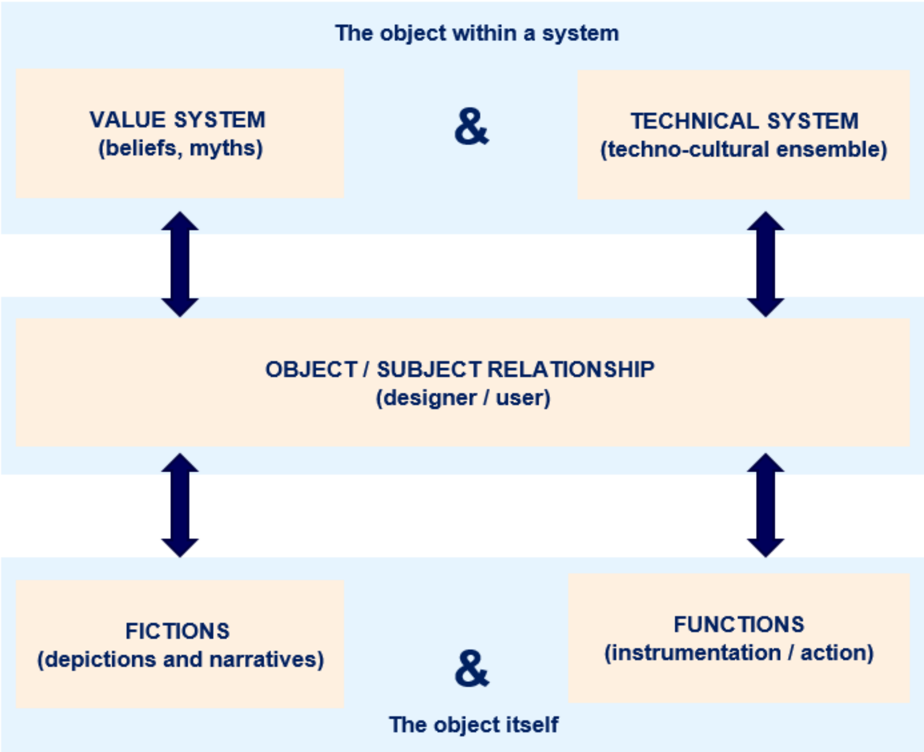

Figure 2 - Three-level object definition matrix
Source: (Musso P. et al., 2014) formatted as part of this report

Approaching virtual worlds by "use cases"

Six "*use cases*" have been selected to be representative, to date, of the major players' offerings in the digital ecosystem, since these offerings significantly impact the global carbon footprint of the digital sector.

The **narrative transcription** of these "use cases" is the first step in the approach developed in this report, with the aim of **aggregating the various offerings in the ecosystem and translating the services provided into technical and infrastructural requirements (devices, networks, data centres)**. Based on the concrete characterisation of the uses represented in these case studies, each of them will then undergo a systematic analysis.

Among the selected applications, some are social or recreational, while others are professional. The "*Représentations et usages du métavers*" (*Renaissance Numérique* & *L'Observatoire Société & Consommation,* 2023) study reveals that for early adopters[12], entertainment is at the core of usage; and on the professional side, the expansion of usage is already underway in the industrial sector.

[12] Early adopters : Understood here as a specific community of users who, as well as being pioneers in the adoption of a technology or the purchase of a device, are generally at ease with technical objects and sometimes act as relays in the mass adoption of uses. Definition from the (*Renaissance Numérique*, 2023) glossary.

The six case studies selected are as follows[13] :

- **Immersive online conferences and meetings:**
    - Narrative*:* ***Metaconferencing***
    - This narrative describes the evolution of a teleconferencing service, productivity tools and functionalities, and collaboration software towards immersive and intelligent services.
    - Existing application example: virtual reality workspaces, videoconferencing tools
    - Type of devices: screens, virtual reality headsets[14]
    - Target audience: businesses, individuals

- **Video games and social worlds:**
    - Narrative: ***The « I » in gaming***
    - This narrative describes the integration of social networks and service providers into video games.
    - Examples of types of games involved: sandbox games, adventure games, role-playing games (World of Warcraft, Half Life Alyx, Zenith: The Last City, Roblox, Decentraland, The Sandbox) for home use; mobile games, "battle-royale" games (Pokémon Go, Fortnite) for mobile use.
    - Types of devices: gaming consoles, virtual reality headsets, home screens; portable augmented reality[15] devices like "glasses", mixed reality[16] headsets for mobile use.
    - Target audience: gamers and individuals.

- **Online shopping:**
    - Narrative: ***A not-so-virtual business***
    - This narrative proposes an extension of online sales platforms. The model described is that of data collection, archiving, and processing adapted to marketing (geolocation and emotional marketing), with the abundance of data made possible by immersive devices.
    - Example of services involved: dedicated e-commerce platform, online platform for major retailers, etc.
    - Type of devices: screens, mixed reality headsets
    - Target audience: private individuals

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[13] For each narrative, the references used are listed. Additionally, in "Appendix - Bibliographical analysis of the construction of virtual world offerings", a table references studies of different corpora on these use cases, including industrial products, industry marketing, economic intelligence prediction, culture, institutions, mainstream press and scientific research.
[14] Virtual reality: computer technology that simulates the physical presence of a user in an environment artificially generated by software. Virtual reality creates an environment with which the user can interact. (Wikipedia, 2024b) definition.
[15] Augmented reality: Technology enabling 2D or 3D digital elements to be added to perceived reality using digital devices (smartphones, tablets, headsets, smart glasses, etc.). Definition from the (*Renaissance Numérique*, 2023) glossary.
[16] Extended reality can be used to describe all the expressions "virtual, augmented, and mixed reality". Définition from the (*Renaissance Numérique*, 2023) glossary.

- **Cultural experiences:**
  - Narrative: ***The cultural metaverse***
  - The first "face-to-face" narrative describes augmented reality devices in museums, providing immersive and entertaining experiences. A second "remote" narrative describes virtual reality devices for remote visits or events.
  - Example of experience: immersive experiences ("Eternal Notre-Dame")
  - Target audience: individuals
- **Digital twins:**
  - Narrative: ***The industrial metaverse***
  - This narrative describes the use of digital twins, mainly in industrial sectors.
  - Existing examples: information systems (solutions deployed in the industry), BIM (Building Information Model), digital twin (applications in the energy and automotive industries), etc.
  - Type of devices: augmented reality glasses
  - Target audience: industry, networks (electricity, rail)

- **Pornography:**
  - Narrative: ***Immersive pornography***
  - This narrative integrates 360° videos and data collection for individualised marketing, possibly enabled by intelligent algorithms.
  - Example of devices: haptic equipment

To fully understand the application of "use cases" in this report, a few theoretical and methodological clarifications are required:

- **The selection of use cases presented in this report aims to reflect a diversity of virtual world uses from a technological and material perspective, however, it is not exhaustive**[17]. The complementarity with the approach based on technological directions (see below) offers a certain robustness that counterbalances the non-exhaustive nature of the selection of cases (table 2).
- The cases presented here are scenarios developed based on references produced in journalistic, commercial, or academic contexts. They thus reflect visions primarily generated by the designers and promoters of virtual worlds.
- The cases presented serve as a basis to produce models. They are not intended to be predictions of technological diffusion. The academic literature on the use of information and communication technologies calls for caution in this respect.

[17] For example, the following cases have not been selected, without implying anything about their ability or likelihood to occur, or about discouraging or encouraging them to do so: training and learning, healthcare, administration and online services, and ubiquitous computing.

- Although the expression "*use case*" is well established, it does not necessarily reflect the existence of a use, since only possible projections, trends, and assembled offerings are being discussed here.
- Like any tool, virtual worlds will undergo processes of appropriation and diversionary practices by users. Future uses are thus challenging to predict.

As an example, the ***A not-so-virtual business*** narrative is presented below; all constructed narratives can be found in "Appendix - 'Use cases' and narratives".

A not-so-virtual business

In 2024, every retailer has its own meta-showcase, like Amazon in India [1]. An experience in a virtual world is offered, sometimes immersive, often promotional; the main goal is to promise new shopping experiences and encourage changes in customer habits.

In 2027, Amazon sends a virtual reality headset to its 300 million Amazon Prime subscribers; an enticing product enabling users to do their shopping in a virtual store with reconstructed and personalised displays [2]. At the same time, the widespread adoption of smart glasses allows platforms to better understand the consumer's environment and habits.

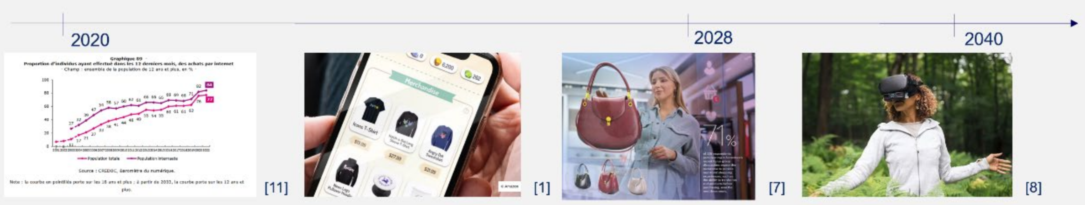
Virtual shopping assistants, a true personification of UX (User Experience) and buying journeys, are boosting sales tenfold thanks to their persuasive potential, based on brain, body, and visual data collected in real time, and a persistent history of this data.

Geolocation marketing and emotional marketing have come a long way since emotion understanding algorithms in call centres and video games; and since the game Pokémon Go that led its players to shopping centres [3,4].

Augmented reality shopping experiences have also become increasingly popular: in stores [5,6] or at home, where a LIDAR scanner is now indispensable for anyone planning to design their kitchen [7].

It's not virtual goods that are being sold and bought, but real goods [1].

