Pollution-reducing and pollution-generating effects of the metaverse

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Highlights

- *Different metaverse applications vary in their impacts on the environment.*
- *Many consumer metaverse applications have adverse environmental impacts.*
- *Industrial metaverses have been developed to enhance environmental sustainability.*
- *Four pollution-generating mechanisms and three pollution-reducing mechanisms are discussed.*

Abstract

Different metaverse applications vary widely in terms of their carbon footprints and environmental impacts. In general, leisure and enjoyment activities of the consumer metaverse has adverse energy and environmental consequences. Many industrial metaverse applications, on the other hand, are likely to have a positive environmental impact. This editorial analyzes the current stage of development patterns and use of different metaverse applications and critically evaluates the pollution-generating and pollution-reducing effects of the metaverse.

Keywords: consumer metaverse; industrial metaverse; pollution-generating effects; pollution-reducing effects; sustainability

Introduction

A fierce debate is brewing over whether the metaverse will be an environmental sustainability disaster or if it will make the world cleaner and greener (Dwivedi et al., 2022a). One view is that the metaverse makes it possible to work, collaborate, shop, and study virtually, which would reduce physical activities such as commuting for work, leading to lower energy consumption (Fried, 2021). A study of multinational professional services company Ernst & Young found that by creating a digital twin of a building in the metaverse and incorporating machine learning (ML) and artificial intelligence (AI), it will be possible to realize up to 50% savings in energy consumption and expenditures during the building's life cycle (Yonge and Bianzino, 2022).

The opposite argument is that compared to hosting web technologies, such as an Apache web server, the metaverse requires many times higher energy and generates significantly higher carbon footprint (CEO for Life, 2022). Running the metaverse requires a vast amount of computational and processing power due to the incorporation of augmented reality (AR), virtual reality (VR), AI, blockchain, cloud computing and other emerging technologies, which can lead to high carbon dioxide (CO_2) emissions (Green Revolution Cooling, 2022). The metaverse activities thus may result in a negative environmental impact. In management consulting firm Arthur D. Little's (ADL) survey, which was conducted among banking executives in the UK, 67% of the respondents believed that the energy required to power the metaverse will have a negative impact on their carbon footprint (Bleach, 2022).

People in this camp also tend to believe that the metaverse will not make in-person office spaces, that are collaborative-focused, obsolete (Walsh, 2021). Devices such as VR headsets and software to run them are not fully developed, which would act as barriers that prevent the metaverse from replacing in-person physical interactions. For instance, in October 2022, the U.S. multinational technology conglomerate Meta (previously Facebook) had hosted hands-on press demos of Meta Quest Pro (Greenwald, 2022), which is among the most advanced VR headsets. A *Wired* article asserted that despite being more technologically advanced than ever before, Meta Quest Pro had various technical drawbacks and it failed to "make a great case for VR". The author of the article pointed out that the headset is “a great escape from reality, but a good reminder that physical presence is better” (Goode, 2022).

In order to provide insights into this complex issue, metaverse researchers have called for more research on the positive as well as negative impacts that this innovation has on the environment (Dwivedi et al., 2022ab). However, the metaverse is a rapidly evolving phenomenon and will take time to fully unfold and develop. Some even argue that a genuine metaverse platform with a broader appeal to a wide range of users does not exist yet (Mello, 2022). It is thus difficult to measure and predict the metaverse’s energy consumption with a reasonable level of accuracy. This editorial critically looks into the pollution-generating and pollution-reducing effects of the metaverse by analyzing the current stage of the development pattern and use of various types of metaverses.

Types of metaverses and their carbon footprints

Since the pollution-generating and pollution reducing effects of the metaverse vary significantly across different activities, it is important to consider the current as well as future uses of this innovation. In this editorial, following the approach suggested by President and CEO of Nokia Pekka Lundmark (Lundmark, 2022) and others, we distinguish the differences between three types of metaverses-- the consumer metaverse, the enterprise metaverse and the industrial metaverse—although some also consider the third to be a subset of the second (e.g., Lawton, 2022).

The consumer metaverse involves a three dimensional (3D) virtual world with enhanced social interactions where people can live their second lives (thalesgroup.com 2022). Individuals can engage with immersive experiences to play games and socialize (Shah, 2022). They can also shop for items such as virtual clothes to wear when joining friends for a metaverse concert

(Microsoft, 2022; wsj.com 2022). The consumer metaverse may not necessarily resemble the real world. Major payers include Fortnite, Roblox, and Minecraft (Shah, 2022).

The enterprise metaverse provides a digital environment to replicate and connect key aspect of an organization in order to optimize experiences and decision making. The experiences provided by the enterprise metaverse could include immersive 3D virtual environments (mckinsey.com, 2022). It facilitates collaboration in workplace environments (thalesgroup.com, 2022). The enterprise metaverse leverages metaverse tools and techniques and expands their usage and efficiencies to a company's internal processes (such as human resources and training) and external processes (such as customer service, product development, marketing, communications, and sales). On the external front, by reducing the gap between virtual and real-world experiences, the enterprise metaverse may help reach a global audience. The metaverse can help track consumer requirements in real time and adjust experiences to best meet the requirements (LeewayHertz, 2022). Companies can also use the enterprise metaverse to co-design products with their customers (Lundmark, 2022).

President of Bell Labs Solutions Research at Nokia, Thierry Klein has defined the industrial metaverse as follows: "The industrial metaverse combines physical-digital fusion and human augmentation for industrial applications and contains digital representations of physical industrial environments, systems, assets and spaces that people can control, communicate, and interact with" (MIT Technology Review, 2022, para 2). Applications involving digital twins and simulations are mainly considered to be components of the industrial metaverse. Some notable industries in which such applications are being implemented include manufacturing, utilities, aerospace and defense (Lawton, 2022). The industrial metaverse involves mirroring real machines, factories, buildings, cities, grids, transportation systems, supply chain and logistics processes in the virtual world to simulate the physical system and find, analyze, and fix problems quickly. More importantly, problems can also be discovered before they arise or become critical (siemens.com, nd). By connecting the physical and digital world, the industrial metaverse can play a crucial role in designing and manufacturing products and optimizing operations (King, 2022).

