Energy and climate: What virtual worlds for a sustainable real world?

Positioning our technological choices towards digital sobriety

Final report

March 2024
Cover illustration : Virgile Bellaiche
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Appendix 1: Context and history

An analysis of the hype cycles for emerging technologies published by the Gartner consultancy and analysis company between 1995 and 2023 highlights the reflection of the past enthusiasm for the development of virtual worlds by the digital industries.

![Figure 1 - Mention of technologies in emerging technology hype cycles published by the consultancy and analysis company Gartner between 1995 and 2023](Source: Analysis for the purposes of this report based on (Gartner, 1995))

An analysis of reality headset releases shows that technological developments will intensify over the 2016-2019 period.

![Figure 2 - Number of virtual reality headsets launched each year](Source: List of virtual reality headsets (Wikipedia, 2024c))
Since 2015, the leading 6 headset manufacturers have introduced new products approximately every 1.4 years.

<table>
<thead>
<tr>
<th>Headset launch year</th>
<th>HTC Vive</th>
<th>HP Reverb</th>
<th>Meta / Oculus</th>
<th>Pico</th>
<th>Samsung</th>
<th>Varjo</th>
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Figure 3 - Yearly product launches by virtual reality headset suppliers
Source: List of virtual reality headsets. (Wikipedia, 2024c) - CC BY-SA 4.0

While the previous graphs date back to the early 1990s, the foundations and construction of virtual worlds go back even further:

- The first devices date back to the 1950s-1960s: Morton Heilig's Sensorama booth allowed users to experience 3D films, and Ivan Sutherland's first "Sword of Damocles" head-mounted display showed computer-generated images (Lécuyer A., 2023);
- The first company to market virtual reality products (VPL Research in San Francisco) was founded in 1984 by Jaron Lanier (Lécuyer A., 2023);
- The Cave Automatic Virtual Environment\(^1\) was invented in 1992 at the University of Illinois in Chicago (Lécuyer A., 2023);
- Academic disciplines such as computer vision have made possible the conceptual and algorithmic developments that enable today's augmented reality and virtual reality devices (Lécuyer A., 2023);
- The growth in usage has been underway in the industrial sector for several decades (Lécuyer A., 2023; Renaissance Numérique & L'Observatoire Société & Consommation, 2023).

\(^1\) A CAVE is an "automatic virtual environment", which is usually closed. It is similar to a "cave". Generally, "screen walls" surround one or more users who are placed at the centre of the CAVE structure. To enhance perceptual immersion, people wear equipment such as 3D headsets and glasses, or suits and gloves to capture movements. (Renaissance Numérique, 2023) glossary definition
Appendix 2: A multitude of definitions for virtual worlds

The definitions put forward (Ball M., 2020; Basdevant A., François C., Ronfard R., 2022; CERRE, 2023; Fuchs P. & Techniques de l'ingénieur, 2023) are all different, but a consensus has been reached on the four characteristics of immersion, persistence, simultaneity, and virtualisation.

The characteristics-based approach adopted for the purposes of this report can be found in the section entitled "Approaching virtual worlds by technological direction".

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>(CERRE, 2023)</th>
<th>(Ball M., 2020)</th>
<th>(Fuchs P. &amp; Techniques de l'ingénieur, 2023)</th>
<th>(Basdevant A., François C., Ronfard R., 2022)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Immersion</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Simultaneity</td>
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<td>Localisation</td>
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<tr>
<td>Persistence</td>
<td></td>
<td>x</td>
<td></td>
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<tr>
<td>Virtualisation &amp; content creation</td>
<td></td>
<td>x</td>
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<td></td>
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<tr>
<td>Commercialisation</td>
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<tr>
<td>Size</td>
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</tbody>
</table>

Table 1 - Multiple definitions of virtual worlds
Appendix 3: “Use cases” and narratives

These narratives aim to describe the technological directions being taken and the ways in which the digital ecosystem is planning to use virtual worlds. These narratives are constructed by giving careful consideration to the current offerings in the sector and can therefore, by construction, be characterised as “techno-push”. From a hardware inventory point of view, and therefore in terms of electricity consumption and carbon footprint, it seems hard to get much more maximalist than this.

