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

Positioning our technological choices towards digital sobriety

Final report

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THE SHIFT PROJECT

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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.

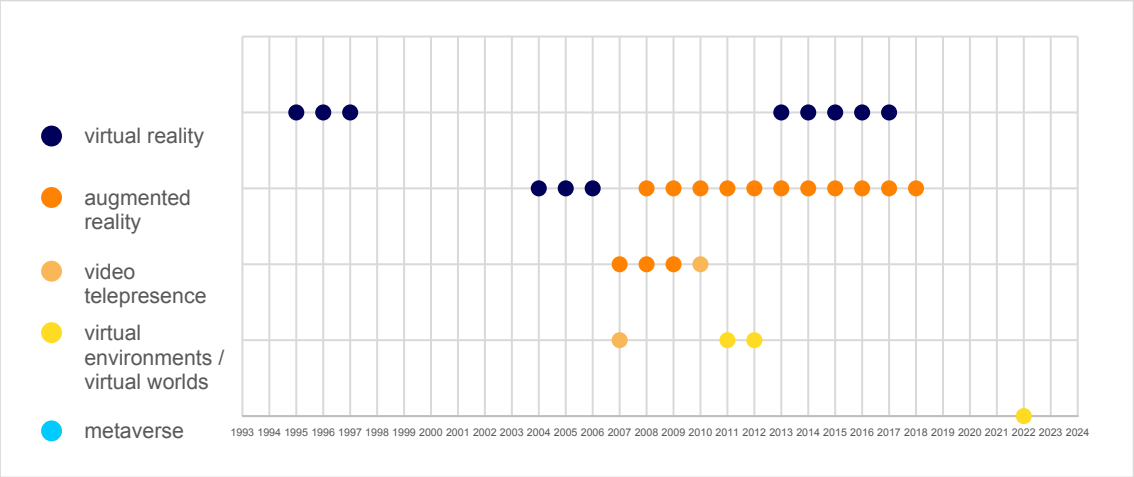


Figure 1 - Mention of technologies in emerging technology hype cycles published by the consultancy and analysis company Gartner between 1995 and 2023
Source: Analysis for the purposes of this report based on (Gartner, 1995)

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

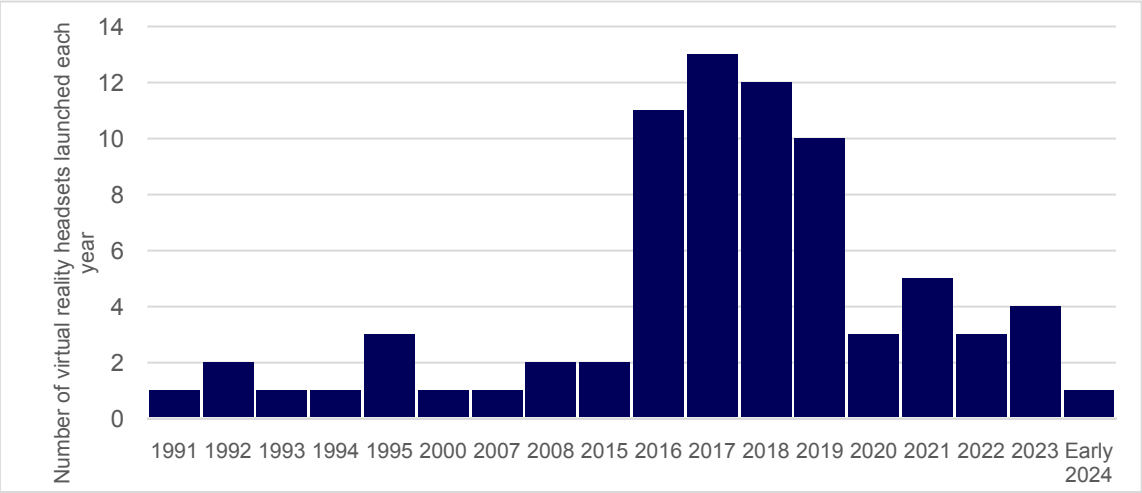


Figure 2 - Number of virtual reality headsets launched each year
Source: List of virtual reality headsets (Wikipedia, 2024c)

Since 2015, the leading 6 headset manufacturers have introduced new products approximately every 1.4 years.

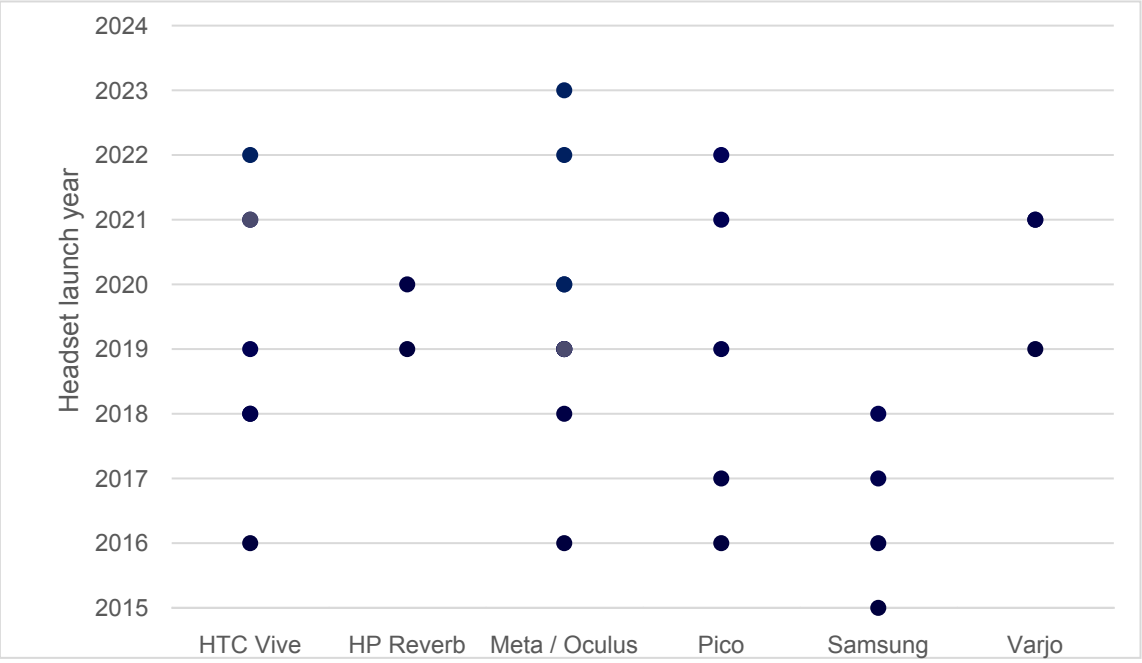


Figure 3 - Yearly product launches by virtual reality headset suppliers
Source: List of virtual reality headsets. (Wikipedia, 2024c) - CC BY-SA 4.0

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".