It is important to note that most of the investments in emerging technologies such as the metaverse are in sectors such as entertainment and games. For instance, during 2017-2021, about half of the US$31 billion invested in the metaverse went on entertainment use cases that are related to the consumer metaverse (Minevich, 2022). However, many analysts have argued that the metaverse's true transformative potential is more likely to be realized in the industrial context. Pekka Lundmark recently put the issue this way: "The real future of the metaverse is not for consumers" (Lundmark, 2022). According to the global technology intelligence firm ABI Research, the size of the industrial metaverse market will be US$100 billion by 2030. The combined estimated size of the consumer metaverse (US$50 billion) and the enterprise metaverse (US$30 billion) is expected to be smaller than the industrial metaverse by then (Lawton, 2022).

A number of industrial metaverse projects are already in operation. Some early metaverse solution developers have found that business customers are a more attractive market segment than individual consumers for their offerings. For instance, consider the 3D virtual collaboration platform Omniverse, which is a metaverse created by the U.S. technology company NVIDIA. The company reportedly expected the initial market for the Omniverse to be the content creation community such as creators of games and animation. However, the Omniverse was found to be more useful in improving industrial operation. For instance, companies can create digital twins of their physical buildings and factories in the Omniverse (Chen, 2022). By incorporating technologies such as AI, the fifth-generation (5G) standard for cellular networks, and autonomous robots, industrial digital twins in the Omniverse allow a company to represent the physical space in the virtual space with all the constraints and details of the physical system (Saracco, 2021). During NVIDIA's 2021 third quarter earnings call, the company reported that more than 700 companies were evaluating the platform (seekingalpha.com 2021).

The Omniverse is being used by companies such as Amazon, AT&T, BMW, Ericsson, Foxconn, GM, Kroger, Lowe's, Mattel, PepsiCo, manufacturing software maker Siemens, Sony, Universal Robots, and Valeo to model reality by creating digital twins to improve operations and designs (Freund, 2022). Likewise, automobile company Renault's industrial metaverse has been running for some time (Omeñaca, 2022).

Serious concerns have been raised about the negative environmental impacts of some consumer metaverse applications such as games. Especially the shift from personal gaming hardware to cloud gaming is expected to produce significant environmental costs. Such a shift is being driven by high costs of the latest gaming hardware. For instance, the price of state-of-the-art gaming computer has been in the range of a US$2,000 to US$5,000. One estimate suggests that 30 times more bandwidth is required to stream ultra-high-definition (UHD) video in VR compared to current cloud gaming techniques (Pote, 2022).

On the contrary, many industrial metaverse applications are reported to have a substantial positive impact on firms' environmental sustainability goals. The industrial metaverse can be used to create different scenarios for an entity such as a factory in order to assess their impact on energy consumption. Especially digital twins in the metaverse can be employed to simulate real-world performance scenarios in a safe environment (Hughes, 2022). For instance, Renault's industrial metaverse initiative is expected to reduce the carbon footprint of vehicle production by 50% (Just Auto, 2022). Likewise, PepsiCo hopes that its digital twins in the Omniverse will improve the efficiency and environmental sustainability of its supply chain, which consists of over 600 distribution centers in 200 regional markets (Kerris, 2022).

Pollution-reducing effects of the metaverse

A number of pollution-reducing mechanisms of the metaverse have been suggested. In this section, we discuss four mechanisms that are likely to be pivotal in the reduction of carbon footprint and pollution (Table 1). First, the metaverse can eliminate some activities that are responsible for generating pollution. Second, the metaverse can make it possible to perform an activity in a more environmentally sustainable way. Third, when more and more people spend substantial amount of time in the metaverse, they might reduce the consumption of physical products. Finally, some metaverse technologies make it possible to more accurately measure pollution generated by different activities. A more accurate measurement makes it possible to reward activities that are environmentally sustainable and penalize unsustainable practices.

Table 1: Some key mechanisms by which the metaverse can reduce pollution

Mechanism	Explanation	Example
Elimination of pollution-generating activities	The metaverse can help cut pollution-generating activities	RippleMatch’s employees are not required to commute to work. They use gather.town for teamwork and collaboration.
Reduction in pollutions generated by an activity	The metaverse can be used to create different scenarios to assess their impact on energy consumption	Digital twins helped Hellenic cut energy consumption by over 9%.
Reduction in the consumption of physical products	The metaverse can help realize the potential for significantly less materialistic consumptions.	In a survey conducted by EY, 21% of consumers expected to do more things digitally and reported their intention to buy fewer physical items in the future.
Accurate measurement of pollution generated and improvement in reward and enforcement	By accurately measuring pollution generated by an entity, reward and enforcement processes can be improved and environment friendly behaviors can be incentivized	ReSeed’s 8,723 small farm partners were reported to manage over 2 million MTs of carbon stock

Elimination of pollution-generating activities

The enterprise metaverse can help cut many pollution-generating activities such as commuting, face to face meeting and offsite work events. According to the International Energy Agency, transport accounts for about 25% of CO_2 emissions worldwide. Road vehicles such as cars, trucks, buses and motorbikes account for about 75% of CO_2 emissions that come from transport (Timperley, 2020). When technological advancements related to the metaverse make it possible to work and collaborate, this innovation can help cut everyday activities requiring transport such as commuting to work. Other pollution-generating activities such as pilots flying warplanes in military training can also be conducted in the metaverse.

Some success has already been achieved in this direction. The virtual meeting space gather.town, which mimics features of real-life interactions had more than 4 million users as of early 2021 (The Guardian, 2021). The recruitment automation platform RippleMatch's engineering product team use gather.town for teamwork and collaboration. The company's cofounder and CEO noted that the company's employees are not required to commute to work through heavy and congested traffic in Manhattan or crowded subways (Myers, 2021).