- Metaconferencing
- The "I" in gaming
- A not-so-virtual business
- The cultural metaverse
- The industrial metaverse
- Immersive pornography

Metaconferencing

As of 2023, avatars will be making their way discreetly into videoconferencing tools [1]. Initially as a complement to audio or a substitute for video, for both amateur and professional users [2,3], attracted by the feeling 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.

In videoconferencing tools, immersive collaboration functionalities are becoming more sophisticated: they offer multitasking and greater productivity: simultaneous multilingual translation [5], automatic note-taking and synthesis, and collaborative tools [1].

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

The mass adoption of metaconferencing, particularly by professionals, could be triggered by augmented reality, possibly mixed [7], and holograms [8,9], which provide additional immersive realism [10].
The “I” in gaming

In 2025, there is no longer any need to go to the cinema: gamers are now the heroes of a meticulously orchestrated plot that is constantly readjusted according to their current and past actions, influencing a constantly evolving universe where there is a total sense of immersion.

Public authorities are gradually requiring game publishers to inform users about their online connection time. This information is then used by advertisers, who pre-empt gamers’ need for sustenance by notifying them of their favourite delivery application. “Feeling peckish? Save gaming time by having your favourite pizza delivered!” [1].

The porosity between advertisers and video games is increasing as game publishers migrate towards a "service producer" model [2], enabling them to monetise more and more content (subscriptions, avatar customisation, unlocking artefacts or features, etc.). Similarly, the
permeability between the cultural sector and video games is increasing (events, concerts within video games). [2bis]

2035: the standardisation of metaverses [3][4] makes it possible for different virtual worlds to be completely interoperable. They allow players to embody, if they wish to, the same avatar in different theme-specific environments [5] depending on their mood, with no disruption to the social and recreational experience.

Real-time machine translation tools [6] make it possible to overcome language barriers and see communities emerge across physical, linguistic, and cultural boundaries.

The main social networks are fully integrated into the metaverse's internal discussion threads.

Thanks to the advent of edge computing [7] and 6G [8], even on mobile, during giant treasure hunts organised in mixed-reality cities, a plethora of hardware resources is now dedicated to processing petabytes of data in real time from the sensors fitted to gaming equipment. These include heart rate, eye tracking, perspiration, and even any comments made by players during the game (who have signed up beforehand to the conditions of use allowing them to "maximise their gaming experience") [9][10].

The force feedback effect of a full haptic suit and haptic gloves, the acquisition cost of which has become 'democratized', at least for the middle classes (600 euros), means that you can feel the bullets fired during skirmishes... in a lighter version, of course, and ‘touch’ objects in the environment. The new generation of hybrid headsets can also ‘smell’ the environment in which players are playing [11]. A system of ‘cartridges’ of essential oils is reloaded, whose chemical compositions are combined to produce these ‘ambient fragrances’ (ranging from the delicate scent of a rose to the foul odours of an open-air rubbish dump).

Products whose existence is purely digital are sold and promoted. It is now considered normal to dress one’s avatar with care, especially as it is made hyper-realistic thanks to the "morphological capture" functionality offered online by most game publishers [12].

Game publishers are adapting to new health constraints and regulations that require them to recommend regular breaks to users to counter the increased sedentary lifestyle and a veritable epidemic of morbid obesity in the gamer community: Gameplay and equipment now require a minimum number of movements to compensate for gamers' potential inactivity!

2040: The convergence of "action-adventure" [14], "role-playing" [15] and "sandbox" [16] worlds and gameplay, to which access is offered "free of charge", is being widely adopted by a growing population of gamers; generative AI [13] having made it possible, for more than a decade now, to adapt the gaming experience to each player, in real time.

All age groups are embracing it, looking for alternatives to a physical lifestyle that is becoming increasingly harmful as a result of the many consequences of climate change [17].