By 2040, virtually smelling the leather scent of a handbag or being able to assess its texture is made possible by new haptic and sensory devices [8,9] and the sixth generation of mobile networks [10].



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Images

[11], [1], [7], [8]

Approaching virtual worlds by technological direction

In addition to the "use case" approach to virtual worlds, the technological direction approach will enable us to **highlight the technical characteristics that virtual worlds may have, in order to describe the hardware configurations required** to quantify energy consumption and carbon footprint. This approach is largely inspired by: "A Metaverse Maturity Model" (Weinberger M. & Gross D., 2023).

Here is a **definition adapted to the energy and climate analyses** that we carry out: **a virtual world is any application or service that has all or some of the following characteristics, to varying degrees** (Table 1):

Characteristics	Definition (and examples)
Physical and digital coexistence	Capacity for interactions between the virtual system and the real world through interfaces: a change in one world influences the other (up to permanent interaction). e.g. Sensors, Internet of Things (IoT), automation, digital twins, actuators, robotics
Immersion	The system's ability to alter the perception of reality and immerse the user in an artificial environment where they feel as immersed as in the material reality (up to not perceiving the difference between the artificial environment and the real world). e.g. Text chat, screen, avatar, sense of presence and co-presence, virtual reality headsets, volumetric capture, holographic projection, haptic equipment, brain-computer interfaces
Simultaneity	Ability to manage increasingly rapid interactions, until they are perceived as real-time. Simultaneity is a function of latency. e.g. videoconferencing, video games

Localisation	Constraint related to the physical location of access to the system: access is possible in specific places or anywhere (on the move, at home, etc.). Depending on the participants' locations, different networks may be used. e.g. Virtual reality experiences in dedicated spaces (cinema...), mobile gaming
Persistence	The system's ability to exist and evolve continuously (under the influence of designers and other users), even when the user is disconnected. Persistence offers the user the possibility of permanent modifications to the environment. e.g. social worlds (Second Life)
Virtualisation and content creation	The system's ability to create virtual representations of the real world and produce a wealth of digital content that can be facilitated or enhanced by AI. e.g. Content creation (avatars, non-player characters, worlds, and environments), supported by 3D creations and AI, potentially generated by user actions.
Commercialisation	The system's ability to market goods through centralised or decentralised marketplaces. e.g. Data collection and analysis, targeted advertising, sales of virtual objects or accessories, currency, tokens, transactions, certificates, properties.
Size	The need for a large system to deliver the promised services. e.g. An event (concert) may require many users to fulfil its promise of substitutability for the same physical experience in the real world.

Table 1 - Structural characteristics of virtual worlds
Source: The Shift Project, for the purpose of this report, approach based on that of (Weinberger M. & Gross D., 2023)

Our definition thus includes virtual worlds that differ in terms of characteristics presented[18]**. The contribution of this technology-focused approach will be to allow us to link these characteristics to material content (devices and infrastructures)** (see Impacts on the digital system: presentation of the matrix section).

It should be noted that certain characteristics of the approach proposed by (Weinberger M. & Gross D., 2023) have not been included in this summary because they are not strictly related to energy and climate[19] impacts. For the same reasons, characteristics present in other definitions have not been considered as criteria in their own right, such as the web and blockchain[20]aspects. Lastly, these characteristics do not sum up all the levers that could be used to reduce the induced (direct) effects on the digital system[21].

The degree to which the technological direction is pursued is an important element: “Appendix - Virtual worlds’ technological maturity and technological directions” presents several

[18] Note that our characterisation of virtual worlds is based on the previous features and the logical operator "or". Our characterisation of virtual worlds therefore covers a broad spectrum of digital services. In (Weinberger M. & Gross D., 2023), the selection is made using an "and" when the characteristics are presented "at maturity level 1". However, since "maturity level 1" is relatively widespread, this is why we chose "or". See the relevant maturity levels in "Appendix - Virtual worlds’ technological maturity and technological directions".
[19] For example, interoperability between virtual worlds is not necessarily synonymous with a greater or lesser energy-climate footprint: would several interoperable virtual worlds or a single monopolistic one have the greatest adoption and the highest footprint? Another example: scalability, while essential to the development of a virtual world, is not characteristic of that virtual world.

[20] For certain virtual worlds (e.g. Decentraland, The Sandbox), the concepts of decentralisation and Web 3.0 are inseparable from virtual worlds and are therefore considered as separate criteria in certain analyses (Basdevant A., François C., Ronfard R., 2022). Here, these elements are part of the commercialisation characteristic and may have an environmental impact (such as the energy consumption of the proof of work, for example).
[21] For example, the use of virtual worlds, particularly at peak times, has an impact on energy consumption, but is further removed from the design and technological direction of virtual worlds.

existing quantifications: a virtual world's capacity scale (Weinberger M. & Gross D., 2023), technological maturity levels (TRL) (Arthur D Little, 2022), and analysis frameworks conducive to parametric carbon analyses in the context of the IoT (Pirson T., Bol D., 2021).

The need to follow a technological direction or not for a "use case" is also an essential factor: is the feature essential to the functioning of the virtual world? Useful? Optional?

To get to grips with this complex but necessary definition and get the energy and climate analyses underway, the example of the Fortnite[22] gaming platform is emblematic (even if it is only one of a number of virtual worlds that do not have the same characteristics):

- The vectors of ***physical and digital coexistence*** and ***immersion*** are relatively standard (a smartphone, a console, a computer, a screen);
- Gaming requires fast operations and therefore ***simultaneity***;
- The smartphone gaming option offers a new type of ***localisation***, making it suitable for ***mobile*** use (not without impact for mobile access networks with the video streams that need to be transmitted);
- Depending on the gaming options, the environment is not ***persistent***, but the avatar (the player's profile) is ***persistent*** in the sense that the statistics collected will be used to improve the gaming experience;
- In terms of ***virtualisation***, rendering the universe as a whole and the avatars' interactions with it calls for a set of calculations;
- The gaming experience and ***commercialisation*** involve data collection of around 5 PB per month in order to improve the player experience (Amazon Web Services, 2018);
- Fortnite keeps its ***size*** in check with gaming options that are tailored to its size (sandbox in several sectors, battle royale with a finite number of players), particularly for its large number of users (8 million at the same time). Fortnite also organises events designed to bring together all its users (125 million). What's more, it is widely adopted (over 200 million users and 350 million subscribers), making it all the more popular (Amazon Web Services, 2018).

This approach also allows us to be robust to any "use case", even if it has not yet been identified: the 6 "use cases" currently in vogue in the digital ecosystem and described in this report (in the Approaching virtual worlds by "use cases" section and in "Appendix – 'Use cases' and narratives") cover all the technological directions studied:

Features	Online conferences and meetings	Video games (and social worlds)	Online shopping	Cultural experiences	Digital twins	Pornography
Physical and digital coexistence					x	
Immersion	x	x		x		x
Simultaneity	x	x				x

[22] Fortnite: is an online game, and its most popular game mode, known as "battle royale", brings players together in an open world with defined boundaries. In this mode, players must survive against each other, with victory going to the last surviving player.

Localisation		x (mobility)		x (designated location)		
Persistence		x	x		x	
Virtualisation and content creation	x	x		x	x	x
Commercialisation		x	x			x
Size		x	x			

Table 2 - The selection of "use cases" carried out as part of this report enables the study all the characteristics of virtual worlds.

The "uses - digital systems" matrix: a tool for translating service proposals into physical impacts

The technological directions that virtual worlds are taking and may take are structuring and dimensioning the global digital system materially and energetically. **The aim of the matrix below is to integrate technological development choices into a systemic, infrastructural, and long-term dimension, in order to link them to the resulting energy dynamics** and address the following questions:

- Which technological directions lead us towards increased device consumption (and thus a material dependency at the expense of resilience)?
- Which technological directions exert pressure on the expansion of network infrastructures?
- Which technological directions are driving the inflation of data volumes and the intensity of computing resources (calculations, etc.)?

The matrix is read from the centre:

- **The first circle** represents the virtual worlds analysed, which may follow all or some of the possible technological directions described and to varying degrees.
- **The second circle** describes the **possible technological directions** for virtual worlds, as currently considered by most of the digital ecosystem.
- **The third circle** describes the effects of technological directions **on one of the three components of the digital system.**
- Finally, there are the **induced impacts on the digital infrastructure, which then need to be translated into energy and greenhouse gas emissions.**