Characteristics	(CERRE, 2023)	(Ball M., 2020)	(Fuchs P. & *Techniques de l'ingénieur*, 2023)	(Basdevant A., François C., Ronfard R., 2022)
Physical and digital coexistence	x	x	x	
Immersion	x	x	x	x
Simultaneity	x	x	x	x
Localisation			x	
Persistence	x	x	x	x
Virtualisation & content creation	x	x	x	x
Commercialisation		x	x	
Size		x	x	

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

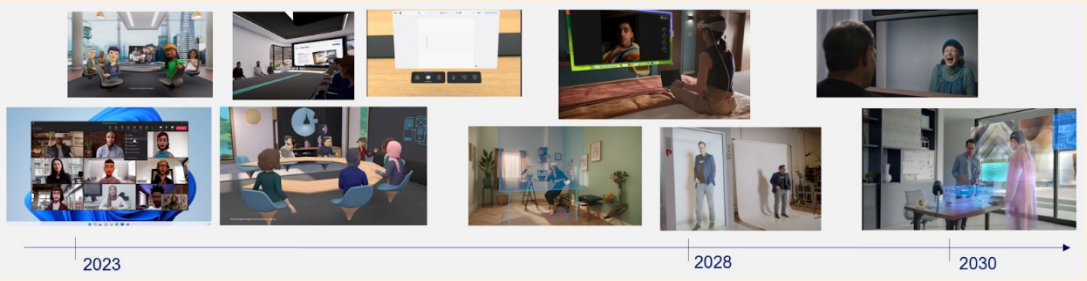
As of 2023, avatars will be making their way discreetly into videoconferencing tools [1]. Initially as a complement to audio or a substitute for video, for both amateur and professional users [2,3], attracted by the feeling of comfort and inclusion [4].

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].



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From left to right: [2], [1], [1] [4], [1], [1], [7], [9], [8], [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].

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Images

Grand Theft Auto V video game poster, Travis Scott's concert in Fortnite, Ready Player One film poster

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.

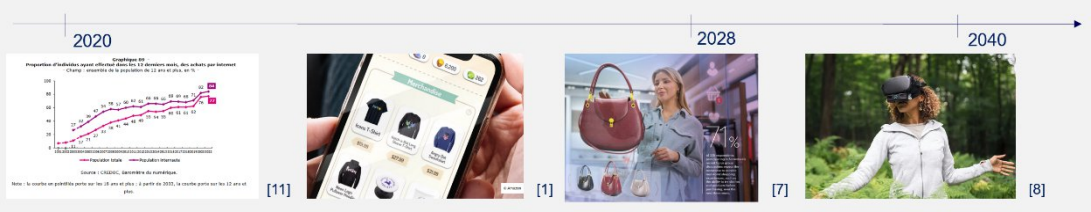
Virtual shopping assistants, a true personification of the UX (User Experience) and of the buying journey, are boosting sales tenfold thanks to their persuasive potential, made possible both by brain, body, and visual data collected in real time, and by a persistent history of this data.

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].



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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].

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Images

Poster for the Eternelle Notre-Dame immersive experience

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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].

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Images

Jean-Michel Jarre concert poster 21 June 2020

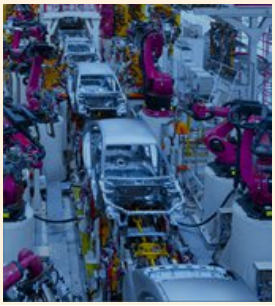
The industrial metaverse

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].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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.

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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.**

Type d'offre	Type d'acteurs	Références justifiant ce type d'offres
Achats en ligne	Produits industrie	ByondXR. (2024). Metaverse Shopping Platform. ByondXR. https://www.byondxr.com/solutions/use-case/metaverse/ Semblance World. (2024). https://semblance.world/ Royex Metaverse. (2024). Metaverse Shopping App Development. Royex Metaverse. https://royexmetaverse.com/services/metaverse-services/metaverse-shopping-app/ Onversed fashion metaverse shop. (2022, décembre 18). Onversed. https://onversed.com/
Achats en ligne	Marketing industrie	Mutual Mobile. (2017). Walmart : Reimagining retail with virtual reality. Mutual Mobile. https://mutualmobile.com/ Accenture. (2022, novembre 29). Accenture metaverse shopping solutions for retailers. https://www.youtube.com/watch?v=IAt3qMYFLKI
Achats en ligne	Prédiction intelligence économique	Deloitte. (2022). Metaverse for The Future of Retail. Deloitte United States. https://www2.deloitte.com/us/en/pages/consulting/articles/metaverse-for-the-future-of-retail.html Standish, J., & Reddy, G. (2022). Retailers, meet me in the metaverse (Vision 2022). Accenture. https://www.accenture.com/content/dam/accenture/final/a-com-migration/pdf/pdf-175/accenture-retail-tech-vision-final.pdf#zoom=40 Statista Market Insights. (2023). Metaverse eCommerce—Worldwide | Statista Market Forecast. Statista. https://www.statista.com/outlook/amo/metaverse/metaverse-ecommerce/worldwide
Achats en ligne	Culture	Matsuda, K. (Réalisateur). (2016, mai 16). Hyper-Reality [Court-métrage, Science-fiction]. Spielberg, S. (Réalisateur). (2018, mars 28). Ready Player One [Action, Aventure, Science-fiction]. Warner Bros., Amblin Entertainment, Village Roadshow Pictures
Achats en ligne	Institutions	Niestadt, M. (2023). Virtual worlds (metaverses) (At a Glance PE 751.408). European Parliament - Think Tank. https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2023)751408
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 Dogadkina, O. (2022, octobre 14). Why Retailers Are Racing To Have A Metaverse Presence. Forbes. https://www.forbes.com/sites/forbestechcouncil/2022/10/14/why-retailers-are-