Recording brain activity (electroencephalogram) [18], estimating the level of fatigue based on the level of reflexes detected by haptic equipment, and the player’s intellectual capacity to solve puzzles, suggested by data collected during previous games - everything is done to understand the player's profile and maximise their 'engagement' over time [19], benefitting advertisers, who reuse all this data for micro-targeted marketing purposes [20].
References


[2] Epic Games is making the transition from a "video game developer" ("Gear of War") to an online video game publisher using games as a "service model" ("Fortnite"), Source: https://aws.amazon.com/fr/solutions/case-studies/EPICGames/


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 the UX (User Experience) and of the buying journey, are boosting sales tenfold thanks to their persuasive potential, made possible both by brain, body, and visual data collected in real time, and by a persistent history of this data.
Geolocation marketing and emotional marketing have come a long way since the algorithms used to understand emotions in call centres and video games, and since the Pokémon Go game that moved its players around 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].

References


Images

[11], [1], [7], [8]
Can culture be virtual?

Case study:

2025: in France's most popular tourist sites [1,2], audio guides are gradually being replaced by an augmented reality application coupled with a guide powered by artificial intelligence, made available to visitors on a download platform installed on smartphones or tablets rented for the duration of the visit.

Virtual reality headsets with integrated controllers are also available for a 'Premium' experience in suitable environments.

You can be greeted by Gustave Eiffel [3] as you climb the steps of the tower of the same name, or be invited to follow the Sun King on his morning stroll through the gardens of Versailles, while completing quests or solving enigmas in the form of educational escape games.

2030: the use of augmented reality has become widespread, particularly in major French museums.

Augmented reality applications offering a virtual guide are available in all the smaller museums that are also equipped with high-performance WI-FI.

The biggest museums offer immersive experiences that allow visitors to see a work of art in the context in which it was created: at the Louvre, for example, visitors can be transported back to Leonardo da Vinci's studio where he was painting the Mona Lisa. You can interact with the Mona Lisa as she poses, as well as with the artist himself at work, who explains the historical context of his work and the techniques he used, and even lets you try your hand as an apprentice on a virtual canvas set up in front of you in the studio, using the same technique and the same compositional principles.

In addition to the virtual reality headset, haptic gloves will allow users to grasp objects in the setting, such as a palette and a paintbrush.

The artwork created in this way will remain available in the form of an NFT in the museum's ‘visitors’ collection [4]

Numerous other applications are also offered based on tourist and cultural sites: visual and linguistic contextualization in historical museums, and certain pieces previously inaccessible to the public (protected artworks or antiquities) become accessible.

Experiences can be moved to other locations [1,6].

References

[1] "Eternal Notre-Dame" is an immersive experience for exploring the cathedral.
https://www.eternellenotredame.com/
Can culture be virtual?

Remote case study:

In 2030, remote virtual reality cultural visits will be on the rise, thanks to a much higher penetration rate of virtual reality equipment and headsets in households and a public commission [1].

It is now possible to visit a museum from home, in a virtual world akin to a digital twin, populated by other visitors’ avatars. It is possible to benefit from the services of an interactive guide, customisable in terms of era, presentation, expression style, etc.

In terms of immersive experience [2], the same type of interaction (artists, context, etc.) is offered as in person, but with a lesser degree of rendering and access: not all the works are digitised, and the virtual visit remains a product of appeal, to come and discover the real place. The limitations inherent in the virtual realm, such as the absence of the smell of paintings, the creaking of the wooden floor underfoot, etc., mean that the virtual tour offering cannot entirely replace the real-world visit.

At the same time, international concerts in virtual reality are proving extremely popular [3], encouraged by the introduction of carbon quotas for long-distance travel and the virtual reconstruction of sites after their destruction or disappearance [4].

References


The industrial metaverse

Digital twins are synchronised representations of an existing entity or system [1][2]. In 2025, whether on industrial production tools or cutting-edge equipment such as fighter jet seats [3], sensors embedded in devices will be able to produce data that is transmitted to a digital twin. In this way, maintenance or replacement operations can be optimised to save parts and manpower, while at the same time generating knowledge about how devices behave in different scenarios [4]. Manufacturers are adapting their logistics and transport lines [5]. Engineering and design are becoming increasingly immersive with more powerful virtual reality headsets [6].

In 2030, maintenance of the French rail network, which is mainly covered by sensors sending daily data on track conditions, will be programmed using digital twins [7]. Decision-support services and data on track usage are made available to the various departments of the operator and the railway companies. The amount of work dedicated to track monitoring is reduced.