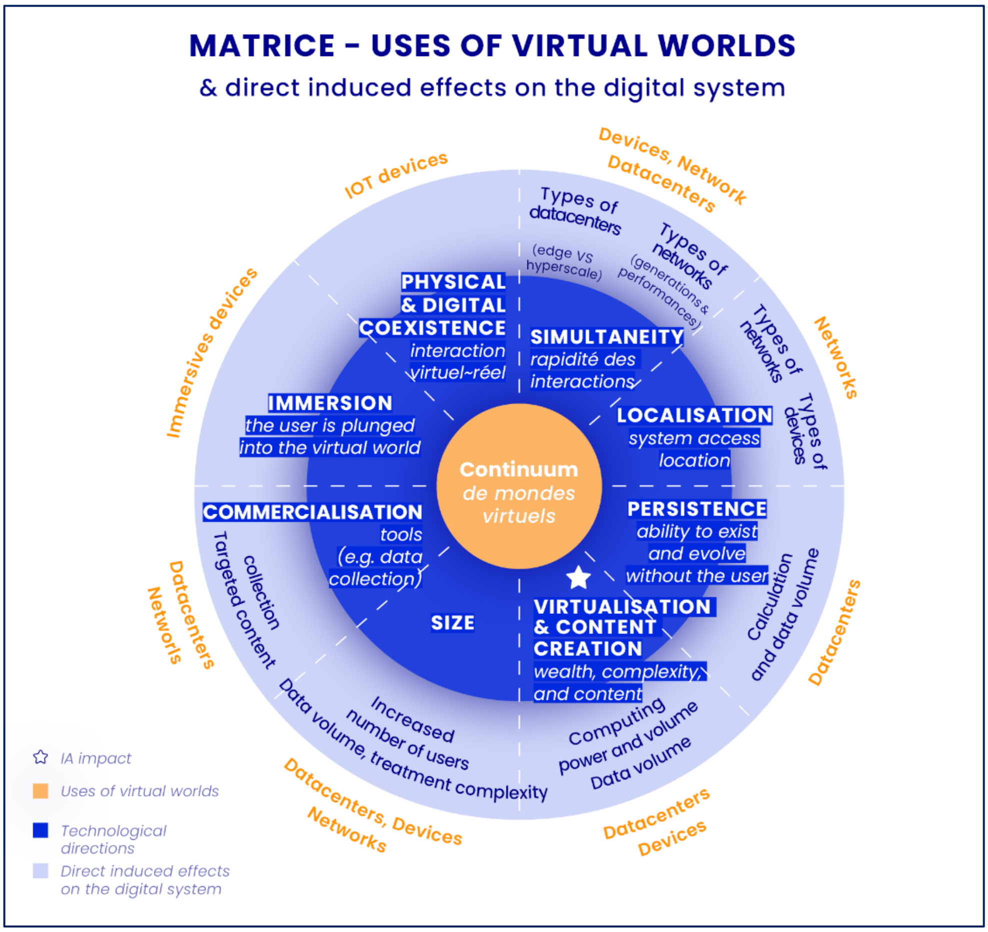

Figure 3 - "Uses of virtual worlds and direct induced effects[23] on the digital system" matrix
Source: The Shift Project, for the purpose of this report

The effects of virtual worlds on the digital system are as follows:

- The ***immersion*** axis influences the volume of immersive devices as well as their carbon footprint and unit consumption;
- The ***virtualisation and content creation*** axis could lead to the installation of new servers or the establishment of new data centres to enable richer content, just as the ***persistence*** axis ensures the continuity of the virtual world's service even without the user's device power consumption;
- The combination of the two axes, ***virtualisation & content creation*** and ***immersion***, impacts the embedded carbon footprint and power consumption of immersive devices, which then become increasingly powerful to enable more realistic rendering (with perhaps more moderate impacts on data centres and networks) or by leading to the installation of more powerful and numerous servers (with more significant network impacts but lighter devices);

[23] Unlike Figure 2 in the "Planning the decarbonisation of the digital system in France: Specifications" document (The Shift Project, 2023), this representation stops at the effects induced on the digital system and does not aim to describe second-order or higher-order effects.

- Combined with AI and the ***commercialisation*** axis (with the generation of personalised content, for example), the ***virtualisation and content creation*** axis could amplify the previous phenomenon;
- Combining the ***commercialisation*** axis with the ***immersion*** axis could result in the collection of new types of data (geolocation marketing, emotional marketing, optimisation of the gaming experience), which would result in higher data rates and therefore effects on the networks: instantaneous, with an increase in the variable energy consumption of the networks, but also longer-term, leading to capacity deployment or even new generations dedicated to meeting this specification.
- The same applies to ***simultaneity*** and ***immersion***, via the latency requirements for larger flows (for example, in the case of immersive videoconferencing and cloud computing);
- The ***simultaneity*** axis can lead specifically to an increase in edge computing, to bring computing, storage, and data processing capacities as close as possible to the user;
- The ***physical and digital coexistence*** axis affects the volume of IoT modules (greater entanglement of virtual worlds with the real world), but also the embedded carbon footprint and power consumption of the modules, which then become increasingly powerful;
- The ***size*** axis as well as widespread adoption greatly amplify these phenomena, making them change scale and therefore the order of magnitude of their carbon footprint and electricity consumption.

This matrix is a tool that enables stakeholders in virtual worlds to understand the decisive choices for the induced impacts of a service or application:

- The effects induced on the digital system depend on the intensity with which the technological directions are pursued;
- The effects depend on the combination of observed technological directions.
- The effects may occur at different timescales (purchase of a server / establishment of a data centre) and may be the result of different dynamics (capacity-driven network deployment / organised by regulators);
- The effects depend on the strategies adopted by the players (increasing computing power on devices / on data centres).

How does artificial intelligence increase the impact on the digital system tenfold?

AI can be used on the ***virtualisation*** axis to make it easier to populate the universe, making it more attractive and immersive. Several use cases are concerned:

- In the case of ***video games***, for example, there are three main phases in the use of AI, supported by a range of technologies of varying impact:
    - At the design and development stage, to create production tools, generate and test content (characters, gameplay and graphics), or optimise game experience models (gameplay) using reinforcement learning and deep learning to fuel narratives, environments (generative adversarial networks (GANs)), or control Non-Player Characters (NPCs) (pathfinding, decision trees, hunting, survival instinct, dynamic navigation, etc.).

- At runtime: to improve gameplay in real time (Monte Carlo Tree Search (MCTS)), protect players from toxic behaviour, improve accessibility, and personalise the discovery process (Amazon Web Services, 2019);
- Post-execution: Machine Learning (ML) can be used for analytics and decision-making, generating predictions of player behaviour with the aim of optimising its "Lifetime Value" (LTV), with regard to the probability of unsubscribing or purchasing (Amazon Web Services, 2018);
- By combining the ***virtualisation*** axis with other axes of the model, AI can also make the virtual world more interesting: with the ***commercialisation*** axis by generating more targeted content, for example.
- For ***online conferences and meetings***, AI can facilitate text generation and can be used to summarise a conversation and transcribe it in writing. It can also transform elements of reality in real time so as to modify the perception of participants, such as their face or voice (DeepFaceLive, n.d.). Certain functionalities seem destined to become widespread, such as the ability to give the illusion that the gaze remains focused on the camera (and therefore perceived as facing the interlocutors) when taking part in an online conference while walking in the street or reading a document (Radio-Canada, 2023) (deep learning for image and/or voice recognition, GAN, or variational autoencoders (VAE) to generate images or video).

- Whether for ***video games or online conferences and meetings***, AI is breaking down language barriers by enabling instant translation into different languages without the need for an interpreter (Wordly, n.d.) (Natural Language Processing (NLP), and Large Language Models (LLM)).

Incorporating this matrix into all methodologies

Originally, this matrix is a representation designed to **elucidate the consequences of collective choices in usages and digital systems made by economic and public players** (public policies, financing, economic and industrial strategies, etc.) **on greenhouse gas emissions and energy consumption in the digital sector.**

The **scope** of this matrix of induced effects on the digital system is:

- Broader than the eco-design perimeter of a virtual world (induced effects on the digital system), since medium- and long-term dynamics are taken into account in order to identify medium- and long-term effects on the digital system;
- Narrower than an approach that takes account of indirect (second-order or higher-order) effects, such as our systemic representation in Figure 2 of the "*Planifier la décarbonation du système numérique en France: Cahier des charges"* ("Planning the decarbonisation of the digital system in France: Specifications") document (The Shift Project, 2023), or the ITU L.1480 standard (ITU, 2022a), the aim of which is to assess how emissions from the digital sector may impact on emissions from other sectors.
- Similar to pillar "A" (in the sense of the three types of non-fungible actions of the Net Zero Initiative (NZI) (Net Zero Initiative, 2022)) which aims to reduce direct and indirect emissions to levels required by decarbonisation scenarios compatible with the Paris

Agreement; whereas pillar "B" aims to contribute to reducing emissions "elsewhere", by marketing decarbonising products and services or financing greenhouse gas avoidance projects outside its value chain, and pillar "C" aims to preserve and develop carbon sinks, within or outside its value chain.

This matrix therefore contributes to the study of the direct effects and the digital footprint, i.e. the scope considered in the SBTi objective of a -45% reduction in greenhouse gases between 2020 and 2030[24], and particularly the **interaction between the design of future offerings and the digital system**. In addition, principles 4 to 7 of the NZI reiterate that reductions in direct and indirect emissions are a priority and that it is urgent for companies to achieve tangible and rapid results in reducing their own emissions.

However:

- **This matrix is not suitable for studying net greenhouse gas emissions**. Such studies need to be conducted on specific use cases (as discussed at the end of the "Methodology for weighting technological directions for virtual worlds: the metaconferencing case study" chapter) and for specific usage contexts;
- While this matrix indicates the energy pitfalls of digital offerings, **it does not answer the important question of a company's *raison d'être* in a decarbonised world**, a question that is nonetheless essential in the construction of a Zero Net Emissions world;

This matrix is not a substitute for a carbon footprint, which is necessary to steer the transformation of businesses.

Furthermore, **by describing the collective and infrastructural energy and climate consequences of digital offerings, this matrix serves as a valuable tool**[25] **for engaging in collective discussions among players and stakeholders regarding the specifications of future offerings.**

When used in conjunction with widespread eco-design, it can be used to challenge the specifications that are part of the functional unit to enable greater reductions in electrical consumption and greenhouse gas emissions. By questioning high-level specifications, it must be accompanied by an appropriate project or company strategy and a true transformation of business models. Its use as a decision-making aid in the design of less carbon-intensive offerings and infrastructures will then encourage the construction of offerings that are compatible with structural digital sobriety.

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[24]The ITU's recommends a -45% reduction between 2020 and 2030 in the digital sector's own footprint, with an SBTi trajectory established based on ITU's recommendation L-1470 (ITU-T, 2020) as outlined in SBTi et al., 2020. This recommendation acknowledges the existence of indirect impacts of the digital sector on emissions in other sectors, both positive (emission avoidance) and negative (induced emissions). It explicitly mentions these impacts but does not conclude that there should be a form of compensation effect leading to a less ambitious target for reducing the digital sector's own emissions (The Shift Project, 2023).