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Achats en ligne	Recherche scientifique	Yoo, K., Welden, R., Hewett, K., & Haenlein, M. (2023). The merchants of meta : A research agenda to understand the future of retailing in the metaverse. Journal of Retailing, 99(2), 173-192. https://doi.org/10.1016/j.jretai.2023.02.002
Réunions et conférences en ligne	Produits industrie	Lang, B. (2021, août 31). 27 VR Apps for Remote Work, Education, Training, Design Review, and More. Road to VR. https://www.roadtovr.com/vr-apps-work-from-home-remote-office-design-review-training-education-cad-telepresence-wfh/
Réunions et conférences en ligne	Marketing industrie	Langston, J. (2021, mars 2). Microsoft Mesh. Microsoft. https://news.microsoft.com/source/features/innovation/microsoft-mesh/ Apple Vision Pro. (2023, juin 5). Apple Newsroom (France). https://www.apple.com/fr/newsroom/2023/06/introducing-apple-vision-pro/ Remote Work in the Metaverse. (2024). Workplace from Meta. https://www.workplace.com/metaverse-work-infinite-office HTC VIVE (Réalisateur). (2022, février 27). VIVERSE - A Day in the Metaverse with VR, AR, AI, 5G & NFTs. https://www.youtube.com/watch?v=4FlSqGq5XEg
Réunions et conférences en ligne	Prédiction intelligence économique	Virtual Meeting Software Market Size, Share & COVID-19 Impact Analysis (FBI104064; p. 160). (2019). Fortune Business Insights. https://www.fortunebusinessinsights.com/virtual-meeting-software-3d-virtual-event-market-104064 Statista Market Insights. (2023, octobre). Metaverse Workplace—Worldwide. Statista. https://www.statista.com/outlook/amo/metaverse/metaverse-workplace/worldwide
Réunions et conférences en ligne	Culture	Gibson, W. (1984). Neuromancer (1re éd.). Ace. Vaughn, M. (Réalisateur). (2015, février 13). Kingsman : The Secret Service [Action, Adventure, Comedy]. Twentieth Century Fox, Marv Films, Cloudy Productions.
Réunions et conférences en ligne	Institutions	Niestadt, M. (2023). Virtual worlds (metaverses) (At a Glance PE 751.408). European Parliament - Think Tank. https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2023)751408
Réunions et conférences en ligne	Presse généraliste	Doherty, B. (2024, janvier 3). Can AR and VR finally disrupt the exhausting culture of video meetings? BBC. https://www.bbc.com/worklife/article/20240125-can-ar-and-vr-finally-disrupt-the-exhausting-culture-of-video-meetings Isaac, M. (2021, août 19). Facebook's New Bet on Virtual Reality : Conference Rooms. The New York Times. https://www.nytimes.com/2021/08/19/technology/facebooks-new-bet-on-virtual-reality-conference-rooms.html
Réunions et conférences en ligne	Recherche scientifique	Park, H., Ahn, D., & Lee, J. (2023). Towards a Metaverse Workspace : Opportunities, Challenges, and Design Implications. Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, 1-20. https://doi.org/10.1145/3544548.3581306
Jeux vidéo	Produits industrie	List of augmented reality video games. (2024). In Wikipedia. https://en.wikipedia.org/w/index.php?title=List_of_augmented_reality_video_games&oldid=1194912058 List of VR games. (2023, septembre 21). PCGamingWiki. https://www.pcgamingwiki.com/wiki/List_of_VR_games
Jeux vidéo	Marketing industrie	Meta (Réalisateur). (2021, octobre 28). Gaming in the metaverse. https://www.youtube.com/watch?v=5FwztKGQmd8 Steam (Réalisateur). (2023, décembre 5). Steam Link : Play Steam VR games on Meta Quest 2, 3, and Pro. https://www.youtube.com/watch?v=wYJwxsRhPrY