Reduction in pollutions generated by an activity

The metaverse can be used to create different scenarios for an entity such as a city, and a factory in other to assess their impact on energy consumption. Especially digital twins in the industrial metaverse can be employed to simulate real-world performance scenarios in a safe environment at a low total cost (Hughes, 2022). For instance, Microsoft has implemented industrial metaverse capabilities for Hellenic, which is among the largest Coca Cola bottlers. Hellenic has more than 55 facilities across Europe and serves 29 markets in the region. Just one Hellenic production line produces 90,000 bottles of Coca Cola products per hour. Microsoft created digital twins utilizing data from sensors, which made it possible for factory workers to become immersed in the twins. It was reported that, in a 12-week period, the factory cut energy consumption by over 9% (King, 2022).

In the NVIDIA Omniverse, which is a metaverse consisting of industrial digital twins, and autonomous robots to allow a company to represent the physical space in the virtual space with all the constraints and details (Saracco, 2021), it is possible to create digital twins of physical buildings. The digital twins allow architectures to work on different scenarios to lower energy consumption and carbon emission**.** For instance, it is possible to simulate in the virtual worlds to increase energy efficiency of air conditioning distribution. The simulations can also be used to install and place solar panels to maximize light exposure. All these can help to redesign a building so that it cool down more efficiently during the summer to save the need for air conditioning (Chen, 2022).

Cities worldwide are estimated to be responsible for about 70% of the global carbon emissions (IEA, 2021). Buildings account for significant energy consumption and hence carbon dioxide emissions. Digital twins of major cities would help to dramatically reduce this emission. Thousands of digital twins can constantly monitor energy consumption and interact with their physical twins that are interconnected. The digital twins can help to optimize electricity consumption and reduce wastage for the whole city (Sprinzen, 2022).

Reduction in the consumption of physical products

The metaverse can help realize the potential for significantly less materialistic consumptions. In a survey conducted by EY, 21% of consumers expected to do more things digitally and reported their intention to buy fewer physical items in the future (Yonge and Bianzino, 2022). Regarding the mechanisms as to how the metaverse can cut materialistic consumptions, it is increasingly evident that many consumers do not view digital lives separate from physical ones. They consider online selves to be extensions of physical selves (Wonderland, 2021).

Some even view that the metaverse will accelerate the importance of online selves, which will be viewed as more important than physical ones (Bove, 2022). A January 12, 2022, post which argued that the metaverse is a time rather than a place: “The time when our digital lives become more important than our physical lives. For many, this is already the case”. (https://www.instagram.com/p/CYou5faMbHd/) had received 70,950 likes as of October 16, 2022. Since many consumers now spend substantial time congregating in open worlds such as The Sandbox and Decentraland, walking around, meeting friends and playing games, the metaverse has seen a significant growth in spending on digital items such as clothing for avatar or other avatar accessories. For instance, in Decentraland alone, non-fungible token (NFT) wearables sales volume amounted US$750,000 in the first half of 2021 (Howcroft, 2021). The consumption of digital items is likely to have displacement effects on physical consumption.

Accurate measurement of pollution generated and improvement in reward and enforcement

By accurately measuring pollution generated by an entity, reward and enforcement processes can be improved and carbon friendly behaviors can be incentivized. While tracing carbon across the real world is complex, it is possible to trace it in the metaverse by creating fungible digital assets on blockchain. Tokenization facilitates transaction of carbon credits and create a market for carbon, where voluntary carbon credits can be freely traded. The credits may represent emissions that have been mitigated due to activities such as forestry conservation and engagement in ways to sequestrate carbon such as soil improvement and changes in land use management (Heintzman and Pappas, 2022).

To take an example, blockchain platform Reseed has created carbon assets represented by digital tokens, which it refers to as “ReSeed Carbon Protection Credits”. The Credits are awarded to blocks of farm lands that store carbon in vegetation and soil. Satellite imagery and AI are used to measure and ensure ownership of the stored and protected carbon. Prices can fluctuate on a market that is free and decentralized (Butts, 2022). ReSeed compensates farmers for reducing carbon emission. ReSeed's 8,723 small farm partners were reported to manage over two million metric tons (MTs) of carbon stock. By selling carbon protection credits, ReSeed was reported to more than double the annual income of many farmers (Cheikosman, 2022).

Pollution-generating effects of the metaverse

In this section, we analyze three categories of pollution-generating effects of the metaverse (Table 2). First, the development, use and application of various digital technologies and tools consume a significant amount of energy (Dwivedi et al., 2022c). Second, data storage, processing, and transmission for the use of the metaverse can lead to substantial emission of CO_2. Finally, e-waste from electronic products could have significant effects on the environment (Dwivedi et al., 2022c).

Table 2: Pollution-generating effects of the metaverse

Mechanism	Explanation	Example
Developing and running various technological tools	Technologies and tools such as AI and NFTs used in the metaverse could generate substantial pollution.	Training one NLP model: over 284 MTs of carbon dioxide. GPT-3 training: 552 MTs of carbon dioxide during. NVIDIA's StyleGAN3: 552 MTs of carbon dioxide
Data storage, processing, and transmission	Data storage, processing, and transmission lead to significant carbon emissions.	High-end gamers that own the hardware required for state-of-the-art VR would generate about 0.91 MT of carbon each year for the next five years. Cloud-gaming, consume larger amount of energy;
E-waste from electronic products built for the metaverse	To deliver sophisticated, high-performance experiences, new hardware products such as high-end dedicated graphics cards, VR headsets and simulation peripherals are needed, which are subject to rapid model obsolescence.	Accelerating trend of programmed obsolescence*:* a continuous cycle of metaverse gadget upgrades.

Developing and running various technologies and tools

The development of various technologies and tools to support the metaverse could generate substantial pollution. Among the technologies driving the metaverse, AI deserves mention. For instance, deep learning-based software will be used in many metaverse activities (Melendez, 2022).

A particularly useful AI-based tool is natural language processing (NLP). NLP tools such as chatbots are used to facilitate interactions. Such tools can help understand words, images, video and text and generate appropriate response (Melendez, 2022). For instance, typically handheld controllers, gestures, or eye-tracking are used to navigate VR content and control VR devices. The user needs to press buttons in VR headsets, move the joystick, or scroll up and down. NLP adds voice-based controls to VR experience. For instance, in a VR game, the player can speak into their microphone to open a doorway. Since a major goal of the Metaverse is to replicate real-world experiences with a high degree of realism, voice commands play a critical role (XR Today, 2022).