[25] A suggestion that requires improvement.

Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario

The ***Meta-metaverse*** scenario is designed to aggregate and translate the essential **dynamics of undifferentiated deployment and widespread adoption of virtual worlds on the carbon impact of the global digital economy.** This scenario is based on:

- Gartner's macroscopic[26] prediction: "In 2026, 25% of people will spend 1 hour in the metaverse" (Gartner, 2022). This order of magnitude has been incorporated as the basis for usage penetration in our trajectory, albeit shifting it to 2030 rather than 2026;
- The carbon footprint in the manufacturing and the power consumption during the use of a virtual reality headset (CEPIR, 2023);
- The data rates associated with virtual reality (Ericsson, 2023);
- Computing power targets that are linked to this (Intel, 2021);
- The increase in the embedded carbon footprint of IoT devices (Pirson T., Bol D., 2021), and an increase in the number of IoT devices and surveillance cameras to model the intertwining between physical and digital worlds proposed by virtual environments.

All the input data is available in "Appendix - Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario" and the modelling is based on our Lean_ICT model.

However, this initial trajectory remains conservative in several respects:

- With Gartner's assumption shifted to 2030 instead of 2026, the penetration of equipment and usage is lower than in the initial formulation;
- The metaverse hour predicted by Gartner does not add to existing uses but, by assumption in our model, replaces 1 hour of online video already consumed today;
- Only virtual reality headsets are considered among the range of equipment that could be deployed as part of widespread virtual world services. A surplus of computers and consoles used in conjunction with headsets, augmented reality glasses, haptic equipment, controllers, holographic design and projection equipment, etc. could also have been considered.
- Only an increase in download speeds is considered, with the choice of an average value of 50 Mbps not being extreme in the announced speed ranges (Cisco, 2020; Ericsson, 2023), while an increase in upload speeds is planned up to 10 Mbps (Ericsson, 2023) (see orders of magnitude at the beginning of "Appendix - Quantifying the pressures exerted by virtual worlds on (mobile) network infrastructure");

[26] Gartner's macroscopic prediction does not break down the sum of the actual uses of virtual worlds in 2030, so the result is not projected by type of use. This deployment and adoption can just as easily be the result of a single major player and a single type of use as of multiple applications and varied uses.

- The rate of ownership with virtual reality headsets is considered to be one headset per user. However, a user might own multiple headsets with different functionalities (professional or entertainment, virtual or augmented reality, for example) or to access different virtual worlds with non-generalized compatibility (similar to needing multiple gaming consoles to play various video games).

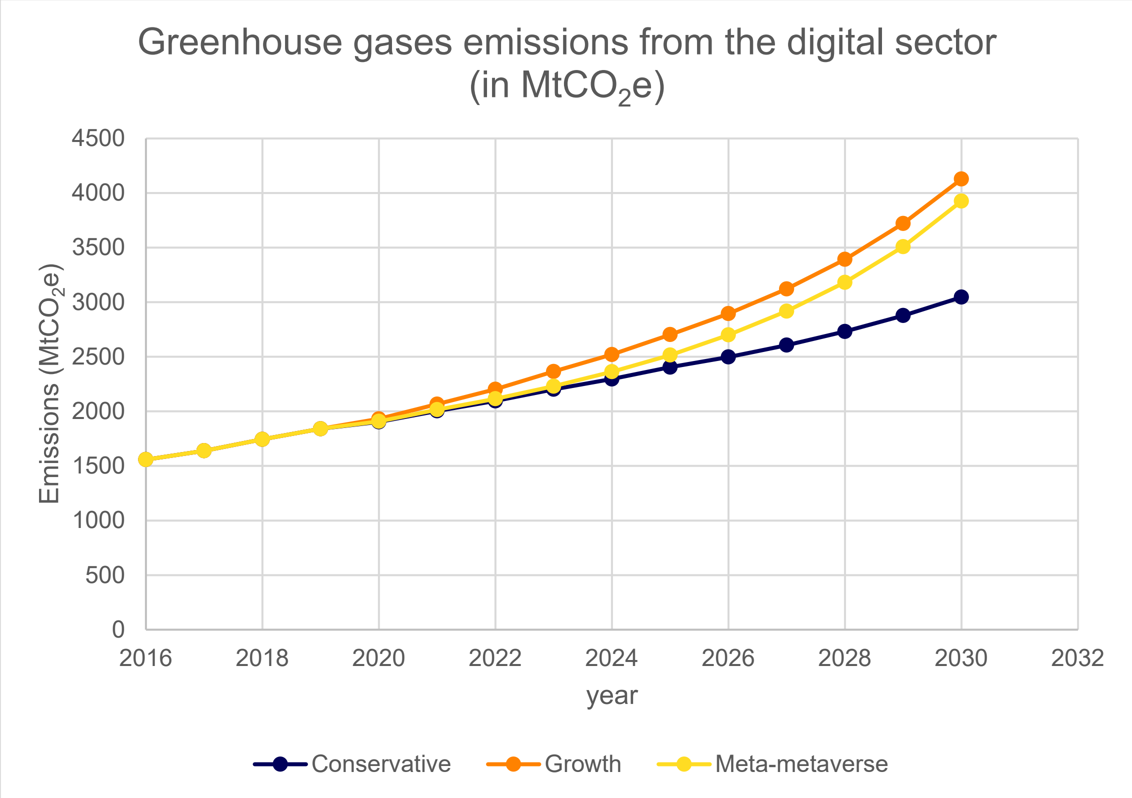

Figure 4 - 2016-2030 trends in greenhouse gas emissions from the digital sector: 2016-2025 Conservative and Growth scenarios (The Shift Project, 2021) extended to 2030 and Meta-metaverse scenario
Source: The Shift Project, for the purposes of this report

Placed in the context of the ***Conservative*** (reference scenario built by extending observed trends) and ***Growth*** (maximalist scenario at the time) scenarios established in 2021 by The Shift Project (The Shift Project, 2021), the ***Meta-metaverse*** scenario reflects a significant acceleration in the evolution of the digital system's impacts. **In this projection, the carbon footprint of the world's digital economy moves away from the "Conservative" scenario towards the dynamics of the "Growth" scenario, and the carbon footprint of the digital economy reaches 3.9 $GtCO_2e$ in 2030, or 7%**[27] **of global emissions.**

An undifferentiated deployment and widespread adoption of virtual worlds has the effect of putting the digital realm on an unsustainable trajectory, incompatible with the Paris Agreement, while perpetuating and accentuating our dependencies and vulnerabilities to fossil energy and material supplies (Figure 3)**:**

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[27] Compared to 54 $GtCO_2eq$ in 2030 by limiting warming to 3°C (>50%), SPM.2 Table (Intergovernmental Panel On Climate Change (IPCC), 2023). If we compare this to 44 $GtCO_2eq$ in 2030 (limiting warming to 2°C (>67%), SPM.2 Table (Intergovernmental Panel On Climate Change (IPCC), 2023)), we get 9%. However, the Meta-metaverse scenario seems incompatible with a 2°C trajectory (>67%) on a global scale.

- The increased demand on networks places their electrical consumption on the same trajectory as the “Growth” scenario;
- The production of devices results in an embedded carbon footprint equivalent to the “Growth” scenario (although usage-phase consumption remains lower due to the development of multiple devices with reduced size and direct consumption, such as IoT);
- The demand for computing resources and servers of a new magnitude leads to the electrical consumption of data centres beyond the trajectory outlined by the “Growth” scenario.

For comparison, to date, only two scientific studies (Liu, F. et al., 2023; Zhao N., 2023) quantify the carbon emissions “from the metaverse”, but with entirely different scopes.[28]

The scope considered in the ADEME-Arcep study is comparable in terms of system boundaries, although it differs geographically (global scope in the context of this report, French scope in the case of ADEME-Arcep):

- **By the year 2030, the *Meta-metaverse* scenario has already surpassed the ADEME-Arcep *business as usual* scenario (ADEME & Arcep, 2023):**
    - The number of immersive devices (virtual reality headsets) or devices that allow virtual worlds to interact with the real world (IoT devices) is increasing more rapidly;
    - The increase in traffic on networks and data centres generated by these new devices is greater (see comparison in “Appendix - Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario”) (ADEME & Arcep, 2023);
- **By 2050, the *Meta-metaverse* scenario would only be compatible with the ADEME's *Pari réparateur* (“repair bet”) scenario (ADEME & Arcep, 2023):**
    - The number of devices is evolving in line with the business as usual scenario, with an explosion in the number of connected objects;
    - The deployment of networks and data centres is sustained.
    - The general principles of the *Meta-metaverse* are similar to those of the *Pari réparateur* scenario for the digital world: "all services are digital", "all homes are smart", "interactions between people are virtualised in both private and professional relationships", "leisure activities involve very large data flows (videos, video games)" (ADEME & Arcep, 2023).

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[28] Liu, F. et al project 115.3 $MtCO_2e$ for electricity consumption alone and Zhao & You project 4.03 $GtCO_2e$ in their "Multi Metaverse applications (near term)" scenario, again for electricity consumption alone.
All the scenarios include initial prospective studies (on the development of metaverse consumption and uses), but the studies are different. Zhao & You limit their calculations to the United States, using figures from the U.S. Energy Information Administration. Liu, F. et al base their calculations on previous scientific work modelling the prospective dynamics of energy mixes supplying electricity to information and communication technologies.

