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A Comprehensive Review on Environmental Impact and Challenges of Industrial Metaverse

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# Declaration

This thesis is composed of our original work and contains no material previously published or written by another person except where due reference has been made in the text. We have clearly stated the contribution of others to our thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial and any other original research work used or reported in our thesis. The content of our thesis is the result of work we have carried out since the commencement of the Thesis.

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# Approval

The thesis titled **“**A Comprehensive Review on Environmental Impact and Challenges of Industrial Metaverse**”** has been submitted to the following respected members of   
the board of examiners of the department of computer science in partial fulfilment of the requirements for the degree of Bachelor of Science in Computer Science and Engineering on 26 September 2024and has been accepted as satisfactory.

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# Author Contributions

List the significant and substantial inputs made by different authors to this research, work and writing represented and/or reported in the thesis. These could include significant contributions to the conception and design of the project; non-routine technical work; analysis and interpretation of research data; drafting significant parts of the work or critically revising it to contribute to the interpretation.

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# Project-Thesis Planning

Table 1: Project-Thesis Deliverables

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| --- | --- | --- |
| **Project Tasks** | **Schedule Data** | **Execution Data** |
| 1. Planning | 2024.01.23 - 2024.01.30 | 2024.01.23- 2024.01.30 |
| 1. Literature Review | 2024.01.30 – 2024.03.20 | 2024.01.30 – 2024.03.20 |
| 1. Selecting Literature Review | 2024.03.20 – 2024.04.20 | 2024.03.20 – 2024.05.20 |
| 1. Writing thesis report | 2024.04.15 - 2024.05.20 | 2024.05.15 - 2024.06.20 |
| 1. Submission and review | 2024.05.21- 2024.07.02 | 2024.06.23 - 2024.07.10 |

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Description automatically generated with medium confidence

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# List of Abbreviations

|  |  |
| --- | --- |
| CS | Computer Science |
| CSE | Computer Science and Engineering |
| HCI | Human Computer Interaction |
| NLP | Natural Language Processing |
| IM | Industrial Metaverse |
| VR | Virtual Reality |
| AR | Augmented Reality |
| IoT | Internet of Things |
| AI | Artificial intelligence |
| XR | Extended reality |
| ICT | Information and Communication Technology |
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# Abstract

The industrial metaverse is a digitally expanded space for both the physical, industrial world and intangible digital universe converge. Its call is to create digital duplicates also known as digital twins of physical entities such as factories, production lines, supply networks, cities and even whole industries. These digital replicates enable real-time collaboration, connectivity and location positioning within industrial environments. The industrial Metaverse has the potential to significantly increase resource efficiency and sustainability. By putting tools such as digital twins, artificial intelligence, and extended reality to work, the industrial metaverse pursues both efficiency in, and of engineering, manufacturing and field services. Imagine a powerful interface that mirrors and simulates real machines, factories, transportation networks, and other complex systems, enabling businesses to model, prototype, and test design iterations in an immersive, physics-based environment before committing resources to projects. Only when everything had been modeled and tested was hypothetical expanded into timely, predictable services at cost. It is a bridge between the physical and the digital realms with a promise to be resource efficient and promote sustainability.

There is a growing concern over the environmental impact of the metaverse. Some analysts also worry that the metaverse could lead to more greenhouse gas emissions. While there are positive aspects, such as potentially reducing travel and pollution, there are downsides as well. Its technological inputs, such as virtual reality and AI training functions, require considerable amounts of energy. Without sustainable AI practices, it is predicted that by the year 2025, AI alone will consume more energy than all of mankind put together and thereby greatly offsetting their carbon-zero accomplishments. As the metaverse continues to expand and develop, firms will have to put environmentally friendly thinking at the forefront. They will have to think up innovative solutions for reconciling the obligation of environmental stewardship with technological development. A recent study suggests that by 2050 the metaverse industry could play a significant role in fighting global warming. It could contribute to emissions-reductions, cut atmospheric carbon dioxide concentration levels and lower energy use. These three factors must be balanced, as the metaverse goes on evolving. However, there has never been a key study on the extent to which this substitution might offset environmental worries. Thus, a knowledge gap remains about concrete effects of digital substitutes on the environment. The aim of this paper is therefore to present a comprehensive analysis of industrial metaverse and investigate its environmental impact.