Likewise, AI can be used to generate 3D images, animation, speech and artworks used in the metaverse. AI will also be used to execute smart contracts, and to facilitate virtual transactions in decentralized ledgers and other blockchain technologies (Melendez, 2022). Similarly generative AI, which involves the utilization of existing text, audio files or images to create new content, can play crucial roles in the metaverse. Using such tools, computers detect the underlying pattern related to the input and produce similar content (Şimşek, 2021). For instance, AI research laboratory OpenAI's generative system DALL-E can create photorealistic images and artwork when descriptions are given (https://openai.com/dall-e-2/). DALL-E is viewed as a scaled-down version of the third generation Generative Pre-trained Transformer (GPT-3) (Wiggers, 2022) , which is a neural network machine learning model that has been trained using internet data. GPT-3's model involves over 175 billion ML parameters, which can be used to generate any type of text (Schmelzer, 2021).

These AI tools need to be trained using a large amount of data and modeling. Training and running various AI tools used in the metaverse thus involve substantial energy and environmental costs. For instance, training NLP models to identify highly customized, context-specific words and phrases is an energy intensive task. A 2019 study found that training just one NLP model generates over 284 MTs of CO_2 (Strubell et al., 2019). Likewise, GPT-3 was reported to use 1,287 megawatts of energy and emit 552 MTs of CO_2 during training (Wiggers, 2022). NVIDIA's StyleGAN3, which can generate portraits of people that do not exist, required 225 megawatts of energy to train, which is equivalent to the generation of 552 MTs of CO_2 (Wiggers, 2022).

Another technology that is at the center of controversy over the consumption of energy is blockchain, specially NFTs. First it should be stressed that not all metaverses involve blockchain, cryptocurrencies and NFTs (Kshetri, 2022). Those who play down the role of decentralization in the metaverse argue that 3D avatars can be created without blockchain and games can be played in closed platforms (Singer, 2022). On the other hand, user ownership of digital assets is a key aspect of decentralized metaverses. Advocates of user-controlled metaverses have envisioned that decentralized technologies based on blockchain will be the key building blocks of the metaverse economy. For instance, NFTs represent ownership of virtual in-game items, avatars, real estate properties and other assets. NFTs also enable the authentication of these assets and identities. In decentralized metaverses, cryptocurrencies play the same role that money does in the modern economy. For instance, cryptocurrencies are needed to buy NFTs such as real estate, and clothes and shoes for the avatar. Metaverse platforms such as Sandbox and Decentraland have their own cryptocurrencies.

Prior researchers have expressed major concerns with the increased power consumption associated with the use of NFTs, mainly through non-renewable sources (Dwivedi et al., 2022; Kshetri and Voas, 2022). Artist and creative technologist Memo Akten's analysis of 8000 transactions from the NFT platform SuperRare suggested that an average NFT consumes 340 KWH of energy (Storey, 2022). As a point of comparison, this amount of energy is similar to that consumed by an individual in South Sudan in 7.7 years or by an individual in high income countries in 13.7 days (The World bank 2022).

Having noted the above issues, however, it is worth emphasizing that, from the energy consumption and carbon footprint standpoints, Ethereum's replacement of its "proof of work" by "proof of stake" is among the most encouraging developments. According to the research company Crypto Carbon Ratings Institute (CCRI), this shift is expected to reduce energy consumption by 99.988%, and carbon emissions by 99.982% (Jhala, 2022). It is worth noting that Ethereum network is the most popular blockchain used in minting NFTs. As of October 2021, Ethereum generated more than 97% of sales in the NFT market (Cointelegraph Research, 2021).

Data storage, processing, and transmission

The host data centers serving the metaverse have to contain all the environments, objects and avatars that are available in the metaverse. Housing such data requires significant power usage (Carlini, 2022). In addition, a number of metaverse experiences demand low latency, which would require data processing closer to users or to the edge of networks. Some data centers thus need to move to markets where renewable energy could be difficult to procure. Also adverse operating conditions such as heat, humidity and grid intermittency may lead to efficiency loss or require carbon-intensive back-up generation (Yonge and Bianzino, 2022).

Moreover, current metaverse activities are highly energy intensive and thus make adverse effect on the environment. For instance, a study of research firm Niko Partners, which focuses on the video game industry in Asia, found that games with meta

verse elements are likely to be most profitable in the short term. The firm predicted that by 2025 cloud gaming will reach 500 million users in Asia (Astle, 2022). Data storage, processing, and transmission for gaming applications are responsible for significant energy consumption and CO_2 emissions. For example, a 2020 study estimated that high-end gamers that own the hardware required for state-of-the-art VR would generate about 0.91 MT of CO_2 each year for the next five years (Dellinger, 2020). Especially cloud-gaming, which involves graphics processing in data centers consume a large amount of energy since huge volumes of data need to be transmitted (Dellinger, 2020). The metaverse's critics thus have a valid point about the energy waste associated with the metaverse-based cloud-gaming.

In order to illustrate the concerns associated with the possible negative impact of the metaverse on the environment, we consider Meta's planned data center in the small town of Zeewolde in the Netherlands, which was approved by the town's council in December 2021 (Judge, 2021). Meta had planned to build the data center was on 410 acres of farmland in order to host a portion of the company's metaverse in Europe. The data center's expected annual energy consumption was 1,380 gigawatt-hours, or about half of the energy consumed by all the data centers in the Netherlands (Carlini, 2022).

However, state approval became necessary since some of the land is owned by the Rijksvastgoedbedrijf (the Central Government Real Estate Agency) (Moss, 2021). Due to the Dutch government's concerns over the environment, Meta was forced to halt its plans (Slater-Robins, 2022). In March 2022, the Netherlands lawmakers voted to stop any site preparation as they debated whether to sell the land (Swinhoe , 2022). In June 2022, the Dutch government decided that it would not sell the land to Meta. The Dutch cabinet also decided to block municipalities from including hyperscale data centers in a zoning plan or in an environmental plan. This decision essentially banned the development of large data centers (Moss, 2022).