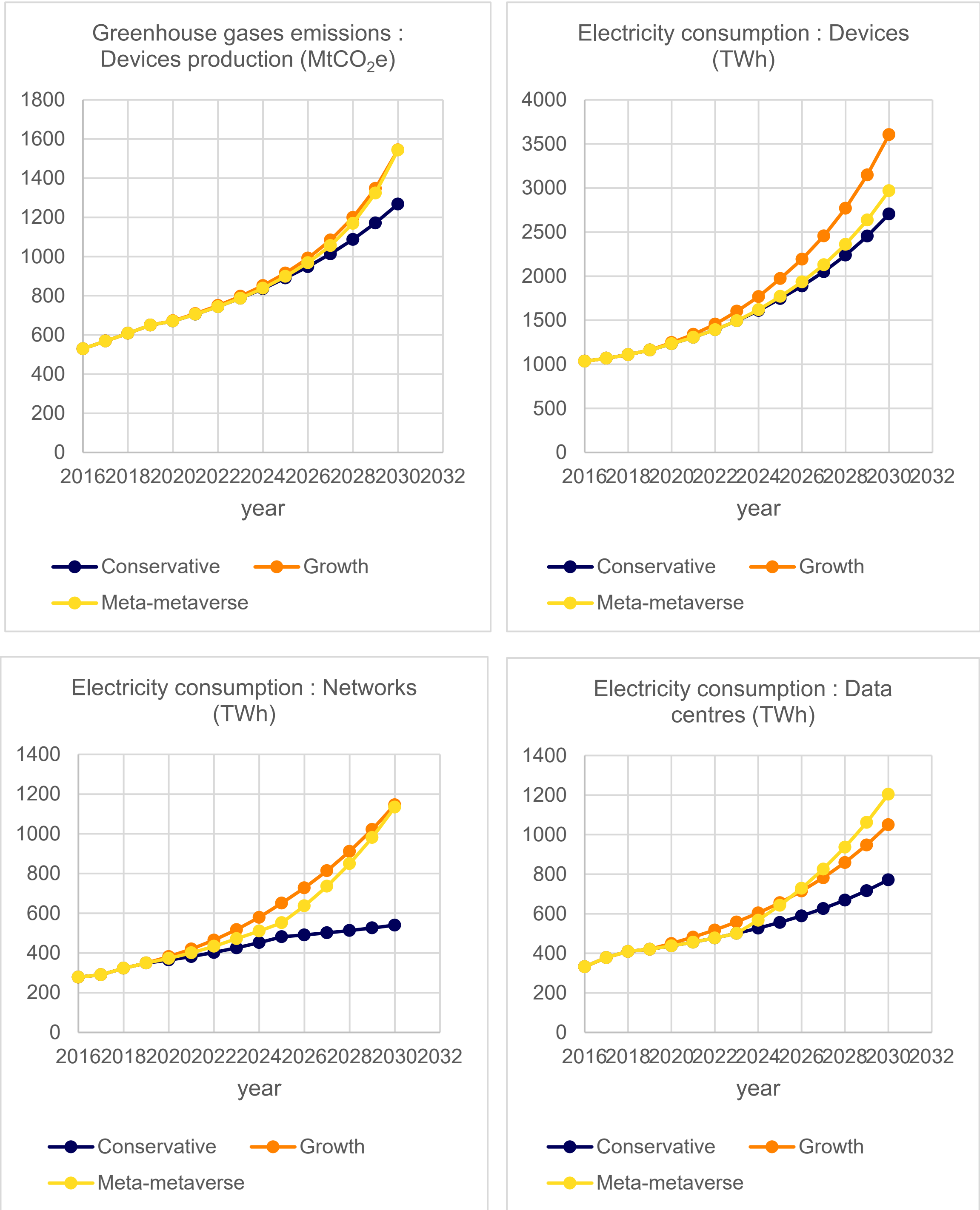


Figure 5 - 2016-2030 trends in greenhouse gas emissions from device production and electricity consumption for each of the 3 components: Extended 2016-2025 Conservative and Growth scenarios (The Shift Project, 2021) and Meta-metaverse scenario. Source: The Shift Project, for the purpose of this report

Quantifying the energy-climate impact of capacity deployment and widespread adoption of virtual worlds: impact on the French mobile network infrastructure

The qualitative description of the effects induced by virtual worlds on the digital system (in the "The 'uses - digital systems' matrix: a tool for translating service proposals into physical impacts" chapter) helps to understand that **deploying and adopting virtual worlds' offerings is not done and would not be done with a constant digital system**. Instead, it would require significant adaptation:

- **From a capacity point of view;**
- **In terms of organisation and functionality (frequency distribution, network slots, etc.).**

These elements are documented in "Appendix - Quantifying the pressures exerted by virtual worlds on (mobile) network infrastructure".

In addition to the quantification carried out with our Lean ICT model (detailed in the previous chapter: "Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario"), the objective of this chapter is to **quantify the portion of the matrix dedicated to mobile access networks to provide quantitative insights into the question: "What impact do virtual worlds have on the deployment of mobile network infrastructure in France and where does it lead us in terms of energy and climate?"** This modelling is based on the method and tool developed and documented in the "Energy and climate: Lean networks for resilient connected uses" report (The Shift Project, 2024a).

The following analysis aims to calculate the energy-climate footprint associated with a capacity expansion of mobile networks[29] **in response to widespread adoption of virtual worlds.** However, at this stage, **this analysis does not consider the energy-climate footprint associated with the development of networks in terms of organisation or functionalities**. In particular, in each location, **the deployed frequencies may not necessarily be compatible with the use of virtual worlds**[30].

[29] In terms of scope, the analysis below considers only 4G and 5G mobile access networks. The methodology used in the report is generic (modelling of a generic operator in particular). The quantified analyses are on a metropolitan French scale. All the modelling can be found in (The Shift Project, 2024a).

[30] Indeed, in the scenarios produced by our modelling, the demand for coverage is met with the so-called low frequency bands, i.e. aggregating the 700, 800, and 900 MHz bands currently used by French operators; frequencies that may be unsatisfactory for access to the promised uses of virtual worlds.

To assess the impact of the widespread adoption of virtual worlds and the accompanying capacity deployment, four scenarios that influence the demand on mobile networks are calculated (the names of the scenarios are taken from our report (The Shift Project, 2024)):

- The "Usages: controlled growth" scenario forecasts data consumption that extends the linear trend historically observed in Arcep data from 2017 to 2023 (Arcep, 2023);
- The "Specifications" scenario forecasts data consumption in line with the projected increase in ADL (Arthur D Little, 2023), extended with a linear trend to 2035;
- The “Usages: exponential” scenario forecasts data consumption corresponding to the forecast increase in ADL (Arthur D Little, 2023), extended with an exponential trend (at the same rate of +26%/year) to 2035;
- The "Meta-metaverse (Gartner, Ericsson)” scenario follows the evolution of traffic on mobile networks described in the Meta-metaverse scenario above.

Modelled traffic trends are available in "Appendix - Quantifying the energy-climate impact of widespread adoption of virtual worlds: impact on the French mobile network infrastructure".

The integration, within the model, of the demand corresponding to the widespread adoption of virtual worlds indicates that this “Meta-metaverse traffic” scenario commits us to an annual increase in emissions more than doubling the carbon footprint of 2024. Only the "Usages: controlled growth" and "Specifications" scenarios make it possible to control greenhouse gas emissions from mobile networks, and none of these scenarios make it possible to reduce them.

In addition to carbon unsustainability, there are the challenges posed in terms of power consumption: while the "Usages: exponential" scenario already requires 3.4 TWh more in 2035 than in 2024, an increase of almost 100%, the "Meta-metaverse traffic" scenario calls for 5.8 TWh more, which corresponds to more than triple the power consumption of the mobile network.

These analyses are conservative, since they don't take into account the specificities of virtual worlds (latency, adapted frequencies), which would require additional hardware deployment, most likely playing a first-order role.

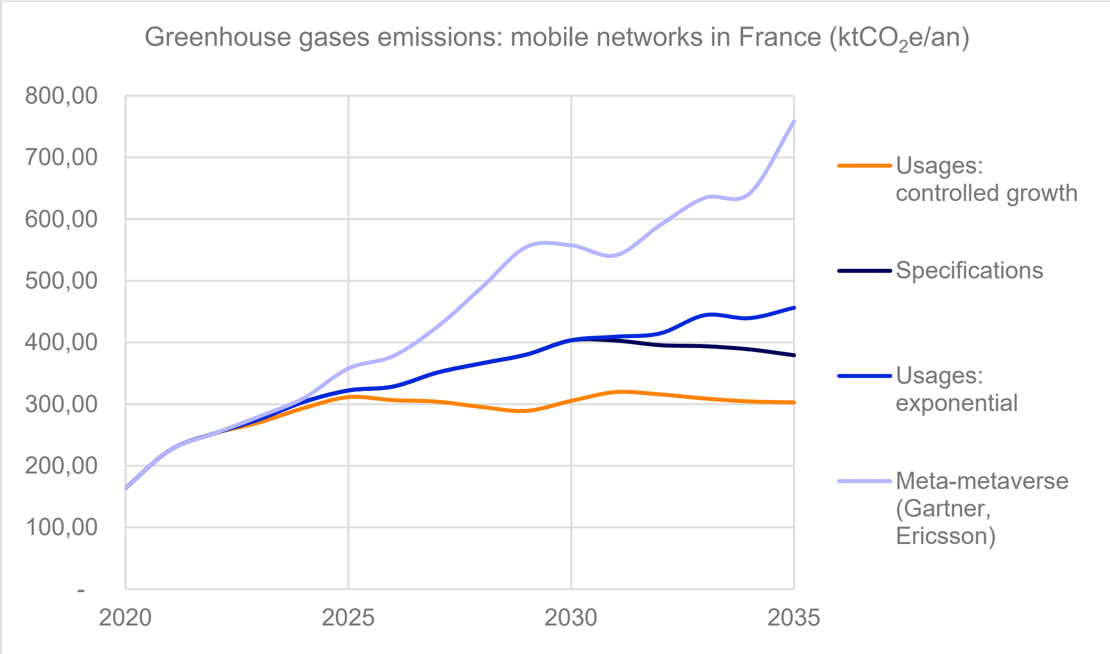


Figure 6 - 2020-2035 trends in greenhouse gas emissions from mobile networks for 4 contrasting traffic scenarios
Scope[31] and calculation method detailed in (The Shift Project, 2024a)
Source: The Shift Project for the purposes of this report and (The Shift Project, 2024a)