In 2035, the EPR2s will be designed natively with a digital twin. Sensors placed in the pipework will enable the status of nuclear power plants to be monitored continuously and with minimal human intervention. Sensors covering supply chains [8], infrastructures, networks [9], logistics flows [10] and data centres [11] are now often accompanied by connected objects acting on the real entity. Information and actions no longer flow simply from the real entity to its digital twins, but also in the opposite direction. The real entity can therefore be controlled directly via the digital twin.

In 2040, digital twins will begin to be deployed in the healthcare sector [12]. The proliferation of external sensors and the consumption of communicating capsules will enable the production of patient digital twins. These twins promote screening, facilitate diagnosis and enable the implementation of personalised or predictive treatments. The existence of a digital twin is a standard for the proper management of physical systems, and cities are no exception. Energy and transport networks, and flows of goods and people, are all twinned in order to regulate the urban system in real time [13-15].
References


[10] Amazon Robotics Builds Digital Twins of Warehouses with NVIDIA Omniverse and Isaac Sim, Nvidia: https://youtu.be/-VQLqs6s9y0?si=PPRRbljmXqWYtGqS to digital twin warehouses


Images
To study the behaviour of a power plant, EDF models its "digital twin", EDF: https://youtu.be/O7bRIIPyuCU?si=Mrn7ydtzceEv-Y


Why digital twins will be the backbone of industry in the future, Siemens Knowledge Hub : https://youtu.be/ObGhB9CCHP8?si=56nP9LHBO0mx8GMG

Immersive pornography

2025: Increase in online 360° video content and the use of VR headsets

The porn industry is increasingly investing in the production of immersive content, starting with the distribution of 360° videos online. Revenues have exceeded one billion dollars for this content [1], [2] an increase of 1506% compared to 2018. While VR accounted for 5% of the market in 2018 [3], it now represents 10%.
Each second of 360° video acquired weighs around 24 times more than an equivalent 2D video in MPEG4 format. In 2020, the average consumption time for online videos is estimated at 6 minutes [5]. So, by 2025, online pornographic videos will be heavier, requiring more bandwidth and server space than ever before. Users are slowly adopting virtual reality headsets to replace PC screens.

2030: Increasing use of 360° video content and content rendered in real-time 3D

Legal immersive pornography has been democratised by its ability to provoke greater physiological activation than a 2D screen [6]-[8].

60% of formerly dedicated internet streams (estimated at 4% of the total [9]) are being replaced by immersive content, which requires more bandwidth and more server space. The 360° videos with real actors of the late 2010s [10] are gradually being replaced by avatars reproducing actors’ gestures with highly photorealistic 3D renderings. Users are increasingly adopting virtual reality headsets to replace PC screens.

2040: Democratisation of dedicated IoT and haptics, social dimension, and generative AI

The progress in connected sex toys [11]-[13] and haptic equipment [14] is producing data used by immersive pornography [15], some of which is stored to improve systems but also to suggest new experiences or carry out individualised marketing. Virtual reality headsets are the main devices used to access this content.

Some applications allow users to meet real partners through their avatars [16], [17] in designated worlds. However, an increasing amount of immersive pornography is associated with generative AI and deepfake technology to instantly generate scenarios that cater to various user fantasies [18].

Thanks to this increase in personalisation and potential stimulation, the average consumption of pornography at least once a month has risen from 91.5% (men) 60.2% (women) in 2018 [19] to 95% (men) 80% (women) in 2040. An increasingly bored [20] and stressed population is also driving this consumption. Bandwidth and space on dedicated servers have exploded.

References


Image

Immersive porn image caption: “Pink Supernova” © Death_Burger / Josan Gonzalez
Appendix 4: Bibliographical analysis of the construction of virtual world offerings

In addition to the references listed below each narrative (in "Appendix 3: “Use cases” and narratives”), the purpose of this table is to reference the studies that describe the use cases studied, in various corpora including industrial products, marketing industry, economic intelligence prediction, culture, institutions, mainstream press and scientific research.