A senator of the Socialistische Partij (Socialist Party), which is one of the biggest political parties in the Netherlands, argued that due to a scarcity of the existing sustainable energy, using such energy for Meta's data centers would mean less energy available for households. The senator suggested that it is important to look at the added value of such a data center. Consumer metaverse applications such as games and entertainment often lack such justification in terms of added value. For instance, the senator argued that Facebook lacks an added value to the society (Hamilton, 2022).

E-waste from electronic products built for the metaverse

The growth of the metaverse can lead to an additional hardware demand. For instance, in order to deliver sophisticated, high-performance 3D experiences in virtual worlds, high-end dedicated graphics cards are required. Many smartphones, laptops and desktop computers lack features such as graphics processing units (GPUs). In order to access the metaverse, consumers may have to upgrade to dedicated graphics cards, which are currently needed only in niche use cases such as gaming. Many existing phones and laptops will thus be obsolete and dumped in landfills. More energy will be spent in manufacturing metaverse-ready devices to replace them (CEO for Life, 2022).

The metaverse is also likely to stimulate the consumption of new categories of physical products. They include virtual reality headsets and simulation peripherals such as joystick and throttle controls, which attach magnetically to the armrests. Due to improvements in technical performance, these products are subject to rapid model obsolescence (Pote, 2022).

E-wastes associated with the metaverse should also be viewed against the backdrop of a broader trend of shortening lives of products in the technology industry and market (Slade, 2006). Due to what is referred to as built-in obsolescence, electronic products' life spans are getting shorter. A German environment agency commissioned study, which was conducted by researchers at European research and consultancy institution Öko-Institut, found that the proportion of electrical and electronic appliances that were sold to replace defective units grew from 3.5% in 2004 to 8.3% in 2012. Likewise, from 2004 to 2013, the share of large household appliances that needed to be replaced within the first five years of use grew from 7% to 13% of total replacements. This was due to an increase in the proportion of recently purchased appliances that needed to be replaced following a defect. All these point to an obsolescence problem (Al-Kurikka, 2015).

Observes have noted an accelerating trend of programmed obsolescence for electronic products. An upshot is that, when some parts break, it is often cheaper to buy a new one than to repair the existing product. Not long ago, it was easier to disassemble many electronic devices and repaired them more easily than today. For instance, if the battery of a smartphone failed, consumers themselves could buy a battery and replace the old one. An average user cannot open cell phones today (Youth Press Agency, 2021). To put things in context, the metaverse's systems are also likely to develop over time since metaverse providers may compete by giving better 3D experiences. Analysts have expressed concerns that this will lead to a continuous cycle of metaverse gadget upgrades (CEO for Life, 2022). The metaverse is thus likely to contribute to significant e-wastes.

Research agenda

The above discussion raises many important questions which should be examined in future research. As noted above, companies such as Renault and PepsiCo expect to achieve substantial energy savings from the adoption of the industrial metaverse (Just Auto, 2022; Kerris, 2022). Prior research has noted that the energy usage pattern and energy saving potential vary across industries due to their diversities in factors such as scale of production, the nature of raw materials used, process technologies employed, and type of product output (Bhattacharya and Kapoor, 2012). Firms in different industries thus may differ in terms of the pollution-reducing effects of the industrial metaverse. In future empirical work, scholars need to compare and contrast firms in various industries such as automotive, manufacturing and retail in terms of the industrial metaverse's impact on energy saving.

As discussed above, an environmental concern is that new hardware products required for the consumer metaverse and the trend of a rapid model obsolescence may result in significant e-waste. However, traditional media and non-metaverse activities such as TV and the Internet have also become significant e-waste producers. For instance, one estimate suggested that, in 2014, per capita electrical and electronic equipment sales and per capita e-waste generation were 35 kg and 25 kg respectively for Australia (Golev et al., 2016). It can be argued that the consumer metaverse would have a replacement effect on the generation of e-wastes. For instance, the target demographics for the metaverse are reported to be watching less TV (Saponaro, 2022). This means that more time in the metaverse is likely to result in reduced e-wastes associated with TV hardware parts such as boards, bulbs, and power supplies. It is not clear whether metaverse activities produce more or less e-waste than traditional media and non-metaverse activities. Thus, further inquiry is needed to investigate the net effect of the metaverse on e-waste generation.

As we have noted above, some companies have adopted the enterprise metaverse for teamwork and collaboration activities, which is likely to cut greenhouse gas emissions with less commute time. For instance, RippleMatch's engineering product team uses gather.town for such activities. The motivation behind this move, as noted by the company's cofounder and CEO, is to cut commuting time in Manhattan's heavy and congested traffic (Myers, 2021). However, not all firms are equally open to the idea of using the metaverse for teamwork and collaboration activities instead of being physically present in the office. Anecdotes have long suggested that some companies prefer employees to be physically present in the office. For instance, in the U.S., companies such as AT&T, JPMorgan and Tesla have forced their employees to return to the office as early as possible (Marks, 2022). A relevant question is thus: why do firms differ in their orientation towards using collaborative tools such as the metaverse? A valuable lead into this question is provided by O'Neil et al. (1998), who suggested that characteristics of an organization affect the adoption of a technology or a strategy. In this regard, a third area of future research concerns the characteristics of firms such as their location, size, industrial sector, labor skills and technological innovation that are likely to affect the adoption of the metaverse in functions and areas that are likely to have pollution-reducing effects such as teamwork and collaboration.

Finally, future researchers could study pollution-reducing and pollution-generating effects of technologies that are currently being researched and developed but have not yet been used in the metaverse. Of particular interest in the context of this editorial is the sixth generation (*6G*) mobile system standard, which is referred to as a platform for the metaverse (Jones, 2022). 6G is currently under development, which is expected to expand the framework of cellular standards to use extended reality (XR) in business and gaming environments (Jones, 2022). More importantly, 6G is expected to be more energy-efficient than current cellular networks and thus sustainability is expected to become a major component of this future cellular standard (Holma and Harish, 2022). Researchers at Nokia Bell Labs believe that 6G will cut the average power consumption by half compared to 5G and support peak capacities 10 times higher. It is envisioned that a 6G radio access network (RAN) consumes no electricity if no users are connected to the network. At any capacity level, the 6G network is expected to support a given number of users or capacity at a significantly lower power than 5G. Telecommunications companies are directing efforts towards lowering the baseline power requirements of the network at all times irrespective of the number of users connected to the network. AI is expected to dynamically match energy consumption with traffic load (Holma and Harish, 2022). A comparison of the use of the 5G and the 6G mobile system standards in the metaverse with respect to their effects on environmental sustainability might thus be worthwhile target of study.