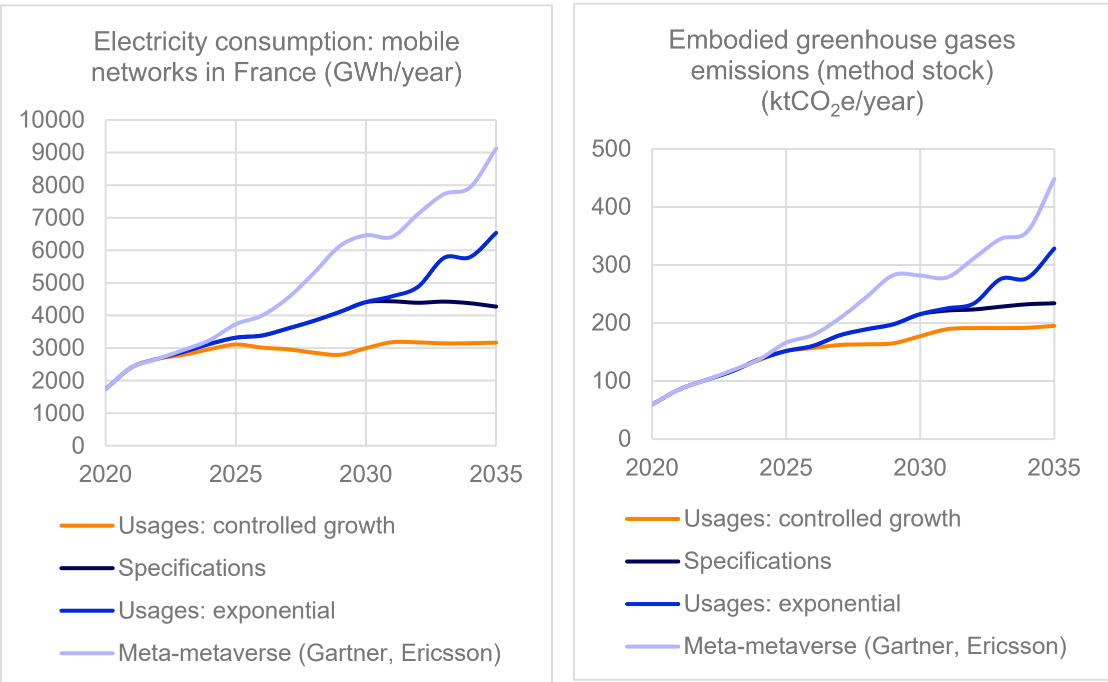


Figure 7 - 2020-2035 trends in electricity consumption and on-board greenhouse gas emissions (stock method) from mobile networks for 4 contrasting traffic scenarios
Scope and calculation method detailed in (The Shift Project, 2024a)
Source: The Shift Project for the purpose of this report and (The Shift Project, 2024a)

[31] Scope of mobile network study: mobile access networks, 4G and 5G, modelling of a generic operator (x4), quantification at the metropolitan French scale. The full model can be found in (The Shift Project, 2024a).

Methodology for weighting technological directions for virtual worlds: the metaconferencing case study

The virtual world differentiation methodology developed in the "Qualifying the energy-climate impact of the virtual world continuum on the digital system" section supports this analysis about ***metaconferencing***. The aim here is to determine whether the deployment of the ***metaconferencing*** "use case" is sustainable in terms of energy and climate impacts, and under what conditions it should be encouraged or discouraged from this point of view. To this end, a five-step methodology is put forward:

- **Step n°1**: Describe the "use case" under study. This can be done with the help of a projection, if one exists: the ***metaconferencing*** narrative was constructed as a tool for synthesising the prospective trends observed in the services promised or mentioned by today's major digital players[32].
- **Step n°2:** Characterise this "use case" among virtual world[33] modalities.
- **Step n°3**: Apply the matrix to qualify the effects induced on the digital system[34].
- **Step n°4**: Quantify the trends and the energy and climate footprint of the "use case" studied.
- **Step n°5**: How to act accordingly?

Step n°1: Describe the "use case" being studied[35]

The "use case" of online meetings and conferences is described using a narrative of a dozen or so lines, the construction of which is based on the study of product and service offerings from the major players in digital services, as well as on visions proposed and shared within the digital ecosystem. By analogy with audioconferencing and videoconferencing, the term "***metaconferencing***" has been chosen for this "case study" to characterise the use studied: the use of a "metaverse" as a means of communication in a meeting or conference. **This is not a unique service but rather a synthetic case allowing us to consider the trend that aims to make online meeting and conference services immersive.**

[32] See the section "Approaching virtual worlds through 'use cases'" for a description of use cases and the construction of narratives.
[33] See "Approaching virtual worlds through technological direction".
[34] See "Induced impacts on the digital system: presentation of the 'uses - digital systems'matrix".
[35] See the section "Approaching virtual worlds through 'use cases'" for a description of use cases and the construction of narratives.

Metaconferencing

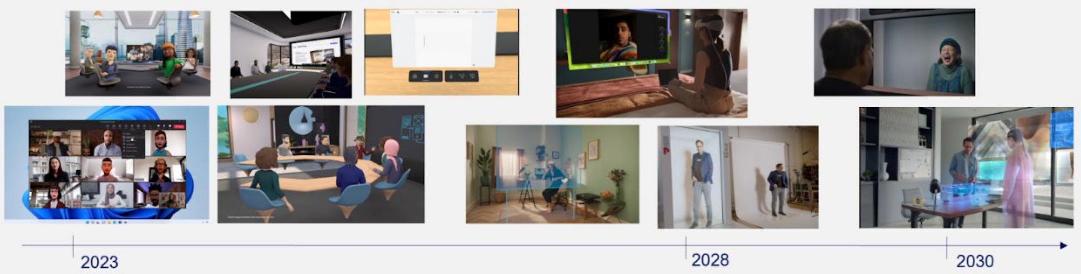
Starting from 2023, avatars discreetly make their way into video conferencing tools [1]. Initially as an addition to audio or a substitute for video, catering to both casual and professional audiences [2,3], drawn in by the sense of comfort and inclusion [4].

At the same time, virtual reality and avatars are becoming commonplace in the entertainment sector, while videoconferencing is becoming the norm for family and friends.

The immersive collaboration features of videoconferencing tools are evolving: they become multitasking and more productive, with simultaneous multilingual translation [5], note-taking and automatic synthesis, and collaborative tools [1].

In the corporate world [3], shared immersive experiences are also becoming more prevalent: training for specific skills, recruitment, on-boarding, virtual offices, access to digital models and twins, and virtual trade shows for commercial purposes [6].

The massive adoption of metaconferencing by businesses, in particular, could be triggered by augmented and possibly mixed reality [7, 11], and holograms [8,9], which provide an extra layer of immersive realism [10].



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[2] Microsoft Mesh | Microsoft Teams, Microsoft Teams, 23 May 2023, https://youtu.be/fSKBHOWOcSM?si=AuRe6QYmwQrsaUt_

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Step n°2: Characterise this "use case" among virtual world modalities[36].

This characterisation step of ***metaconferencing*** aims to identify, among the features of virtual worlds, which ones are essential for the functioning of the virtual world to deliver the promised service, which ones are useful, and which ones are entirely optional[37] :

Characteristics	Online Meetings and Conferences	Metaconferencing	Assessment
Physical and Digital Coexistence	Optional	Optional	(no influence between the virtual world and the real world)
Immersion	Useful	Essential	The specificity of metaconferencing lies in immersion, promising comfort, inclusion, and increased productivity.
Simultaneity	Essential	Essential	It pertains to the utility value: communicating quickly. It can be a productivity gain.
Location	Useful	Useful	Immersive devices permitting, they can also be used on the move.
Persistence	Optional	Optional	(no system capability to exist when the user is disconnected – except for specific cases of automatic notetaking in a meeting from which the user is disconnected – and except for virtual environment settings saved from one meeting to another)
Virtualisation and Content creation	Useful	Essential	Virtualisation enables immersion.
Commercialisation	Optional	Optional	(no specific commercialisation: subscription system)
Size	Optional	Optional	(except for large conferences)

Table 3 - Assessment of the essential nature of technological directions for the "use case" of online conferencing
Source: The Shift Project, as part of this report

Step n°3: Apply the "uses - digital systems" matrix to qualify the effects induced on the digital system[38].

The "uses - digital systems" matrix identifies the effects of ***metaconferencing*** on the digital system:

- **Devices**: ***immersion***, possibly in a ***virtual*** environment, is made possible by an additional device (headsets or glasses), whose connection to the internet is made possible by a connection via a smartphone or computer;
- **Networks**: ***simultaneity*** is made possible with low-latency and possibly high-speed networks, depending on ***immersion*** requirements. ***Mobile*** uses require these same specifications for mobile networks;
- **Data centres:** depending on whether or not devices are used with their own computing power, and whether or not they are linked to ***mobile*** use, and depending on the implementation of virtualisation, data centres could experience varying levels of demand.

Step n°4: Quantify the trends and energy and climate footprint of the "use case" studied.

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[36] See "Approaching virtual worlds by technological direction".
[37] As this qualification exercise using "essential/useful/optional" criteria has to be carried out during an innovation process (i.e. when the possible services are not 100% defined), it is more difficult to carry out than when the service already exists and is perfectly defined.
[38] See "Induced impacts on the digital system: presentation of the "uses - digital systems" matrix".