Jeux vidéo	Prédiction intelligence économique	Metaverse Gaming. (2023, octobre). Statista. https://www.statista.com/outlook/amo/metaverse/metaverse-gaming/worldwide Porter, S., Harrison, J., Ang, A., Golik, R., & Gupta, S. (2022). What's possible for the gaming industry in the next dimension? (Survey US SCORE no. 15854-221US ED 2204; p. 15). Ernst & Young. https://assets.ey.com/content/dam/ey-sites/ey-com/en_us/topics/tmt/ey-tmt-gaming-metaverse-report-final.pdf?download Bloomberg Intelligence. (2021, décembre 1). Metaverse may be $800 billion market, next tech platform | Insights. Bloomberg Professional Services. https://www.bloomberg.com/professional/blog/metaverse-may-be-800-billion-market-next-tech-platform/
Jeux vidéo	Culture	Lisberger, S. (Réalisateur). (1982, décembre 15). Tron [Action, Aventure, Science-fiction]. Walt Disney Productions, Lisberger/Kushner. Pyun, A. (Réalisateur). (1994, mars 30). Arcade [Science-fiction]. Full Moon Entertainment. Dietter, S. (Réalisateur). (2000, mars 19). A Bicyclops Built for Two (9). In Futurama—Season 2. Oshii, M. (Réalisateur). (2002, mars 27). Avalon [Action, Drame, Fantastique]. Deiz Production, Bandai Visual Company, Media Factory. Kawahara, R. (2012). Sword Art Online (ソードアート・オンライン) : Arc 1—Aincrad (1re éd., Vol. 1). Kadokawa. Cline, E. (2011). Ready Player One (1re éd.). Crown Publishers.
Jeux vidéo	Institutions	On E-sport and videogames : Motion for a resolution (Draft Repport PE731.488v01-00; p. 10). (2022). European Parliament - Committee on Culture and Education. https://www.europarl.europa.eu/doceo/document/CULT-PR-731488_EN.pdf
Jeux vidéo	Presse généraliste	Marr, B. (2023, juillet 11). Two Technology Trends Shaping The Future Of Gaming. Forbes. https://www.forbes.com/sites/bernardmarr/2023/07/11/two-technology-trends-shaping-the-future-of-gaming/ The video-game industry has metaverse ambitions, too. (2021, novembre 17). The Economist. https://www.economist.com/business/the-video-game-industry-has-metaverse-ambitions-too/21806341?utm_medium=cpc.adword.pd&utm_source=google&ppccampaignID=18151738051&ppcadID=&utm_campaign=a.22brand_pmax&utm_content=conversion.direct-response.anonymous&gad_source=1&gclid=Cj0KCQiA5rGuBhCnARIsAN11vgSNRPJrcyGIoI8m8y_DpqDda8jFyW5ZqU8rw3ZL8rn9PftMDYdSYmkaAhGPEALw_wcB&gclsrc=aw.ds
Jeux vidéo	Recherche scientifique	Gil, R. M., Gutiérrez-Ujaque, D., & Teixidó, M. (2023). Analyzing the Metaverse : Computer Games, Blockchain, and 21st-Century Challenge. International Journal of Human–Computer Interaction, 0(0), 1-18. https://doi.org/10.1080/10447318.2023.2290380
Expériences culturelles	Produits industrie	Sliice XR - Business in the Metaverse (Réalisateur). (2023, mars 23). 10 striking museums in the metaverse 2023. https://www.youtube.com/watch?v=4rN1-wNBk1w
Expériences culturelles	Marketing industrie	HTC VIVE (Réalisateur). (2022, février 27). VIVERSE - A Day in the Metaverse with VR, AR, AI, 5G & NFTs. https://www.youtube.com/watch?v=4FlSqGq5XEg Meta (Réalisateur). (2023, février 2). LGBTQ+ VR Museum—Meta—Community Voices. https://www.youtube.com/watch?v=w8bnCaFmoaM
Expériences culturelles	Prédiction intelligence économique	
Expériences culturelles	Culture	
Expériences culturelles	Institutions	UK Research and Innovation. (2022, octobre 11). National capability for R&D in screen and performance. https://www.ukri.org/opportunity/national-capability-for-rd-in-screen-and-performance/ European Commission. (2022). Horizon Europe Work Programme 2023-2024 : 5. Culture, Creativity and Inclusive Society [Decision C(2022)7550]. https://ec.europa.eu/info/funding-

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Expériences culturelles	Presse généraliste	Meta Future (Réalisateur). (2022, août 28). Museums Of The Future in The Metaverse. https://www.youtube.com/watch?v=AJY4QGg5LsA Carter, R. (2023, mars 21). Why Are Museums Curating Their Content in the Metaverse? XR Today. https://www.xrtoday.com/mixed-reality/why-are-museums-curating-their-content-in-the-metaverse/
Expériences culturelles	Recherche scientifique	Sylaiou, S., Dafiotis, P., Koukopoulos, D., Koukoulis, K., Vital, R., Antoniou, A., & Fidas, Chr. (2024). From physical to virtual art exhibitions and beyond : Survey and some issues for consideration for the metaverse. Journal of Cultural Heritage, 66, 86-98. https://doi.org/10.1016/j.culher.2023.11.002
Jumeaux numériques	Produits industrie	Marr, B. (2022, janvier 20). The Best Examples Of Digital Twins Everyone Should Know About. Forbes. https://www.forbes.com/sites/bernardmarr/2022/06/20/the-best-examples-of-digital-twins-everyone-should-know-about/
Jumeaux numériques	Marketing industrie	Virtual Twins, Digital Twins and the Metaverse. (2022, octobre 14). Dassault Systèmes. https://www.3ds.com/virtual-twin/digital-twins-and-metaverse Siemens. (2024). Digital Twins : First Strides Into the Industrial Metaverse [fw_Inspiring]. Siemens.Com Global Website. https://www.siemens.com/global/en/company/digital-transformation/industrial-metaverse/digital-twins-first-strides-into-the-industrial-metaverse.html
Jumeaux numériques	Prédiction intelligence économique	Digital Twin Market Size 2030 | Technology & Metaverse Use Cases (ndustry Report and Statistics 80848645). (2022). Strategic Market Research. https://www.strategicmarketresearch.com/market-report/digital-twin-market
Jumeaux numériques	Culture	Wachowski, L., & Wachowski, L. (Réalisateurs). (1999, mars 31). The Matrix [Action, Sci-Fi]. Warner Bros., Village Roadshow Pictures, Groucho Film Partnership.
Jumeaux numériques	Institutions	European Union. (2023, décembre 20). European Virtual Human Twins Initiative. Digital-Strategy.Ec.Europa.Eu. https://digital-strategy.ec.europa.eu/en/policies/virtual-human-twins
Jumeaux numériques	Presse généraliste	Marr, B. (2023, mai 23). Digital Twins, Generative AI, And The Metaverse. Forbes. https://www.forbes.com/sites/bernardmarr/2023/05/23/digital-twins-generative-ai-and-the-metaverse/ Carlini, S. (2023, mars 29). The Industrial Digital Twin Metaverse Of Today And Its Path To The Future. Forbes. https://www.forbes.com/sites/forbestechcouncil/2023/03/29/the-industrial-digital-twin-metaverse-of-today-and-its-path-to-the-future/
Jumeaux numériques	Recherche scientifique	Lyu, Z., & Fridenfalk, M. (2023). Digital twins for building industrial metaverse. Journal of Advanced Research. https://doi.org/10.1016/j.jare.2023.11.019
Pornographie	Produits industrie	18 Best VR Porn Sites : Full-Length VR Porn and VR Sex Videos. (2024, février 5). Chicago Reader. http://chicagoreader.com/reader-partners/best-vr-porn-sites/
Pornographie	Marketing industrie	BBC (Réalisateur). (2023, octobre 29). Love, Sex and Porn in VR - BBC. https://www.youtube.com/watch?v=OHnYi8BDxwg BEME News (Réalisateur). (2017, décembre 8). Is This The Future Of Porn? https://www.youtube.com/watch?v=T-Ct6wQlnas
Pornographie	Prédiction intelligence économique	Booton, J. (2015, juillet 26). Porn industry's billion-dollar new frontier. MarketWatch. https://www.marketwatch.com/story/how-the-future-of-virtual-reality-depends-on-porn-2015-07-15 Market Research Engine. (2017, novembre 20). Virtual-Reality Pornography Market by Regional Analysis—Global Forecast by 2022-2027 [Text]. Marketresearch.