Concluding comments

In this editorial, we discussed the metaverse's pollution-reducing, as well as energy consumption reducing effects. It is not clear which effect would dominate in the long run. The explanations offered in this article shed some light on the current debate by analyzing both types of effects.

Currently the metaverse is being mainly used for leisure and enjoyment activities such as games and entertainment rather than for economically more productive purposes such as teamwork and collaborative activities. The metaverse's applications in leisure and enjoyment are likely to have a negative effect on environmental sustainability. For instance, there is a possibility that the metaverse stimulates the demand of new graphics technology in consumer devices. However, on the plus side virtual products and experiences used in such activities may replace physical products.

However, when the metaverse advances, it is likely to facilitate useful work-related interactions, which can eliminate pollution-generating activities such as work-related commutes and nonleisure rides. Companies can also leverage technologies, such as VR, the Internet of things (IoT), cloud, and digital twins to virtualize entire production processes, which can help to measure and control energy consumption.

References

Al-Kurikka, S. (2015) Lifespan of consumer electronics is getting shorter, study finds, The Guardian. Guardian News and Media. Available at: https://www.theguardian.com/environment/2015/mar/03/lifespan-of-consumer-electronics-is-getting-shorter-study-finds.

Astle, A. (2022) Niko partners: Games with metaverse elements will be most profitable short term, pocketgamer.biz. Available at: https://www.pocketgamer.biz/asia/news/79713/niko-partners-games-with-metaverse-elements-will-be-most-profitable-in-the-short-term/Bhattacharya, T. and Kapoor, R. 2012. Energy Saving Instrument—ESCerts in India, Renewable and Sustainable Energy Reviews, Vol. 16, No. 2, 2012, pp. 1311-1316. http://dx.doi.org/10.1016/j.rser.2011.10.007

Bleach, T. (2022) Banks jump into the metaverse but concerns over environmental impact linger, The Fintech Times. Available at: https://thefintechtimes.com/banks-jump-into-the-metaverse-but-concerns-over-environmental-impact-linger/.

Bove, T. (2022) This metaverse theory will keep you up at night, Fortune. Fortune. Available at: https://fortune.com/2022/01/13/metaverse-theory-digital-identity/.

Butts, D. (2022) World Economic Forum Launches Coalition to use web3, blockchain for positive climate action, *Forkast*. Available at: https://forkast.news/world-economic-forum-launches-coalition-to-use-web3-blockchain-for-positive-climate-action/.

Carlini, Steven (2022). How Edge Computing Will Power The Metaverse, May 18, https://www.forbes.com/sites/forbestechcouncil/2022/05/18/how-edge-computing-will-power-the-metaverse/?sh=566b3e2d630d

CEO for Life (2022) Will the metaverse help or hinder sustainability?, https://www.ceoforlifeawards.com/blog/will-the-metaverse-help-or-hinder-sustainability/.

Cheikosman, E. (2022) Web3 tech can be used to fight climate change. here's how, World Economic Forum. Available at: https://www.weforum.org/agenda/2022/09/regenerative-finance-web3-climate-change/.

Chen, A. (2022) How "green" is the metaverse? the two sides of the environmental impact of the metaverse, *Medium*. Geek Culture. Available at: https://medium.com/geekculture/how-green-is-the-metaverse-the-two-sides-of-the-environmental-impact-of-the-metaverse-6a35913fd329.

Cointelegraph Research (2021). Blockchains vie for NFT market, but Ethereum still dominates — Report, https://cointelegraph.com/news/blockchains-vie-for-nft-market-but-ethereum-still-dominates-report

Dellinger, A.J. (2020) The Unseen Environmental Cost of gaming. Mic. Available at: https://www.mic.com/impact/gamings-environmental-impact-is-bigger-than-you-think-21753800.

Dwivedi, Y. K., Hughes, L., Baabdullah, A. M., Ribeiro-Navarrete, S., Giannakis, M., Al-Debei, M. M., ... & Wamba, S. F. Dwivedi, Y. ….. et al. (2022a). Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy, International Journal of Information Management, Volume 66, October 2022, 102542, https://www.sciencedirect.com/science/article/pii/S0268401222000767

Dwivedi, Y. K., Hughes, L., Kar, A. K., Baabdullah, A. M., Grover, P., Abbas, R., ... & Wade, M. (2022c). Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action. International Journal of Information Management, 63, 102456.

Dwivedi, Y. K., Hughes, L., Wang, Y., Alalwan, A. A., Ahn, S. J., Balakrishnan, J., ... & Wirtz, J. (2022b). Metaverse marketing: How the metaverse will shape the future of consumer research and practice. Psychology & Marketing, doi: https://doi.org/10.1002/mar.21767

Freund, K. (2022) Nvidia Omniverse: The useful metaverse, Forbes. Forbes Magazine. Available at: Oct 7, 2022, https://www.forbes.com/sites/karlfreund/2022/10/07/nvidia-omniverse-the-useful-metaverse/?sh=52260837359a.

Fried, I. (2021) Facebook unveils "Metaverse" app that seeks to move work meetings to VR, *Axios*. Available at: https://www.axios.com/2021/08/19/facebook-vr-zuckerberg-meetings.

Golev, A., Schmeda-Lopez, D.R., Smart, S.K., Corder, G.D. and McFarland E.W. (2016). Where next on e-waste in Australia? Waste Management, 58, 348–358. https://doi.org/10.1016/j.wasman.2016.09.025

Goode, L. (2022) The bizarre duality of Meta's new quest pro VR headset, Wired. Conde Nast. Available at: https://www.wired.com/story/meta-quest-pro-vr-headset/.