<table>
<thead>
<tr>
<th>Type d’offre</th>
<th>Type d’acteurs</th>
<th>Références justifiant ce type d’offres</th>
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Accenture. (2022, novembre 29). Accenture metaverse shopping solutions for retailers. [https://www.youtube.com/watch?v=IAt3qMYFLKI](https://www.youtube.com/watch?v=IAt3qMYFLKI) |
| Achats en ligne | Presse généraliste | Murphy, H., & Lee, D. (2022, février 23). Retailers seek real-world profits in the metaverse. [https://www.ft.com/content/ed66a2a0-dfe6-41e9-9d09-64b71acc5e50](https://www.ft.com/content/ed66a2a0-dfe6-41e9-9d09-64b71acc5e50) 
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<td>Expériences culturelles</td>
<td>Produits industrie</td>
<td>Jumeaux numériques</td>
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### Table 2 - References to use cases studied in different corpora, including industrial products, marketing industry, business intelligence prediction, culture, institutions, mainstream press, scientific research, etc.

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
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Appendix 5: Virtual worlds' technological maturity and technological directions

In the chapter "Approaching virtual worlds by technological direction", a characterisation of virtual worlds for the purposes of this study is set out: a virtual world is considered to be any application or service presenting all or some of the following characteristics to varying degrees: physical and digital coexistence, immersion, simultaneity, localisation, persistence, virtualisation and content creation, commercialisation and size.

This approach is inspired by the publication "A metaverse maturity model" (Weinberger M. & Gross D., 2023), in which, in addition to the characteristics, a standardised "maturity level" scale is proposed for each characteristic.

This is what "to varying degrees" implies in our characterisation. The following figure (Figure 12) uses Weinberger's scale, while the table below (Table 7) uses elements of an analysis by Technology Readiness Level (TRL) from "The metaverse beyond fantasy. Synthetic world, real economy," (Arthur D Little, 2022a). This report does not put forward a rating or maturity scale for virtual worlds. The scale deemed appropriate for highlighting our work is not based on maturity levels but rather on the amount of energy or greenhouse gas emissions. The analysis framework set up by Pirson et al on IoT products, which enables quantified analyses to be carried out parametrically (with the definition of levels according to functional blocks and IoT equipment profiles), could reinforce the framework set up in this report for the (Pirson T., Bol D., 2021) study.

<table>
<thead>
<tr>
<th>Core Attribute</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
<td>Persistence</td>
<td>turn-based; no persistence; resets are normal</td>
<td>persistent online-platform; not turn-based; continuously online and accessible; planned resets; revanues and updates occur sometimes</td>
<td>persistent virtual world, continuously online; entering or leaving has no impact on the world; no resets; partly not persistent</td>
<td>Large parts of the virtual world are fully persistent; some exceptions exist</td>
<td>Fully persistent virtual world - no exceptions</td>
</tr>
<tr>
<td>Synchronicity</td>
<td>Not an online world; no real-time interaction</td>
<td>Live interaction with a limited number of users in a limited space (e.g. lobby)</td>
<td>Live interaction with all users in the virtual world, but limited to regions of the physical world</td>
<td>Live interaction with all users in the virtual world; worldwide; sometimes exceptions with increasing latency or pausing</td>
<td>Whole virtual world is accessible in real time; live communication and interaction; worldwide</td>
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<td>Characteristic</td>
<td>Technological maturity levels for virtual worlds by technological direction</td>
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<td>Immersion</td>
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</tbody>
</table>

**Figure 4 - Table 3 of "A metaverse maturity model" (Weinberger M. & Gross D., 2023)**
Simultaneity

Size

Localisation

Persistence

Commercialisation

Virtualisation

Table 3 - Current levels of technological maturity (TRL) by technological direction for virtual worlds (Table 1)
Source: Formatted by The Shift Project for the purposes of this report, based on analyses in the "The metaverse beyond fantasy. Synthetic world, real economy" report. Figures 12 to 17 (Arthur D Little, 2022a)
Appendix 6: Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario

The input data and assumptions of the Meta-metaverse scenario as described in the "Quantifying the energy-climate impact of undifferentiated deployment and widespread adoption of virtual worlds: Meta-metaverse scenario" chapter are listed here and assessed in the (The Shift Project, 2024f) calculation file.