There is a stipulated methodology in the field. It is to conduct a rigorous literature survey in order obtain the present situation in research of industrial metaverse. This work required analyzing academic papers, industry reports and business cases on metaverse technologies, applications and environmental impacts from various sources and databases. For this comprehensive review, sources include web science, ACM Library, IEEE Library and Google Scholar. Altogether, a thorough understanding of the advancement of today's industrial metaverse is obtained. We begin by examining the architectural structure and technologies of the industrial metaverse to clarify this concept, its enabling technologies. We then look at industrial applications for the metaverse. We also discuss how the industrial metaverse affects the environment. Finally, we identify upcoming research challenges, emphasizing the industrial metaverse's reliance on a robust data fabric. Research indicates today that the Industrial Metaverse is environmentally beneficial overall, with some negative aspects arising from its development. The results point to the Industrial Metaverse as having both positive and negative environmental effects by energy consumption, e-waste, and pollution. In general, however, it suggests that most industrial metaverse applications have a positive environmental impact as well as a subsequent trend towards sustainability. To achieve this sustainability in the industrial metaverse, businesses should think of using cloud services and renewable energy sources. Also, it will involve looking at the environment effects of products together with a circular economy.

# Keywords

Metaverse, environment, environmental impact

# Chapter 1

# Introduction

# **Background Analysis**

In 2021, Meta's rebranding brought attention for the term ‘metaverse’ into the spotlight. However, the underlying concept is not related to this and predates the existence of Facebook itself. The term 'metaverse' was first coined in 1992 by science-fiction novel ‘Snow Crash’, a combination of 'meta' and 'universe' – suggesting a realm beyond our physical world. Second Life was an early virtual world platform where digital avatars could be created Nearly two decades ago. Now an online network has emerged to enable users to explore and navigate virtual 3D spaces.

The metaverse lacks a universal definition, as its evolution remains uncertain. The industrial metaverse involves integrating advanced digital technologies into industrial processes, creating an immersive, interconnected virtual space. Combining elements from traditional metaverse concepts with industry-specific tech, it enables real-time data exchange, simulation, and collaboration across industrial stages. This evolution promises to transform production, maintenance, and business processes. Users interact in this meta-universe, creating content, applications, and businesses. Meta sees it as a successor to mobile internet, while Microsoft and others focus on enterprise offerings and gaming. The metaverse, according to thought leader Matthew Ball, is a massive, interoperable network of real-time, three-dimensional virtual worlds that can be accessed by an infinite number of users. Each user can have their own unique presence and continuous data, including identity, history, entitlements, objects, conversations, and payments.[1]’’

In this world of metaverse digital twins is becoming a digital virtual replication of physical things. Buildings, vehicles and even cities have their identical twin on the web. These replicas are made from data coming off IoT devices and sensors, and by other means. The metaverse virtualization of physical entities allows these digital models to be monitored, simulated and optimized in real time by their real-world peers. In experimental and theoretical science, technology and practical application, digital twins can save a huge amount of time on the production. In practical applications, digital twins in science and technology can significantly reduce production time, assist in final product preparation, enhance retail market modeling for attracting more customers, and contribute to climate prediction and various business fields.

Digital twins offer numerous advantages in monitoring systems to greatly improve efficiency through immediate diagnostics. Predictive maintenance is a prime capability, allowing forecasts of problems before critical impacts and minimization of downtimes. Simulations and tests can be run virtually too, analyzing scenarios without physically affecting the asset. However, digital twin architectures present difficulties. Installation and continuing support demand sophisticated solutions and cutting-edge tools which carry high price tags initially and over the long run. Additionally, the huge datasets are at risk, vulnerable to cyber threats aiming to do harm with the abundant information. While digital twins have clear benefits, such as helping boost uptime and optimize function, organizations must carefully weigh potentially large costs and security when incorporating these virtual representations into various operations.