Green Revolution Cooling, (2022) Metaverse: Is it a growing threat to the environment? Available at: https://www.grcooling.com/blog/metaverse-growing-threat-environment/.

Greenwald, W. (2022) Project Cambria Hands On: Take a first look at the meta quest pro VR headset, PCMag Middle East. Available at: https://me.pcmag.com/en/vr/13870/project-cambria-hands-on-take-a-first-look-at-the-meta-quest-pro-vr-headset

Hamilton, T.B. (2022) In a small Dutch town, a fight with Meta over a massive data center, *The Washington Post*. WP Company. Available at: https://www.washingtonpost.com/climate-environment/2022/05/28/meta-data-center-zeewolde-netherlands/

Heintzman, D. and Pappas, A. (2022) The metaverse and the carbon economy, IT World Canada - Information Technology news on products, services and issues for CIOs, IT managers and network admins. Available at: https://www.itworldcanada.com/blog/the-metaverse-and-the-carbon-economy/486874

Holma, Harri and Viswanathan, Harish 2022 " In the 6G era, we won't need to sacrifice sustainability for the sake of performance" 1 November, https://www.bell-labs.com/institute/blog/in-the-6g-era-we-wont-need-to-sacrifice-sustainability-for-the-sake-of-performance/#gref

Howcroft, E. (2021) Crypto fashion: Why people pay real money for virtual clothes, *Reuters*. Thomson Reuters. Available at: https://www.reuters.com/business/finance/crypto-fashion-why-people-pay-real-money-virtual-clothes-2021-08-12/.

Hughes, O. (2022) Bored of office life? here's how the metaverse could transform your future job, *ZDNET*. Available at: https://www.zdnet.com/article/bored-of-office-life-heres-how-the-metaverse-could-transform-your-future-job/.

IEA, (2021). Empowering Cities for a Net Zero Future Unlocking resilient, smart, sustainable urban energy systems, July 2021, https://www.iea.org/reports/empowering-cities-for-a-net-zero-future

Jhala, K. (2022) Ethereum, the NFT market's blockchain of choice, cuts its CO2 output by 99%, The Art Newspaper - International art news and events. The Art Newspaper - International art news and events. Available at: https://www.theartnewspaper.com/2022/09/15/nft-blockchain-ethereum-cuts-climate-impact.

Jones, Dan 2022 "It's About Time to Begin Foundational 6G Research " -12-02 https://www.eetasia.com/its-about-time-to-begin-foundational-6g-research/

Judge, P. (2021) Zeewolde approves Meta/Facebook to build Netherlands' largest data center Small d1tch village to get country's biggest facility December 17, https://www.datacenterdynamics.com/en/news/zeewolde-approves-metafacebook-to-build-netherlands-largest-data-center/

Just Auto (2022) Renault claims First 'industrial metaverse' Available at: https://www.just-auto.com/news/renault-claims-first-industrial-metaverse/.

Kerris, R. (2022) Nvidia Omniverse Ecosystem expands 10x, amid new features and services for developers, enterprises and creators, NVIDIA Blog. Available at: https://blogs.nvidia.com/blog/2022/03/22/omniverse-ecosystem-expands/.

King, J. (2022) Microsoft touts industrial metaverse as innovation, Sustainability Tool, Sdx Central. Available at: https://www.sdxcentral.com/articles/news/microsoft-touts-industrial-metaverse-as-innovation-sustainability-tool/2022/10/.

Kshetri, Nir (2022) "A Typology of Metaverses,", IEEE Computer 55(12), 150-155

Kshetri, Nir and Voas, J. (2022)." Blockchain's Carbon and Environmental Footprints" IEEE *Computer* 55(6): 89 – 94

Lawton, G. (2022) "Why the industrial metaverse will eclipse the consumer one", December 23, 2022 https://venturebeat.com/virtual/why-the-industrial-metaverse-will-eclipse-the-consumer-one/

Lundmark, P. (2022) The real future of the metaverse is not for consumers, November 23, https://www.ft.com/content/af0c9de8-d36e-485b-9db5-5ee1e57716cb

Marks, Gene 2022. Is the work-from-home debate already over?, 28 Aug https://www.theguardian.com/business/2022/aug/28/remote-work-home-office-debate-pandemic

Melendez, Carlos (2022) The Metaverse: Driven By AI, Along With The Old Fashioned Kind Of Intelligence, April 18, https://www.forbes.com/sites/forbestechcouncil/2022/04/18/the-metaverse-driven-by-ai-along-with-the-old-fashioned-kind-of-intelligence/?sh=3202beb51b36

Mello, John P. Jr. (2022). Metaverse Maybe a Moneymaker for Enterprises by 2027, October 20, https://www.technewsworld.com/story/metaverse-maybe-a-moneymaker-for-enterprises-by-2027-177277.html

Microsoft (2022), What the metaverse means for retail and consumer goods 10 November https://powerretail.com.au/sponsored-post/what-the-metaverse-means-for-retail-and-consumer-goods/

Minevich, Mark (2022) Technology may solve climate change problems, but it's also causing them, VentureBeat. Available at: https://venturebeat.com/datadecisionmakers/technology-may-solve-climate-change-problems-but-its-also-causing-them/.

MIT Technology Review (2022). The Industrial Metaverse: A Game-Changer For Operational Technology: How enterprises can unlock the full potential of the industrial metaverse. https://www.technologyreview.com/2022/12/05/1063828/the-industrial-metaverse-a-game-changer-for-operational-technology/

Moss, Sebastian (2021), Dutch Senate stymies huge Meta data center in Zeewolde by blocking Government land sale to Facebook: Calls for a new national strategy for data centers, December 22, https://www.datacenterdynamics.com/en/news/dutch-senate-stymies-huge-meta-data-center-in-zeewolde-by-blocking-government-land-sale-to-facebook/

Moss, Sebastian, (2022). Dutch government won't sell Zeewolde land to Meta, hyperscale data center development moratorium moves forward**:** Draft decision would ban large data centers outside of two regions, June 13, https://www.datacenterdynamics.com/en/news/dutch-government-wont-sell-zeewolde-land-to-meta-hyperscale-data-center-development-moratorium-moves-forward/

Myers, A. (2021) Learning how to lead a remote workforce - fast company, As a leader, I resisted remote work. Here’s how I flipped the script. Available at: https://www.fastcompany.com/90703425/as-a-leader-i-resisted-remote-work-heres-how-i-flipped-the-script.