<table>
<tr><th colspan="2" rowspan="3">Add-on for Metaconferencing</th><th colspan="6">2030</th></tr>
<tr><th colspan="3">GHG emissions ($MtCO_2e$)</th><th colspan="3">Final energy (TWh)</th></tr>
<tr><th>Total</th><th>Manufact-uring</th><th>Usage</th><th>Total</th><th>Manufact-uring</th><th>Usage</th></tr>
<tr><td>Immersion: devices</td><td>• Assumption: by 2030, 400 million users (same number of users as Outlook in 2015 (Microsoft, 2015))
• 1 hour of use per day in 2030 (Gartner, 2022)
• VR headsets: OLED, battery, integrated computing (CEPIR, 2023)
• Headset lifespan: 2 years (assumption based on (Statista Research Department, 2023b; Wikipedia, 2024c))</td><td>26</td><td>26</td><td>0,4</td><td>94</td><td>93</td><td>1</td></tr>
<tr><td>Simultaneity: networks</td><td>• Download speed: 50 Mbps (Ericsson, 2023)
• Assumption: by 2030, 400 million users (same number of users as Outlook in 2015 (Microsoft, 2015))
• 1 hour of use per day in 2030, replacing videoconferencing (Gartner, 2022)</td><td>28</td><td>3</td><td>26</td><td>68</td><td>9</td><td>59</td></tr>
</table>

Table 4 - Metaconferencing: what is the trend in terms of energy and carbon costs?
Source: The Shift Project for the purposes of this report

All data can be found in the Materials file (The Shift Project, 2024c).

This estimate is based on the assumption that 400 million users (i.e. the number of Outlook users in 2015[39]) could be enticed by 2030 to use metaconferencing rather than videoconferencing for 1 hour a day. This assumption has been made in this exercise for the purposes of quantification in the context of this "case study", but would need to be updated as penetration scenarios for the technologies concerned become available.

This calculation is undoubtedly conservative, as a number of elements have not been taken into account: client heavy downloads, automated or intelligent collaborative or productive functionalities, the complexity of the virtual environment and the computing power required, and the embedded carbon footprint and power consumption of a headset with high computing power.

This assessment is not generalisable, but specific to the "case study" constructed here: these results do not mean that all ***metaconferencing*** solutions would have this carbon footprint and power consumption. Quantification here simply enables us to characterise the key items and drivers among what appears to be envisaged by industry players in terms of services and applications of this type.

[39] A number of the same magnitude as the number of videoconference users in 2023 (assuming that each user uses it for 1 hour a day), since Zoom is likely to account for 3.3 billion minutes (Search logistics, 2023) and hold 40% of the market (webinarcare, 2023).

With this scenario, encouraging and adopting ***metaconferencing*** would imply 26 $MtCO_2e$/year for headsets (mainly due to the manufacturing of devices required by ***immersion***) and 28 $MtCO_2e$/year for networks (mainly due to increased data rates driven by the combination of ***immersion x simultaneity***) globally. In other words, **to benefit from these immersion features would result in greenhouse gas emissions equivalent to 6.4 times the emission reduction efforts achieved by France each year**[40]**.**

In the event of widespread adoption of the service, and considering its direct and induced effects on the digital system, adding *immersion* to videoconferencing functionalities would take us further away from the compatible trajectories of the Paris Agreement.

Step n°5: How to act accordingly?

The previous steps demonstrate that **substituting *metaconferencing* for videoconferencing in the workplace increases energy consumption and direct and induced** (first order) emissions on the digital system. However, this is the very scope on which the ITU recommendation indicates a target of -45% reduction in greenhouse gas emissions between 2020 and 2030 (SBTi et al., 2020)[41].

This "use case" falls into the category for which the question of **indirect emissions arises: is it possible to leverage *metaconferencing* to achieve a favourable greenhouse gas emissions balance?**

- From an energy-climate perspective, it is necessary to **identify if there are conditions under which the substitution of *metaconferencing* usage for carbon-intensive mobility usage, for example**, would result in a **net reduction in indirect emissions (and associated energy consumption). This assessment would need to consider whether the increase in impact on the digital system caused by the service is outweighed by the reduction in indirect emissions.**
- **We suggest carrying out this analysis within a company, since the gain can only come from the potential capacity of *metaconferencing* to shift additional in-person meetings or interactions to remote ones, even though video conferencing is already an option.**
- The parameters that can be used to determine the size of the gain are:
    - Employees' and external partners' **marginal preference** for ***metaconferencing*** over videoconferencing;
    - Also, the company's **human resources policy**, which may, on the contrary, aim to maintain a minimum level of physical presence in the premises.
- **The company context has the advantage** of taking into account the company's specific characteristics, which can have an impact on the footprint, as well as the advantage of **measuring and monitoring greenhouse gas emissions over the medium and long term**, to ensure that the overall balance remains favourable despite possible new effects.

Several factors call for caution in setting up *metaconferencing* with a view to decarbonisation:

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[40] Over the 2019-2021 period, the average annual decrease observed is 8.1 $MtCO_2e$ for gross emissions (excluding carbon sinks from land use, land-use change, and forestry sector (LULUCF)) (High Council for the Climate, 2023). (11.0 $MtCO_2e$ in 2022, 6.7 $MtCO_2e$ observed over the 2011-2021 period).

[41] The SBTi trajectory is based on recommendation L-1470 published by the ITU (ITU-T, 2020). This recommendation does not ignore the existence of indirect impacts of digital technology on emissions from other sectors, whether positive or negative. It mentions them explicitly, but does not deduce that a sort of offsetting effect should be taken into account, which would lead to a less ambitious target for reducing the digital sector's own emissions (The Shift Project, 2023).

- **Identifying and estimating rebound effects:** The study on the characterisation of rebound effects induced by teleworking (ADEME, 2020) estimated that for a reduction in mobility enabled by teleworking, 31% of the gain can be offset by rebound[42] effects. Studies on the subject have historically overestimated avoided emissions (Roussilhe G., 2023). The introduction of an initial standard methodology in December 2022 provides the foundation for supporting the identification of indirect effects (ITU, 2022a).
- **The net gain depends on economic and social, geographical, and temporal conditions, as well as on adoption:** for teleworking, for example, the net gain depends on the type of office and organisation (organised flex office or not, for example), the profiles and the way employees adopt teleworking, but also on the evolution of organisations, the acceptability of virtualising professional relationships, possible latent rebound effects (human resources policies forcing a minimum of physical presence) and the ability to sustain the effects over time.
- **The relevance of remote communication tools as a lever for decarbonisation can also only be achieved through company-wide, and even partner-wide, change management programs.** We demonstrated this in our study of connected technologies presented in our "Deploying digital sobriety" report, where we highlighted that these technologies could only become relevant solutions if they were part of a broader program to support changes in behaviour and paradigms (The Shift Project, 2020).

In the absence of a favourable balance sheet, controlling the carbon footprint of *online meeting and conferencing services* involves refocusing on the main added value: *simultaneity* rather than *immersion* in this case study, to accompany the widespread implementation of eco-design for these services. In this respect, and in view of the parameters taken into account in this "case study", videoconferencing seems more relevant than metaconferencing from an energy-carbon point of view, and audioconferencing more relevant than videoconferencing[43].

[42] -24.9% due to the rebound effects of modal chains and new daily mobility options, -7.6% due to home rebound effects.
[43] The dataset related to the NegaOctet 1.4 project, documented in the Impact database within ADEME's Footprint database (https://base-empreinte.ademe.fr/), and accessible through the AgirPourLaTransition online calculator (https://agirpourlatransition.ademe.fr/particuliers/collectivites/particuliers/bureau/numerique/calculez-lempreinte-carbone-usages-numeriques), contains the assessment of the environmental footprint for 8 services: one-hour audio/video conferences for 2/20 users with a fixed/mobile connection.

Conclusions and recommendations

The sustainability of our essential digital uses will only be guaranteed by adapting our systems to the dual carbon constraint, i.e. by shifting the trajectory of our digital system towards a lean and resilient paradigm, by controlling both our equipment volumes and our data volumes.

The energy-carbon assessments of the "Meta-metaverse" scenario suggest that **ratifying the undifferentiated deployment or widespread adoption of virtual worlds, and translating them into public policies (or the absence of public policies) and economic strategies, would have the effect of consolidating the dynamics that today place digital technology on unsustainable trajectories**, increasing its incompatibility with the Paris Agreement and perpetuating our energy and material dependencies.

The **methodologies for arbitrating the options of development, deployment, and technological adoption must be comprehensive and systematic. On one hand, they should consider the environmental costs imposed on the digital system, and on the other hand, they should evaluate the net energy and climate contributions of virtual worlds analysed by "use case," taking into account usage contexts**. These methodologies should be deployed as comprehensively and systematically as possible by stakeholders within the virtual worlds' ecosystem.

What types of virtual world are discriminating in terms of energy and climate?

Since endorsing the undifferentiated deployment of virtual worlds leads to a climatic impasse, it needs to be differentiated.