<table>
<thead>
<tr>
<th>Consumer devices</th>
<th>Meta-metaverse</th>
<th>CAGR 2023-2030</th>
<th>Summary</th>
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<tbody>
<tr>
<td>VR headsets</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devices Production (in millions of units)</td>
<td>61%</td>
<td>Compliant from connected devices (Gartner, 2022), with hypothesis of 2-years life duration (Statista Research Department, 2023b; Wikipedia, 2024c)</td>
<td></td>
</tr>
<tr>
<td>Production GHG Intensity (in kgCO$_2$e/unit)</td>
<td>7%</td>
<td>VR headset, OLED, battery, integrated computing (CEPIR, 2023)</td>
<td></td>
</tr>
<tr>
<td>Production Energy Intensity (in kWh/unit)</td>
<td>7%</td>
<td>Same hypothesis as production GHG intensity</td>
<td></td>
</tr>
<tr>
<td>Connected Devices (in millions of units)</td>
<td>36%</td>
<td>By 2026, 25% of people will spend at least 1h per day in the metaverse (Gartner, 2022), hypothesis to postpone to 2030</td>
<td></td>
</tr>
<tr>
<td>Connected Devices Unitary Elec. Cons. (in kWh/year)</td>
<td>3.6%</td>
<td>VR headset, OLED, battery, integrated computing (CEPIR, 2023)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consumer devices</th>
<th>Meta-metaverse</th>
<th>CAGR 2023-2030</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devices Production (in millions of units)</td>
<td>24%</td>
<td>CAGR is 2% higher than for the Conservative scenario to model an increased need for real / virtual communication</td>
<td></td>
</tr>
<tr>
<td>Production GHG Intensity (in kgCO$_2$e/unit)</td>
<td>40% / 35%</td>
<td>Production GHG/energy intensity increase (Pirson T., Bol D., 2021) (entanglement of physical and virtual words thanks to IOT modules, the carbon footprint of each module is rising) - except 40% for 2023-2025 period</td>
<td></td>
</tr>
<tr>
<td>Production Energy Intensity (in kWh/unit)</td>
<td>35%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Energy and climate: What virtual worlds for a sustainable real world?

The Shift Project – March 2024

### Connected Devices (in millions of units)
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Connected Devices Unitary Elec. Cons. (in kwh/year)
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Connected Devices
- CAGR is 3% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Consumer devices
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### IP cameras
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Production GHG Intensity (in kgCO₂e/unit)
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Production Energy Intensity (in kWh/unit)
- CAGR is 2% higher than for the Conservative scenario to model an increased need for real/virtual communication

### Connected Devices (in millions of units)
- CAGR of the Conservative scenario is increased by 5% (2023-2025) and then 5% (2025-2030) to model virtual/real communication entanglement

### Connected Devices Unitary Elec. Cons. (in kwh/year)
- CAGR of the Conservative scenario is increased by 2% (2023-2025) and then 2% (2025-2030) to model virtual/real communication entanglement

### Summary
- CAGR conservative kept (expert advice based on Allied Market Research, 2023)

### Networks and data centres
- CAGR of the Conservative scenario is increased by 5% (2023-2025) and then 5% (2025-2030) to model virtual/real communication entanglement

### Meta-metaverse
- CAGR of the Conservative scenario is increased by 2% (2023-2025) and then 2% (2025-2030) to model virtual/real communication entanglement

### Table 4 - Input data and assumptions for the Meta-Metaverse scenario

The following were also used for comparison and consolidation purposes: (ABI Research, 2023; ADEME & Arcep, 2023; Amazon Web Services, 2018; Andrae A., 2017; Cisco, 2020, p. 2; DatacenterDynamics, 2023; IEA 4E EDNA, 2019; Instant gaming, 2024; Iphonote, 2020; ITU, n.d., 2022b; Oko Institute, 2016; Pirson T., 2022; Schneider Electric, Energy Management Research Center, 2023; Statista Research Department, 2023a, 2023c, 2023d; Synergy Research Group, 2023; United Nations, n.d.).