		https://www.marketresearchengine.com/virtual-reality-pornography-market
Pornographie	Culture	Compton, R. (Réalisateur). (1998, juin 22). Virtual Slide. In Sliders, les mondes parallèles. Dietter, S. (Réalisateur). (2000, mars 19). A Bicyclops Built for Two (9). In Futurama—Season 2. Anthony, P. (2013). Eroma (1re éd.). Premier Digital Publishing. MacGregor, & Zacarías, B. (Réalisateurs). (2018, février 14). The VR Shrine. In Future Sex. VR Porn. (2019, février 4). In Slutever. Harris, O. (Réalisateur). (2019, juin 5). Striking Vipers. In Black Mirror.
Pornographie	Institutions	Galissaire, J., Isaac, H., & Lucas, J.-F. (2023). Governing the Metaverse and tomorrow's internet. Renaissance Numérique. https://www.renaissancenumerique.org/en/publications/governing-the-metaverse-and-tomorrows-internet/
Pornographie	Presse généraliste	Krueger, A. (2017, octobre 28). Virtual Reality Gets Naughty. The New York Times. https://www.nytimes.com/2017/10/28/style/virtual-reality-porn.html Ng, D. (2018, janvier 5). Porn industry gets a boost from VR, but manufacturers aren't thrilled. Los Angeles Times. https://www.latimes.com/business/hollywood/la-fi-ct-virtual-reality-porn-20180105-story.html Waugh, R. (2023, novembre 19). VR expert reveals how « metaverse sex » will replace porn apps and websites in 10 years. Mail Online. https://www.dailymail.co.uk/sciencetech/article-12752499/VR-metaverse-sex-replace-porn-apps.html
Pornographie	Recherche scientifique	Simon, S. C., & Greitemeyer, T. (2019). The impact of immersion on the perception of pornography : A virtual reality study. Computers in Human Behavior, 93, 141-148. https://doi.org/10.1016/j.chb.2018.12.018

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.

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.

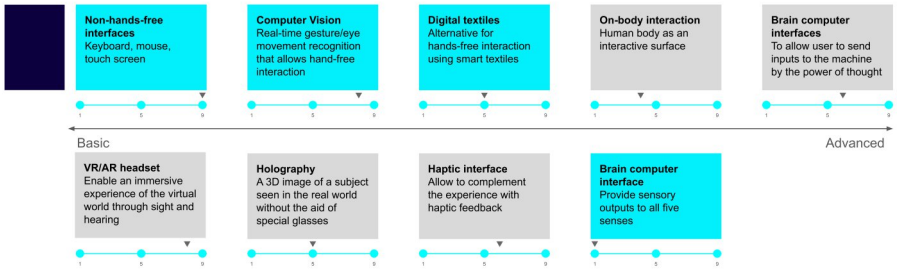
This is what "to varying degrees" implies in our characterisation. The following figure (Figure 12) uses Weinberger's scale, while the table below (Table 7) uses elements of an analysis by Technology Readiness Level (TRL) from "The metaverse beyond fantasy. Synthetic world, real economy," (Arthur D Little, 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.

	Maturity Levels				
Core Attribute	**1**	**2**	**3**	**4**	**5**
Persistence	turn-based; no persistence; resets are normal	persistent online-platform; not turn-based; continuously online and accessible; planned resets, respawns and updates occur sometimes	persistent virtual world, continuously online; entering or leaving has no impact on the world; no resets; partly not persistent	Large parts of the virtual world are fully persistent; some exceptions exist	Fully persistent virtual world - no exceptions
Synchronicity	Not an online world; no real-time interaction	Live interaction with a limited number of users in a limited space (e. g. lobby)	Live interaction with all users in the virtual world, but limited to regions of the physical world	Live interaction with all users in the virtual world; worldwide; sometimes exceptions with increasing latency or pausing	Whole virtual world is accessible in real time; live communication and interaction; worldwide

Scalability	Up to 10 users simultaneously	Up to 250 users simultaneously	Up to 1000 users simultaneously	Up to 10,000 users simultaneously	No limit
Physical and digital coexistence	No connection to the physical world, except for screen and controller-based means to control an avatar.	One interface, e. g. VR or virtual currency tradable for fiat money	Additional interfaces, several interfaces	Generic changes in the physical world influences virtual world and vice versa	physical and virtual worlds are continuously interfacing
Interoperability	No interoperability; prohibitive	One component, e. g. avatar or asset transferable	Several components transferable	Interoperability with several other virtual worlds	Interoperability with all other virtual worlds

User-generated content (UGC)	No UGC is possible. UGC is not in vendors focus.	Users have very limited possibilities to change the virtual world. UGC is not in vendors´ focus.	UGC plays an important role. Users can create worlds or spaces, assets, etc.	UGC is possible in a large variety and complexity; UGC can be monetized	Virtual world depends heavily on UGC. The world has to be created by users building on a given base environment. Everything can be monetized.
Economy	No economy; in-app purchases available	virtual economy with virtual currency; fiat money can be exchanged for virtual currency	virtual economy; free self-regulating market (supply and demand); fiat money purchases	virtual economy; free self-regulating market (supply and demand); virtual jobs and services can generate physical world income	Fully developed economy; self-regulating markets; virtual economy blending with physical world economy
Immersive realism	Hardly any feeling of immersion; text chats; avatars without facial expressions	Little immersive experience; avatars provide feeling of individual presence; user can act freely; voice chat	Individual avatars with facial expressions and gesture; voice chat; VR; 3D audio; motion tracking; individual social presence for all users	Including haptic feedback; high-end VR	High level of realism perfectly serving all human senses; creates an immediate immersive experience; hardly distinguishable from the physical world