The growing metaverse is divided into three distinct industries: Virtual Reality (VR) and Augmented Reality (AR), Blockchain and Decentralized Technology and Content Creation and Social Platforms. VR creates immersive environments where people are completely immersed in—a world where users can use their VR headsets and hand controllers to move through it. These environments might also take the form of athletic simulations, educational pieces or even social spaces where people gather to chat and joke with one another. AR overlays the real world with digital content through devices like smartphones, tablets and AR glasses. With this technology, you can enhance your physical surroundings using interactive elements: graphics, data of any kind, other digital information that gets put in there as it happens. Blockchain technology underlies the entire decentralized metaverse. It ensures transparency, security and immutability of digital transactions and assets. NFTs represent the ownership of unique digital items, such as art collectibles, virtual real estate and in-game assets. They are traded and verified on blockchain networks. Cryptocurrencies are used as the medium of exchange in the metaverse: necessary to establish economies of production and transaction within virtual worlds where goods can be exchanged using these currencies. The Content Creation industry entails the development of digital assets, environments and experiences. This includes tools and platforms for creating 3D models, animations, virtual worlds and interactive content. Social Platforms provide a place for social interaction within the metaverses. They are spaces where people connect, communicate, cooperate and share their experiences in this virtual environment. Some examples might include virtual worlds or gaming communities (MMOs), something fun and decentralized with a lot of users like Bitlanders, projectors like Microsoft's IllumiRoom, social VR software such as AltSpace and something old school but revived again recently: ironic extended memes that people can actually enter and share experiences with live on the internet. These industries are interconnected, contributing to the overall growth and development of the metaverse and opening up new opportunities for entertainment, work, social interaction and trade.

Employing virtual and augmented reality (VR/AR) to create an environment in the metaverse offers people a whole new way of experiencing, communicating and encountering digital content. Virtual Reality (VR), on the other hand, constructs a fully immersive digital world. Users are thrown into entirely digital communities where they can explore and interact just as anyone would in the physical environment. This is done thanks to the hardware and software. Wearing VR headsets that have their own screens as well as motion sensors following head movements, users can see in a complete 360-degree view how they fit into this virtual environment around them. The software generates and updates the virtual world in real-time, responding to user interactions and creating a seamless, immersive experience.

On the other hand, Augmented Reality (AR) sends digital-world information straight into a user's line of vision. AR devices- phones, tablets, and special glasses with cameras or sensors which sense their environment around them-put suitable digital content on top of this then. As such, no matter what direction they are from it or how fast their moving speed is, users can still see and play with elements of digital information as if they were real parts in the world around them. This is why AR is particularly useful in areas like navigation, education and maintenance: it allows people to interact with digital elements that follows offline laws.

In the metaverse, VR and AR technologies are used to create truly interactive and realistic experiences. These can range from immersive training simulations that let users practice skills in a safe controlled virtual space, right through to remote advice: experts supply instructions directly added into the user's view of the world so offering guidance with complex tasks.

With these technologies that are so engaging in the metaverse offer numerous advantages which includes highly interactive, artificial experiences which grip all the senses; training that is interactive, yet it causes no consequences for real learning; and in remote collaboration at one point or another. But these exact same systems also raise Certain problems - VR and AR technology requires lots of resources to create and launch, such as expensive hardware and high-end advanced software development skills. In addition, articulate and technical specialists are needed to design and maintain these applications, including advanced programming skills as well as knowledge of 3D animation techniques. Furthermore, some people feel nauseous or disorientated after wearing a VR headset for long periods. With the total immersion in VR, users can become disordered and tired; the obstacles of long-term use are thus significant.

Despite its virtual nature, the metaverse relies on physical infrastructure and electricity. Essential components include hardware devices like virtual reality (VR) headsets for user immersion. Communication networks and data centers may need upgrades to handle increased data traffic and computing demands. Enablers like virtual platforms and digital payments could also necessitate additional computing power. Intel predicts a thousand-fold increase in computing capability for the metaverse.[2]

Innovation often leads to efficiency gains, such as the AWS Graviton chipset being 25% faster and more energy-efficient than its predecessors.[3] However, innovation doesn’t always have immediate environmental benefits. For instance, cryptocurrencies like Bitcoin, which emerged in 2008, now contribute significant carbon emissions (65 million tons of CO2 annually as of August 2021 up from 22 MTCO2 as of November 2018).[4] Despite this, cryptocurrencies can also enhance carbon markets and accounting through transparency and accessibility. Additionally, technological advancements may eventually reduce energy intensity. As demonstrated by Ethereum, the second-largest cryptocurrency, which switched to a consensus method that uses significantly less energy. Regarding the metaverse, it’s too early to draw definitive conclusions, but its diffusion could aid decarbonization by replacing real-world activities with virtual alternatives.