The following table shows the characteristics taken into account in calculating the generalisation of virtual worlds:

### Consumer devices

<table>
<thead>
<tr>
<th>Devices Production</th>
<th>Immersion</th>
<th>Physical and digital coexistence</th>
<th>Simultaneity</th>
<th>Localisation</th>
<th>Peak use</th>
<th>Persistence</th>
<th>Virtualisation of content creation</th>
<th>Commercialisation</th>
<th>Critical size required</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

The Shift Project – March 2024
Furthermore, the “Conservative” and “Growth” scenarios have been extended with updated assumptions. The Lean ICT model is available here: (The Shift Project, 2024d).

<table>
<thead>
<tr>
<th>Consumer devices</th>
<th>Immersion</th>
<th>Physical and digital coexistence</th>
<th>Simultaneity</th>
<th>Localisation</th>
<th>Persistence</th>
<th>Virtualisation and content creation</th>
<th>Commercialisation</th>
<th>Critical size required</th>
</tr>
</thead>
<tbody>
<tr>
<td>VR headsets</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devices Production (in millions of units)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>67%</td>
<td>30%</td>
<td></td>
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</tr>
<tr>
<td>Connected Devices (in millions of units)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>40%</td>
<td>11%</td>
<td></td>
<td></td>
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<tr>
<td>Smartphones</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Devices Production (in millions of units)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>3.5%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected Devices (in millions of units)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>7%</td>
<td>5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smart speakers</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected Devices (in millions of units)</td>
<td>CAGR 2023-2023</td>
<td>CAGR 2025-2030</td>
<td>40%</td>
<td>20%</td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Networks and data centres</th>
<th>Immersion</th>
<th>Physical and digital coexistence</th>
<th>Simultaneity</th>
<th>Localisation</th>
<th>Persistence</th>
<th>Virtualisation and content creation</th>
<th>Commercialisation</th>
<th>Critical size required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic fixed wired (EB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>15%</td>
<td>9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic fixed Wi-Fi (EB)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>31%</td>
<td>13%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic mobile (EB)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>37%</td>
<td>23%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic fixed wired (TWh/EB)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>-22%</td>
<td>-16%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic fixed Wi-Fi (TWh/EB)</td>
<td>CAGR 2019-2025</td>
<td>CAGR 2025-2030</td>
<td>-22%</td>
<td>-16%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5 - Correlation between Meta-metaverse scenario parameters and technological direction (Table 1)
Table 6 - Updated input data and assumptions for the Conservative and Growth scenario to support scenario building (The Shift Project, 2021)

The Meta-metaverse scenario is higher than the Business as usual scenario among the ADEME-Arcep scenarios for 2030:

Table 7 - Comparison of the Meta-metaverse scenario (The Shift Project, 2024b) with the business as usual scenario (ADEME & Arcep, 2023)
Appendix 7: Quantifying the pressures exerted by virtual worlds on (mobile) network infrastructure

Indicators (from various stakeholders) characterising the network specifications required for the deployment of virtual worlds have been gathered:

<table>
<thead>
<tr>
<th>Input data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile augmented reality devices and edge computing:</td>
<td>50 Mbps maximum traffic speed</td>
</tr>
<tr>
<td>VR streaming:</td>
<td>17 Mbps; HD VR: 167 Mbps; UHD VR: 500 Mbps; UHD cameras (security): 16 Mbps; Cloud gaming: 30 Mbps</td>
</tr>
<tr>
<td>Cloud gaming:</td>
<td>10 Mbps (720p) à 35 Mbps (4K)</td>
</tr>
</tbody>
</table>

Source: (Ericsson, 2022; GSMA, 2019; Wikipedia, 2024a)

<table>
<thead>
<tr>
<th>Download speeds</th>
<th>Typical XR Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object Tracking</td>
<td>6G</td>
</tr>
<tr>
<td>Object Detection</td>
<td>5G</td>
</tr>
<tr>
<td>Map Optimization</td>
<td>5G</td>
</tr>
<tr>
<td>Spatial Mapping</td>
<td>5G</td>
</tr>
<tr>
<td>Point-Cloud Data</td>
<td>5G</td>
</tr>
<tr>
<td>Localization</td>
<td>5G</td>
</tr>
<tr>
<td>Sensor Data Acquisition</td>
<td>5G</td>
</tr>
</tbody>
</table>

Figure 5: Illustration des scénarios de déchargement faible, moyen et élevé entre les dispositifs de réalité augmentée et un cloud périphérique pour une exécution typique de tâche de calcul de réalité augmentée (modifié à partir de la source).