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

Characteristics	**Technological maturity levels for virtual worlds by technological direction** Technological maturity levels can be read below each thumbnail on a scale of 1 to 9: TRL 1: basic principles, TRL 3: proof of concept, TRL 6: prototype, TRL 7: operational, TRL 9: operational and qualified in production
Physical and digital coexistence	
Immersion	

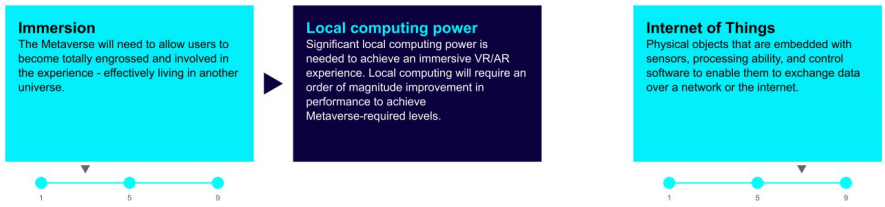
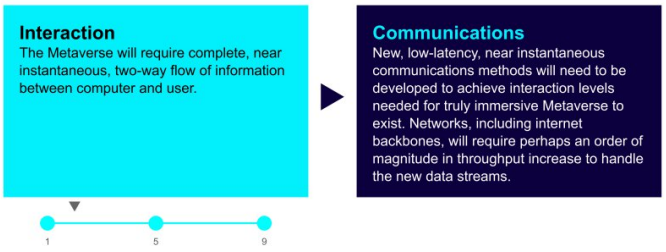
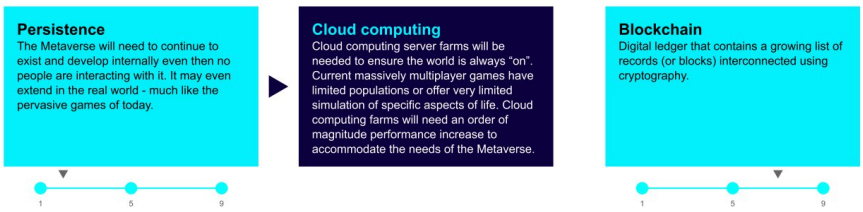
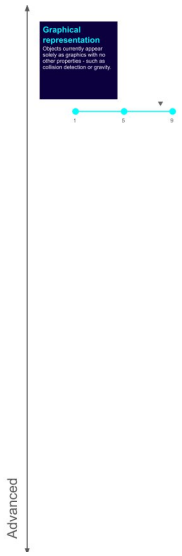
	
Simultaneity **Size** **Localisation**	
Persistence **Commercialisation**	
Virtualisation	

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.

Consumer devices VR headsets	Meta-metaverse	
	CAGR 2023-2030	Summary
Devices Production (in millions of units)	61%	Compliant from connected devices (Gartner, 2022), with hypothesis of 2-years life duration (Statista Research Department, 2023b; Wikipedia, 2024c)
Production GHG Intensity (in $kgCO_2e$/unit)	7%	VR headset, OLED, battery, integrated computing (CEPIR, 2023)
Production Energy Intensity (in kWh/unit)	7%	Same hypothesis as production GHG intensity
Connected Devices (in millions of units)	36%	By 2026, 25% of people will spend at least 1h per day in the metaverse (Gartner, 2022), hypothesis to postpone to 2030
Connected Devices Unitary Elec. Cons. (in kwh/year)	3,6%	VR headset, OLED, battery, integrated computing (CEPIR, 2023)

Consumer devices IOT	Meta-metaverse	
	CAGR 2023-2030	Summary
Devices Production (in millions of units)	24%	CAGR is 2% higher than for the Conservative scenario to model an increased need for real / virtual communication
Production GHG Intensity (in $kgCO_2e$/unit)	40% / 35%	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
Production Energy Intensity (in kWh/unit)	35%	

Connected Devices (in millions of units)	20%	CAGR is 3% higher than for the Conservative scenario to model an increased need for real / virtual communication
Connected Devices Unitary Elec. Cons. (in kwh/year)	-2%	CAGR is 3% higher than for the Conservative scenario to model the intelligence gain in the IOT modules

Consumer devices **IP cameras**	**Meta-metaverse**	
	CAGR 2023-2030	**Summary**
Devices Production (in millions of units)	28%	CAGR is 2% higher than for the Conservative scenario to model an increased need for real / virtual communication (expert advice based on (Allied Market Research, 2023))
Production GHG Intensity (in $kgCO_2e$/unit)	2%	CAGR conservative kept (expert advice based on (Allied Market Research, 2023))
Production Energy Intensity (in kWh/unit)	3%	CAGR conservative kept (expert advice based on (Allied Market Research, 2023))
Connected Devices (in millions of units)	25% / 30%	CAGR of the Conservative scenario is increased by 5% (2023-2025) and then 5% (2025-2030) to model virtual/real communication entanglement (expert advice based on (Allied Market Research, 2023))
Connected Devices Unitary Elec. Cons. (in kwh/year)	2% / 4%	CAGR of the Conservative scenario is increased by 2% (2023-2025) and then 2% (2025-2030) to model virtual/real communication entanglement (expert advice based on (Allied Market Research, 2023))