# **Existing Studies**

The metaverse is composed to become the next major platform in computing after the web and mobile. It aims to enable rich, real-time, globally interconnected virtual and augmented reality environments, enabling billions of people to work, play, collaborate and socialize in new ways. Intel's building blocks for metaverses include a unified programming model, open software development tools and a meta computer layer. Intel's Xe architecture aims to accelerate and render these immersive experiences with Intel's Arc™ Alchemist GPU and Ponte Vecchio.[2]

The Information and Communication Industry has been under recognized as a significant contributor to global greenhouse gas emissions (GHGE) due to its efficiency in reducing other sectors' footprint. The global carbon footprint of the ICT industry includes consumer devices, data centers and communication networks and compares it with the total worldwide GHGE.[5]

The metaverse, a virtual world created by tech giants like Meta Platforms, Microsoft, Apple, Samsung Electronics, Tencent Holdings, Baidu and Byte Dance will require exponential computing power and energy to create a three-dimensional internet. The energy required to power this virtual world is several orders of magnitude more powerful than the current system requiring major upgrades to achieve high bandwidths and low latencies. The energy required to power a future metaverse is almost impossible to imagine with Meta Platforms.[7]

Data centers are experiencing rapid growth in demand due to data-intensive technologies. Despite initial predictions of doubled energy use, new data suggests modest growth in global data center energy use providing a more accurate understanding of its drivers and near-term efficiency potential.[8]

The concept of the metaverse is a virtual reality space where users can interact with a computer-generated environment, and it has rapidly evolved. The industrial metaverse applies this concept to industrial settings, leveraging advanced technologies such as artificial intelligence (AI), Internet of Things (IoT) and extended reality (XR) to revolutionize manufacturing, logistics and other sectors. The industrial metaverse is an integrated digital physical space where industrial operations are simulated and managed through digital twins, augmented reality (AR) and virtual reality (VR).

Digital Twins are exact virtual replicas of physical assets that enable real-time monitoring and predictive maintenance. AR utilizes virtual overlays to increase efficiency of operations in the real-world environment. For instructing and training purposes, virtual reality is developing realistic worlds. AI and Machine Learning enable automated procedures and intelligent decision-making. Blockchain ensures data integrity and facilitates. The industrial metaverse aims to enable holographic intelligent manufacturing by mapping the industrial environment into a virtual world in real time. Wireless communication plays a crucial role in this metaverse, but limited radio resources and diverse tasks pose challenges. Intelligent wireless communication are three main types of tasks: real-world virtualization tasks, closed-loop communication for virtual world realization and cooperative model training tasks.[18]

Manufacturing real-time monitoring of production lines, predictive maintenance, process optimization and enhance tracking and management of logistics through IoT and blockchain are the main applications. Predictive analytics help optimize energy use in industrial processes, reducing waste and emissions. Improved monitoring and management of resources lead to more sustainable practices. Virtual meetings and remote management decrease the need for physical travel. The industrial metaverse ensures different systems and technologies can work seamlessly together. Smart manufacturing is transforming towards industrial digitalization, integrating advanced technologies like the metaverse. The metaverse is a virtual space extended and augmented by reality, allowing users to engage in virtual activities. IM verse Model and an industrial metaverse architecture, IM verse Architecture involving key enabling technologies and the typical innovative applications of the industrial metaverse throughout the product life cycle for smart manufacturing. Increased reliance on advanced hardware could lead to more electronic waste if not managed properly and the operation of large data centers to support the industrial metaverse contributes significantly to greenhouse gas emissions. The industrial metaverse needs significant upfront costs for developing and implementing metaverse technologies.[19]

Nowadays protecting sensitive industrial data from cyber threats and ensuring privacy is becoming challenging. The industrial metaverse needs developing solutions that can scale efficiently with growing data and user demands and ensuring compliance with data protection regulations and safeguarding user information. The industrial metaverse needs a skilled workforce in modern technologies and tools associated with it. The industrial metaverse also needs universal standards for the implementation and operation of metaverse technologies. By addressing the ethical implications of AI and automation including potential job displacement, the industrial metaverse can develop. The industrial metaverse relies on data acquisition and virtual reality technologies which are computationally expensive and require large amounts of energy.

To minimize the environmental impact, data centers and cloud computing could be implemented with virtual renewable energy systems. However, implementing these systems in virtual space may be less efficient and cost-effective than physical systems. Additionally, responsible waste management in the metaverse can help reduce e-waste generation and promote sustainability practices.[20]

De Vries, Gallersdorfer et al. [3] investigated the environmental effects of Bitcoin and provided insights into its carbon footprint by developing a techno-economic model for accurate electricity consumption estimation. The lack of knowledge regarding long-term effects and mitigation methods for reducing Bitcoin carbon emissions was highlighted as well as demand for more recent data and the importance of addressing environmental concerns related to cryptocurrencies and blockchain technology.