(Illustration of low, medium, and high offloading scenarios between augmented reality devices and a peripheral cloud for a typical augmented reality computing task execution) Source: (Ericsson, 2022)
Video games: 10 kbps
Minimal data is exchanged: object positions, actions (use of local algorithms to ensure consistency between players)
Source: Interview

Note: Data rates depend on technical architecture choices: does all the information flow through the networks? (Illustration: WebGPU vs. pixel streaming)
Source: Interview

Mobile augmented reality devices and edge computing: 10 Mbps maximum traffic speed
Source: (Ericsson, 2023)

Augmented reality: based on the tasks downloaded to the edge cloud, 10 Mbps - 40 Mbps
Source: (Ericsson, 2022)

Virtual reality: < 2 Mbps (only the position of the video headset and commands via haptic gloves are transmitted)
Source: (Ericsson, 2022)

Cloud gaming: 500 kbps
Source: Interview

Upload speeds

Latency (and reliability)

Virtual reality: image projection in 20 ms (ideally less than 10 ms) to avoid motion sickness symptoms.
Source: (Ericsson, 2022)

Augmented reality: < 30 ms for objects to be anchored in the environment (value for a single user; the value must be lower for several users). Some existing techniques could reduce these requirements by a factor of 1.5 to 3.)
Source: (Ericsson, 2022)

XR: broadcasts: 10 – 20 s; XR videoconferencing: 200 ms; engaging online games or sports games: < 20 ms.
Source: (Ericsson, 2022; GSMA, 2019)

Player feedback: 50 ms is sufficient.
### Video game designer feedback:

- **Very good experience:** < 20 ms
- **Good experience:** [20 ms; 50 ms]
- **Acceptable experience if latency is consistent:** [50 ms; 100 ms]

### Proposed Infrastructure Modifications

**Mobile augmented reality devices and edge computing:**

- New frequency bands around 3-7 GHz
- Traffic direction based on data rates or latency
- Network densification
- The 5G mobile generation alone will not meet the specified requirements
- 7-15 GHz frequencies used.
- Edge computing

*Source: (Ericsson, 2023)*

**Edge-cloud** (relocating, offsetting, or offloading tasks to the cloud) essential to enable the metaverse by making XR devices affordable, lightweight but powerful, and connected with sufficient battery life.

*Source: (Ericsson, 2022)*

### Table 8 - Virtual world specifications for mobile network dimensioning

*Source: The Shift Project, as part of this report*

Taking into account the technical constraints arising from large-scale AR/VR use, Ericsson forecasts a doubling of mobile network resources in 2030 compared to a business as usual scenario (Ericsson, 2023):

*Figure 5 - Projected demand and capacity dynamics for Ericsson’s mobile networks
Source: (Ericsson, 2023)*
Appendix 8: Quantifying the energy-climate impact of widespread adoption of virtual worlds: impact on the French mobile network infrastructure

In the four scenarios of the "Quantification of the energy-climate impact of widespread adoption of virtual worlds: impact on the French mobile network infrastructure" section, the simulated monthly consumption is as follows.

The construction of scenarios and quantified values are available here: (The Shift Project, 2024).

Figure 6 - Average monthly consumption (GB/month) and total network data usage (EB/year) simulated for 4 scenarios with contrasting data usage levels (GB/month)

Source: The Shift Project for the purposes of this report (Arcep, 2023; Arthur D Little, 2023)
References


The Shift Project est un think tank qui œuvre en faveur d’une économie post-carbone. Association loi 1901 reconnue d'intérêt général et guidée par l'exigence de la rigueur scientifique, notre mission est d'éclairer et influencer le débat sur la transition énergétique en Europe. Le développement exponentiel du numérique, et la façon dont ce développement peut interagir avec les objectifs de décarbonation de nos sociétés, constitue l’un des angles essentiels des enjeux de la transition carbone.

Nos membres sont de grandes entreprises qui veulent faire de la transition énergétique leur priorité.

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