Networks and data centres	**Meta-metaverse**	
	CAGR 2023-2030	**Summary**
Traffic fixed wired (EB)	29%	By 2026, 25% of people will spend at least 1h per day in the metaverse (Gartner, 2022), hypothesis to postpone to 2030 Hypothesis : Users substitute 1h of VOD by 1h of metaverse Peak traffic speed downlink: 50 Mbps (Ericsson, 2023) Hypothesis : data allocation to fixe wired, wi-fi, mobile: 1/3, 1/3, 1/3
Traffic fixed Wi-Fi(EB)	35%	
Traffic mobile (EB)	37%	
Traffic Hyperscale (EB)	30%	Consolidation between: vision of computation power and computational efficiency increase (Intel, 2021): hypothesis to x2.5 data centre electrical consumption 2023-2030; traffic increase higher for hyperscale than edge (DatacenterDynamics, 2023; Synergy Research Group, 2023)
Traffic Others (EB)	25%	

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 **VR headsets**	Immersion	Physical and digital coexistence	Simultaneity	Localisation	Peak use	Persistence	Virtualisation et content creation	Commercialisation	Critical size required
Devices Production									x
Production GHG Intensity	x						x		

Production Energy Intensity	x						x		
Connected Devices									x
Connected Devices Unitary Elec. Cons.	x						x		
Consumer devices IOT modules and IP cameras	Immersion	Physical and digital coexistence	Simultaneity	Localisation	Peak use	Persistence	Virtualisation et content creation	Commercialisation	Critical size required
Devices Production									x
Production GHG Intensity		x					x		
Production Energy Intensity		x					x		
Connected Devices									x
Connected Devices Unitary Elec. Cons.		x					x		
Networks and data centres	Immersion	Physical and digital coexistence	Simultaneity	Localisation	Peak use	Persistence	Virtualisation et content creation	Commercialisation	Critical size required
Traffic fixed wired			x		x		x		
Traffic fixed Wi-Fi			x		x		x		
Traffic mobile			x	x	x		x		
Traffic Hyperscale						x	x	x	
Traffic Others						x	x	x	

Table 5 - Correlation between Meta-metaverse scenario parameters and technological direction (Table 1)

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

Consumer devices	**Conservative**	
VR headsets	**CAGR 2019-2025**	**CAGR 2025-2030**
Devices Production (in millions of units)	67%	30%
Connected Devices (in millions of units)	40%	11%
Smartphones	**CAGR 2019-2025**	**CAGR 2025-2030**
Devices Production (in millions of units)	3,5%	2%
Connected Devices (in millions of units)	7%	5%
Smart speakers	**Conservative, Growth**	
	CAGR 2023-2023	**CAGR 2025-2030**
Connected Devices (in millions of units)	40%	20%

Networks and data centres	**Conservative**	
	CAGR 2019-2025	**CAGR 2025-2030**
Traffic fixed wired (EB)	15%	9%
Traffic fixed Wi-Fi(EB)	31%	13%
Traffic mobile (EB)	37%	23%
Traffic fixed wired (TWh/EB)	-22%	-16%
Traffic fixed Wi-Fi(TWh/EB)	-22%	-16%

Traffic mobile (TWh/EB)	-20%	-15%
Networks and data centres	**Growth**	
	CAGR 2019-2025	**CAGR 2025-2030**
Traffic fixed wired (TWh/EB)	-22%	-18%
Traffic fixed Wi-Fi (TWh/EB)	-22%	-18%
Traffic mobile (TWh/EB)	-20%	-22%

Table 6 - Updated input data and assumptions for the Conservative and Growth scenario to support scenario building (The Shift Project, 2021)

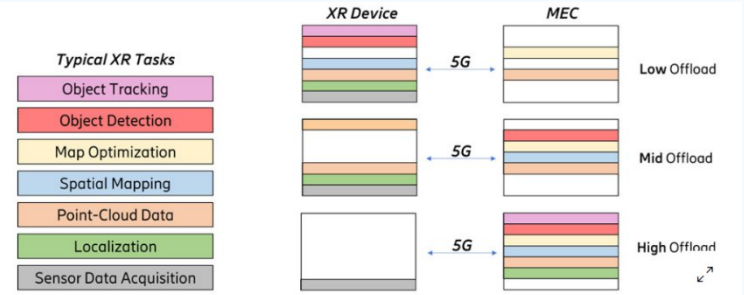
The Meta-metaverse scenario is higher than the *Business as usual* scenario among the ADEME-Arcep scenarios for 2030:

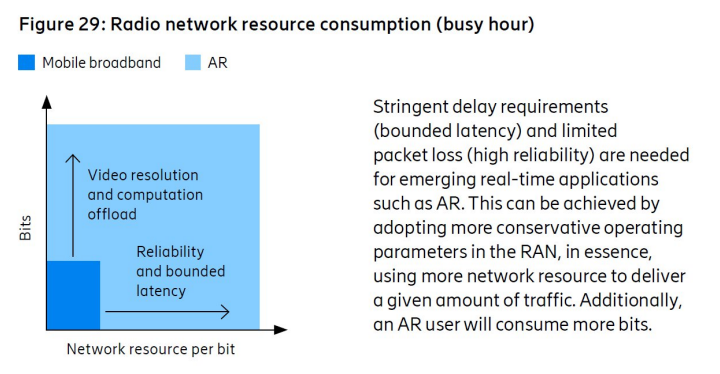
	Meta-metaverse - world	**ADEME-Arcep - France, 2030 business as usual scenario**
Consumer devices - Tier 1: VR headsets	**CAGR 2023-2030**	**CAGR 2020-2030**
Connected Devices (in millions of units)	36%	37.4% until 2025 / 9.9% then
Consumer devices - Tier 1: IOT modules		
Connected Devices (in millions of units)	20%	12%
Networks - Tier 2		
Traffic fixed wired (EB)	29%	20%
Traffic fixed Wi-Fi (EB)	35%	
Traffic mobile (EB)	37%	
Data centres - Tier 3		
Traffic Hyperscale (EB)	30%	[4%; 8%] in surface area
Traffic Others (EB)	25%	
Electricity consumption (TWh)	Hyperscale : 16%	Commercial data centers : 5.62 in 2020, 13.4 in 2030
Electricity consumption (TWh)	Others : 13%	Edge: 0 TWh in 2020, 1.62 TWh in 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:

Input data	Description
Download speeds	**Mobile augmented reality devices and edge computing:** 50 Mbps maximum traffic speed *Source: (Ericsson, 2023)* **VR streaming:** 17 Mbps; **HD VR:** 167 Mbps; **UHD VR:** 500 Mbps; **UHD cameras (security):** 16 Mbps; **Cloud gaming:** 30 Mbps *Source: (Cisco, 2020)* **Virtual reality**: 30 Mbps (for an H.264 2K encoded stream) - 800 Mbps (for an H.266 8K encoded stream) *Source: (Ericsson, 2022; GSMA, 2019)* **Augmented reality**: based on the tasks transferred to the **edge cloud** (see diagram below), 20 Mbps - 80 Mbps  Figure 3 : 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 peripherical cloud for a typical augmented reality computing task execution) Source: (Ericsson, 2022)* **Cloud gaming:** 10 Mbps (720p) à 35 Mbps (4K) *Source: (Wikipedia, 2024a)*

	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*
Upload speeds	**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*
Latency (and reliability)	**Mobile augmented reality devices and edge computing**: unit resource consumption (per bit) is 4 times higher than for high-resolution video.  Figure 29: Radio network resource consumption (busy hour) Mobile broadband AR Bits Video resolution and computation offload Reliability and bounded latency Network resource per bit Stringent delay requirements (bounded latency) and limited packet loss (high reliability) are needed for emerging real-time applications such as AR. This can be achieved by adopting more conservative operating parameters in the RAN, in essence, using more network resource to deliver a given amount of traffic. Additionally, an AR user will consume more bits. *Source: (Ericsson, 2023)* **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.

	Source: *Interview* **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] *Source*: *Interview*
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 30: AR and mobile broadband traffic and capacity evolution

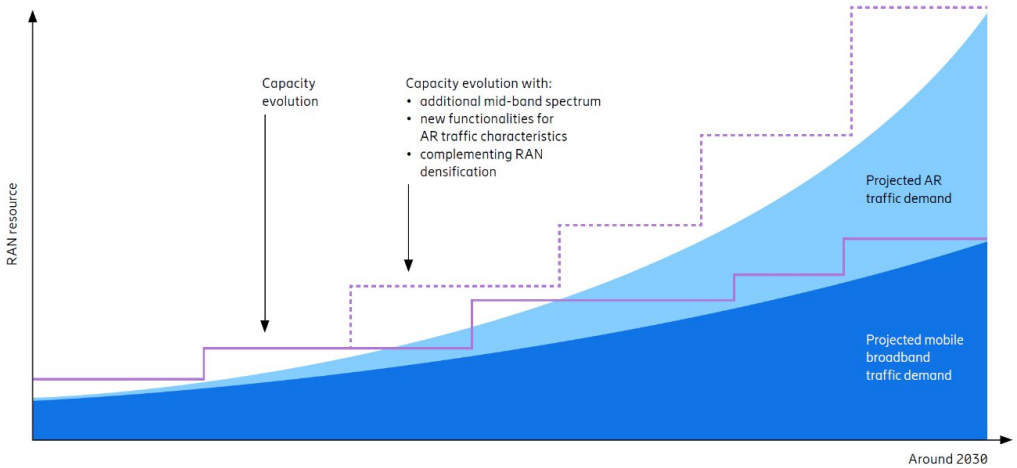


Figure 5 - Projected demand and capacity dynamics for Ericsson's mobile networks
Source: (Ericsson, 2023)

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).

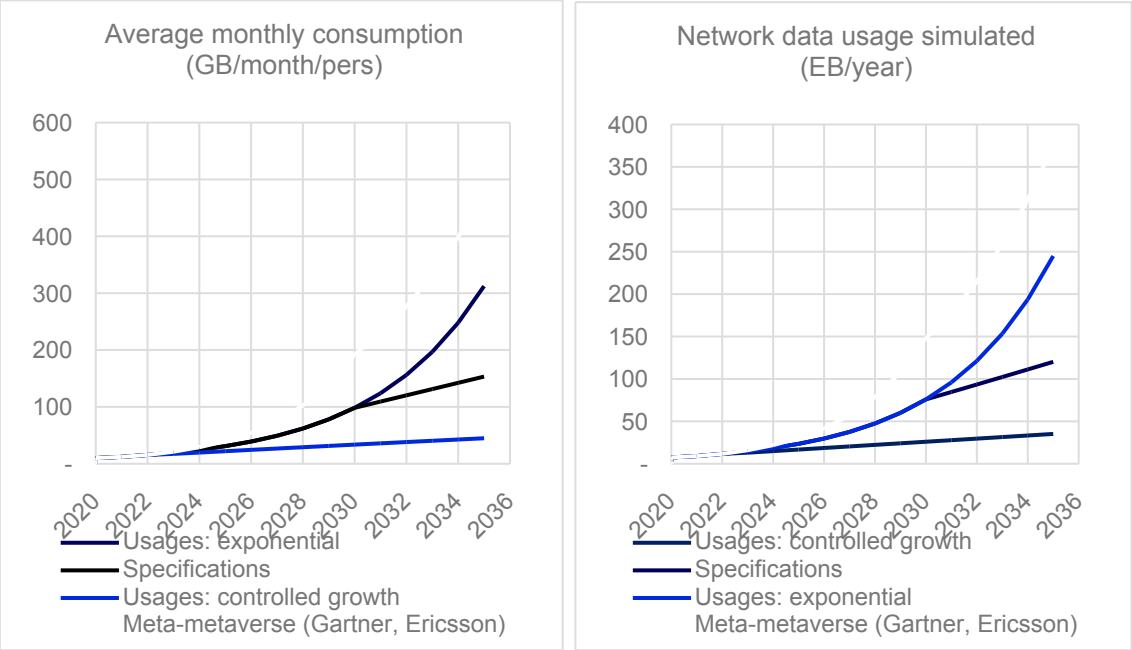


Figure 6 - Average monthly consumption (GB/month) and total network data usage (EB/year) simulated for 4 scenarios with contrasting data usage levels (GB/month)
Source: The Shift Project for the purposes of this report (Arcep, 2023; Arthur D Little, 2023)

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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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