Far, Rad, and Asaar et al. [27] concentrated on technologies such as decentralized finance (DeFi) and the Metaverse looked at jobs in the Metaverse and DeFi-based technology and provided advice on how to adopt DeFi 2.0 through CeDeFi-based platforms while addressing issues with AI and privacy in the future in the study of the future of virtual businesses. Water quantification in data centers was tackled by Lei, Masanet et al. [16] through the development of a physics-based model, estimates of power usage effectiveness (PUE) and water usage effectiveness (WUE) for various US data center types and customized efficiency measures for WUE and PUE enhancement.

A deeper understanding of economic indicators and significant environmental impacts is called for and future research directions include usage among clients, policy considerations, and technology-enabled sustainable consumption. Pellegrino, Stasi, Wang et al. [30] aligned 20 journal papers addressing overlaps between metaverse and sustainable consumption.

Ukhanov, Berggren, et al. [31] underlined the social and environmental effects of the Metaverse that have not received enough attention while also emphasizing sustainable functions and offering a methodology to help firms adopt the Metaverse in their investigation of the Metaverse's potential for operations management. To meaningfully use the Metaverse in education, Lin et al. [3] envisioned it as a radical learning space and identified gaps in instructional design methodologies and pedagogical approaches. Momtaz et al. [34] looked at the financial foundations of Web3 and the Metaverse, examining how blockchain technology might facilitate ownership and exchange of digital assets and proposing studies on value generation, economic models and possible disparities. Swofford, G. P. and J. W.

Baker et al. [35] looked at its application possibilities and environmental costs, highlighting circular economy models and sustainability in their analysis of the industrial Metaverse. They also recommended the incorporation of quantitative data and consideration of the implications for social and ethical issues. Yao et al. [18] introduced the industrial Metaverse as a means of facilitating intelligent manufacturing in an IDC setting. They also talked about the integration of cyberspace and physical space and recommended studies on the quantitative advantages of the Metaverse at various points in the value chain. After examining the connection between the Metaverse and climate change, Palak et al. noted that the Metaverse could reduce emissions by doing away with physical commuting, but it could also increase energy consumption because of its energy-intensive computing infrastructure. They recommended more research to determine the precise environmental footprint of the Metaverse.

Numerous studies demonstrate the metaverse's potential advantages for sustainability. In the future, employment and leisure activities may be moved to the metaverse according to Far et al. [27] which could lower emissions associated with travel. In a similar way, Nleya et al. [35] recognize that the industrial metaverse may be able to streamline production procedures and minimize material waste.

Pellegrino et al. [30] search deeper and explore how the metaverse could be leveraged for sustainable practices in areas like smart cities, education and tourism. These possible advantages are eclipsed, nevertheless, by the pressing issue of energy usage. Data centers which are infamous for having an unquenchable need for electricity are vital to the metaverse. Research by Ukhanov et al. [31] and Lei et al. [16] emphasize the necessity of effective data center operations to reduce the metaverse's negative environmental effects. Momtaz et al.'s [34] vision of the metaverse, a large virtual environment with ever-increasing demands on computing resources raises concerns about its potential expansion.

The literature review provided an in-depth analysis of the demands identification and resources which are currently in use, demonstrating limitations in terms of usefulness and lack of multi-platform support. They bring focus to the significant research gap in the study. To solve these gaps, this study offers a road map to develop an ecologically friendly metaverse to close these gaps. Complete details about the metaverse's both positive and negative consequences on the environment were provided by the systematic literature review. The adoption of environmentally friendly methods and environmentally friendly technologies is essential to resolving these issues. The aim of this study is to create an obvious connection between the goals of the study and the information gathered providing a path forward for creating a metaverse that is more ecologically constructed.

# **Research Motivation and Objective**

The metaverse, a virtual environment that blends physical and digital realities has become a major technological development with emerging importance. It is expected that as more activities migrate into virtual spaces, monitoring and maintaining the impact of this digital infrastructure on the environment will become a subject of increasing concern. Though the metaverse has potential for some physical activities to be cut back and certain kinds of environmental harm lessened, at the moment its overall environmental effect is not well understood. This paper aims to explore the ecological impact of the metaverse, so as to ensure sustainable development in these new virtual environments.