O’Neil, Hugh M., Pouder, Richard W. and Buchholtz, Ann K. (1998). Patterns in the Diffusion of Strategies Across Organizations: Insights from Innovation Diffusion Literature, The Academy of Management Review 23(1), 98–114.

Omeñaca, J.L. (2022) Renault group Lanza El Primer Metaverse Industrial Que Generará Ahorros de 320 millones para 2025, Valenciacars. Available at: https://valenciacars.blogspot.com/2022/11/renault-group-metaverse-industrial.html.

Pote, B. (2022) Metaverse: Video game studios warn of environmental impact, Available at: https://bonpote.com/en/metaverse-video-game-studios-warn-of-environmental-impact/.

Saponaro, Nick 2022 How Brands Can Become Masters of the Metaverse June 16 https://www.nasdaq.com/articles/how-brands-can-become-masters-of-the-metaverse

Saracco, R. (2021) Metaverse vs omniverse, *IEEE Future Directions*. Available at: https://cmte.ieee.org/futuredirections/2021/11/16/metaverse-vs-omniverse/.

Schmelzer, R. (2021) What is GPT-3? everything you need to know, SearchEnterpriseAI. TechTarget. Available at: https://www.techtarget.com/searchenterpriseai/definition/GPT-3.

seekingalpha.com (2021). Nvidia: Lord of The Metaverse, December. 08, https://seekingalpha.com/article/4474215-nvidia-nvda-stock-lord-of-the-metaverse

Shah, A. (2022). What's the Difference Between the Enterprise and Consumer Metaverses? July 15, https://www.electronicdesign.com/markets/automotive/article/21246629/duality-robotics-whats-the-difference-between-the-enterprise-and-consumer-metaverses

siemens.com (nd) What is the industrial metaverse – and why should I care? Available at: https://new.siemens.com/global/en/company/insights/what-is-the-industrial-metaverse-and-why-should-i-care.html

Şimşek, H. (2021) A complete guide to generative AI in 2022, *AIMultiple*. Available at: https://research.aimultiple.com/generative-ai/.

Singer, A. (2022) "Does the Metaverse need blockchain to ensure widespread adoption?", July 4, https://cointelegraph.com/news/does-the-metaverse-need-blockchain-to-ensure-widespread-adoption

Slade, Giles (2006). *Made to break : technology and obsolescence in America*, Harvard University Press, Cambridge, Mass., 2006

Slater-Robins, M. (2022) Meta halts plans for Mega New Data Center after local backlash, *TechRadar*. TechRadar pro. Available at: https://www.techradar.com/news/meta-halts-plans-for-mega-new-data-center-after-local-backlash.

Sprinzen, Marty. (2022).The Metaverse: Saving The World Or Another Digital Distraction?, March 31, https://www.forbes.com/sites/forbestechcouncil/2022/03/31/the-metaverse-saving-the-world-or-another-digital-distraction/?sh=11c29a3f38c8

Storey, Andy. (2022). How Much Energy does it Take to Make an NFT?, January 11, https://postergrind.com/how-much-energy-does-it-take-to-make-an-nft/

Strubell, E, A Ganesh and A McCallum (2019) "Energy and policy considerations for deep learning in NLP", arXiv preprint arXiv:1906.02243.

Swinhoe , D. (2022). Dutch Senate votes for motion to prevent further site works at Meta's Zeewolde data center Lawmakers want site prep stopped while government negotiates land sale March 23, https://www.datacenterdynamics.com/en/news/dutch-senate-votes-for-motion-to-prevent-further-site-works-at-metas-zeewolde-data-center/

thalesgroup.com (2022). Building A Metaverse We Can All Trust, 23 November 2022, https://www.thalesgroup.com/en/group/innovation/news/building-metaverse-we-can-all-trust

The Guardian. (2021) Can virtual meeting spaces save us all from zoom fatigue? Guardian News and Media. Available at: https://www.theguardian.com/technology/2021/may/08/work-can-virtual-meeting-spaces-save-us-all-from-zoom-fatigue.

The World bank (2022). Electric power consumption (kWh per capita), https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC.

Timperley, J. (2020) How our daily travel harms the planet, *BBC Future*. Available at: https://www.bbc.com/future/article/20200317-climate-change-cut-carbon-emissions-from-your-commute

Walsh, B. (2021) Bad commutes make us more likely to want to work virtually, *Axios*. Available at: https://www.axios.com/2021/08/21/remote-work-vr-facebook.

Wiggers, K. (2022) The environmental impact of the metaverse, VentureBeat. Available at: https://venturebeat.com/data-infrastructure/the-environmental-impact-of-the-metaverse/.

Wonderland. (2021) Ashwini Deshpande talks digital dressing with Difference Makers, Available at: https://www.wonderlandmagazine.com/2021/12/21/ashwini-deshpande-interview/.

wsj.com (2022). "What Consumers Think About the Metaverse", August. 24, https://deloitte.wsj.com/articles/what-consumers-think-about-the-metaverse-01661361526

XR Today (2022) What Is Natural Language Processing (NLP)?, March 23, https://www.xrtoday.com/virtual-reality/what-is-natural-language-processing-nlp/

Yonge, J.M.de and Bianzino, N.M. (2022) Metaverse: Could creating a virtual world build a more sustainable one?, Metaverse: could creating a virtual world build a more sustainable one? | EY Sweden. EY. Available at: https://www.ey.com/en_se/digital/metaverse-could-creating-a-virtual-world-build-a-more-sustainable-one.

Youth Press Agency (2021) Programmed obsolescence: The ever shorter life of our devices, Available at: http://youthpressagency.org/programmed-obsolescence-the-ever-shorter-life-of-our-devices/.