To achieve this, **we need to study the net energy and climate contributions of possible uses for virtual worlds. This depends both on the technological choices made at the design stage, and on the context in which they are deployed.**

For each virtual world modality, we therefore need a **systematic and exhaustive methodological and quantified assessment of energy and environmental costs (including adoption and usage assumptions).**

Conclusion of the analysis by technological direction

In terms of **induced (direct[44]) effects on the digital system, it is already possible to identify certain characteristics or combinations of characteristics of highly inflationary virtual worlds:**

- The ***immersion*** axis combined with any other axis involving significant data exchanges should be avoided as it leads to increased data transfers, resulting in an increase in the energy and environmental footprint of networks. In particular:
    - Combinations like (***immersion*** x ***simultaneity***), (***immersion*** x ***simultaneity*** x ***mobility***) need capacity extensions, which consume energy, or new specifications for fixed and mobile networks (as in the case of immersive video conferencing, cloud computing), potentially leading to new deployments.
    - The (***immersion*** x ***commercialisation***) combination involves data collection that calls for new specifications in network upload rates and data centre storage (geolocation marketing, emotional data, game experience optimisation).
- In general, the ***size*** axis has a significant effect on the final impact level, especially when **coupled with another direction such as:**
    - ***Immersion***: mainly linked to the volume of devices, its combination with the ***size*** axis or widespread adoption is detrimental, since the environmental impact is exacerbated by rapid obsolescence and renewal due to the limited compatibility of certain devices with new services;
    - ***Physical and digital coexistence*** (as in the case of the progressive entanglement of the real and virtual worlds, which multiplies the number of small IoT devices).
- The ***persistence*** axis needs to be set against the added value for users, since it may involve consuming energy in the user's absence.
- Similarly, the ***commercialisation*** axis, which economically underpins the virtual world, can be set against the net added value for users.
- The ***virtualisation*** axis increases the volume of data processed and stored tenfold. Combined with AI, this phenomenon is amplified, for example, if driven by the ***commercialisation*** axis (personalised content), as the pursuit of computing power can translate into larger embedded footprints in immersive or IoT devices, as well as in servers.

Conclusion of the analysis by "use cases"

Analysis by "use case" complements analysis by technological direction. It highlights the interweaving of technical and sociological dimensions:

[44] Unlike the systemic representation of digitalisation presented in the "Planifier la décarbonation du système numérique en France: Cahier des charges" ("Planning the decarbonisation of the digital system in France: Specifications") document (The Shift Project, 2023) (Figure 2), the analysis presented in this report is limited to the direct induced effects on the digital system and does not attempt to describe the indirect effects (second-order or higher-order).

- Does immersive conferencing, explored via our ***metaconferencing*** narrative, help attract new users to remote conferencing, or does it simply offer a new, more resource-intensive service to users of traditional video conferencing?

  Immersive conferencing is one of the cases considered by some (Zhao N., 2023) to be "IT for green", i.e. one whose implementation would make it possible to substitute the use of the digital system for that of the mobility system and thus contribute to the reduction of carbon emissions outside the digital value chain.

  Nothing could be further from the truth, since in addition to assessing the direct environmental cost of ***metaconferencing*** (the footprint of the devices required, direct and indirect consumption linked to the demand on the necessary network and server resources, etc.), it is also necessary to assess (measure in pilot trials, and then monitor) the real gain that can be achieved in terms of greenhouse gas emissions avoided. The reality of this gain depends on factors which are neither numerical nor technical, and which are related to the functioning of organisations and the sociology of work (the **actual and additional** shift in travel to remote conferencing compared with traditional video conferencing depends on compatibility with working patterns, mobility habits, and the scope for change, etc.). This analysis should therefore be carried out in the organisation and the company (in the broadest sense). The objective is to document the conditions required for substitution to take place.

  Whether or not there are conditions of relevance (possibility of an effective reduction in travel), the breakdown of greenhouse gas emissions by characteristic and functionality makes it possible to identify the most inflationary technological areas in terms of carbon footprint. In the case of immersive conferencing, this is the case for the "immersion" feature. If immersive conferencing does not result in a greater reduction in the number of kilometres travelled within an organisation than traditional video conferencing, then it will be relevant for the organisation, from an energy-carbon point of view, to avoid it.

- Exporting the use case approach developed in this report to other applications will make it possible, for example, to document the conditions for the relevance of the industrial metaverse, such as the deployment of digital twins. Its relevance must also be assessed in the light of the operational context: the potential for net gains in greenhouse gas emissions needs to be demonstrated, the conditions that need to be met for these gains to be sustained over time need to be characterised and ensured (maintaining certain characteristics of value chains or, conversely, margins of transformation of these chains, the ability to maintain solutions over time, whether or not in-house skills are required to develop the solution and keep it compatible with changes in the company, etc.), and the sustainability of the solution depends on the position of the company's projects in a French economy actively and consistently transitioning towards decarbonisation.

A multi-disciplinary and multi-sector extension would enable the impact study to be completed beyond the energy and climate aspects and conclude (or not) whether virtual world modalities should be encouraged in a French and European society undergoing an energy and climate transition:

- French or European **energy feasibility requirements** could disqualify certain additional virtual world modalities, in that the necessary resources might not be available (**possible network infrastructure dimensions, electricity availability, soil availability, mineral resources, water resources, etc.**), or accessible in a secure manner (in certain unstable zones in particular), or even create usage conflicts.

- The energy-climate perspective adopted here could be supplemented by **elements of societal relevance adapted to a French society in energy and environmental transition.** This includes not only the perspective of environmental impacts not taken into account in our method **(biodiversity, abiotic resources, soil pollution, etc.)** but also for **social, economic, health, cognitive, ethical, or legal reasons**. This is because **virtual worlds, like the digital realm, are social objects in which social relationships, representations, practices, and uses are defined** (IHEST, 2023; *Renaissance Numérique*, 2023). Our study of metaverse and virtual world offerings has allowed us to glimpse certain elements of possible technological futures proposed by their creators and ecosystem. But a technological choice is a societal choice, and not to bring the question of the technological future into an enlightened societal debate would lead not only to self-fulfilling mechanisms whose relevance has not been demonstrated, but also to strong polarisation (The Shift Project, 2021).

Methodological recommendations

Measurement and transparency

- **Condition the deployment of new services on prior, standardised, and transparent impact studies.**

  As the widespread deployment of virtual worlds is not compatible with the trajectories imposed by physical constraints, it is essential to systematise these studies for sector-specific applications, in a way that is tailored to each case.

  These impact studies must be exhaustive and systematic: all phases of the lifecycle must be taken into account, and all new services are concerned, not just those previously identified as "IT for green". They must also be standardised and transparent, so that they can be compared, audited, and reintegrated into a panoramic vision of the challenges facing the digital sector and its stakeholders.

  The identified conditions of relevance or substitution should be implementable, along with potential mechanisms to contain rebound effects: coherent regulatory and operational frameworks, existing buy-in or incentive mechanisms, etc. Demonstrating that these criteria can be met at the time of deployment and monitored over the long term is an essential condition for the assessment to be able to conclude that the deployment is relevant.

- **Make investment** in new services (particularly in the creative and cultural industries, for the applications studied in this report) and infrastructure (5G+ and 6G) **conditional** on **prior impact studies, ensuring that the trajectories of these services and infrastructures are compatible with our carbon budgets, national and European decarbonisation strategies, and energy and materials constraints.**

- **Quantify the environmental impacts of services during the innovation process, according to the technological choices** that can be made (with a **standardised and comparable methodology**), and **make them visible to stakeholders to guide their choices** (transparency of information for consumers and companies, investment guidelines, labels, prioritisation of R&D and the design of new services, etc.).

Optimisation

- **Encourage widespread eco-design in order to design low-carbon services.**
- **Implement tools such as the "uses - digital systems" matrix in order to identify, within the scope of the digital system, the best technical response to the initial needs identified** by relaxing constraints on certain characteristics (see section "Direct impacts induced on the digital system: presentation of the 'uses - digital systems' matrix").

  In particular, this study concludes that a decision to deploy mobile networks designed to increase downstream and uplink speeds and reduce latency to enable ***immersion*** and ***simultaneity*** at the same time cannot be achieved at a controlled energy and climate cost.
- **Transform business models** to enable the same services to be delivered at reduced environmental cost by working across the entire value chain.

Collective reorganisation towards sobriety

- **Develop digital technologies designed to support the development of a low-carbon economy.**

  This means avoiding **following the technological hype** that has put metaverses and virtual worlds on the collective agenda, **by quickly weighing up decisions on technological direction against their environmental impact.**
- In order to be selective about our digital uses and avoid projects with excessive environmental costs and resource consumption, the **encouragement of widespread eco-design must be accompanied by the deployment of methodologies and tools such as the "uses - digital systems" matrix, in order to identify and break free from service specifications** (and combinations of specifications) that are incompatible with a controlled digital system footprint (see section "Conclusion of the analysis by technological direction").

Training and skills

- **Train stakeholders involved in the innovation process** (private and public investors, entrepreneurs, product managers, designers, advisors, roll out intermediaries, content and application designers, etc.) on **systemic and environmental impacts, especially when the stakeholders are sector-specific** (e.g. cultural players).
- **Train stakeholders in the systemic and environmental impacts of business model transformation** (business layers, strategic layers, consortia of players, etc.).
- Train companies and organisations in assessment methods that consider greenhouse gas emissions by technological axes, characteristics, and with a systemic perspective while remaining directly usable by players, as described in the "Methodology for weighing technological directions for virtual worlds: the metaconferencing case study" paragraph.

Positioning our technological choices towards digital sobriety

Technological developments, driven both by underlying trends (such as the development of immersive technologies) and by media buzz that structure and amplify these dynamics (such as the announcement of Meta in 2021), can become watchwords in public policy.

The incompatibility of the undifferentiated deployment of virtual worlds with the double carbon constraint illustrates the need for our technological choices to be guided by their concrete and physical characterisation.

The way in which the digital ecosystem and its stakeholders are organised and interact in the design of offerings and services means that all these players (investors, entrepreneurs, advisors, designers, deployment intermediaries, public policy-makers) are both actors in, and responsible for, energy and environmental assessment, as a prelude to their strategic involvement in encouraging low-carbon, beneficial digital systems and discouraging deleterious digital systems (incompatible with the dual carbon constraint or with no identified societal benefits).

Positioning our technological choices towards digital sobriety is not just a response to physical constraints, but an opportunity to set a new direction around which to structure and coordinate a genuine European digital ecosystem for the 21st century.

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