What this research focused on is, primarily and foremost, an inquiry into the environmental impact of the metaverse by looking at these three indicators: energy consumption, carbon footprint and how much savings there may be in terms of resource use. Also, by assessing these dimensions, it is hoped this research can offer a comprehensive view of just how sustainably one can go about building a metaverse.

The objective of the research is achieved through the following steps:

* **Evaluate Energy Consumption and Carbon Footprint:** This research aims to quantify the metaverse's energy requirements and carbon emissions. This suggests looking at the environmental costs of data centres, for instance - blockchain technology in general where communication equipment is used to keep alive all virtual environments including smartphones among many others.
* **Assess Possible Environmental Benefits:** This research goal is to understand how the metaverse might contribute toward sinks for environmental sustainability by abstaining somewhat or reducing its reliance on physical resources. The idea of research here will be to investigate in various ways virtual worlds can take the place or cut down usage of travel, physical retail environments, major events and others.
* **Identify Weaknesses and Provide Recommendations:** By bringing these omissions in previous studies to light, researchers will identify actionable advice in lowering energy and carbon emissions while also maximizing environmental benefits.

### Research Questions

**RQ1: What is the environmental impact of the metaverse in terms of energy consumption and carbon footprint?**

This question seeks to look at the environmental cost, direct or indirect, that is owed for metaverse. It aims to ascertain how much energy VR environments need and what impact this might have on the environment in terms of greenhouse which also incorporates data centers and even blockchain technology that could have substantial effects on the living space.

**RQ2: How can the metaverse contribute to environmental sustainability by reducing the need for physical resources and activities?**

This question mainly focuses about the environmental benefits of the metaverse which in general determines how virtual environments can replace physical activities that consume a great deal of resources, like commuting - shops and events as well thus potentially cutting back on the total environmental impact.

As interest in the metaverse surges, research on its environmental footprint is conspicuously missing. All existing studies concentrate on technological and economic potential, but scant attention has been paid to the ecological price of this attention. Defining the metaverse in the current debate does not focus on how much electricity, cooling, hardware (chips or other electronic components) plus critical metals consumption it requires or under what environmental costs digital infrastructure operates. This leaves a major research gap that must be addressed and filled prior with great difficulty.

# **Research Contribution**

The history of metaverse heralds’ changes in various areas - from how people work and learn, how contacts among friends differ, or what sporting events can be realized. This study hopes to make contributions to the well-being of society more than anything. It aims to uncover the opportunities and challenges of the metaverse, especially when it comes to sustainability. This paper can provide an unbiased insight into whether the benefits of carbon reduction due to less physical travelling, out glaze its environmental costs related with huge energy-usage data centers in metaverse; which ultimately is vital for policymakers or decision makers.

1. **Architecture and Technologies:** In learning about its architecture and technology, what matters most is the industrial metaverse. Looking at its building blocks allows environmental considerations to take center stage in some instances.
2. **Industrial Applications:** Looking at the practical uses of the metaverse in industry reveals its true social significance. Whether meeting processes or presenting new types of interaction, each of these applications calls for a consideration of sustainability effects.
3. **Impact Assessment:** Providing a detailed analysis of the environmental impact of the metaverse, including energy consumption and carbon emissions associated with its infrastructure.
4. **Potential Environmental Benefits:** By exploring potential environmental benefits in such places as virtual environments, we can reduce real resource use and associated environmental damage.

Companies and NGOs both use virtual platforms to promote sustainability and corporate social responsibility. These are ultimately sustainable technology solutions, but the technology developers and industrial stakeholders should be motivated to implement them without undue haste. It is gratifying to have open questions in research. With its reliance on a powerful data fabric, the industrial metaverse also does so. Identifying gaps in knowledge can help guide future investigations. Building supportive communities with a focus on environmental sustainability contributes to collective action and greater impact. Leadership must raise people's level of consciousness around this, involve a following and conservation efforts. By leveraging the potential of the metaverse, research in this area can make a significant difference in how individuals and society understand and address environmental issues, fostering a more sustainable and informed world.

# Chapter 2

# Research Methodology

# **Conceptual Framework**

Table – 2: Organization structure of this paper

|  |
| --- |
| 1. Industrial Metaverse definition and key components |
| 1. Industrial metaverse architecture, and technologies |
| 1. Industrial applications of metaverse |
| 1. The impact of the industrial metaverse on the environment |
| 1. Upcoming research challenges |
| 1. Conclusion |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Define the Research Question and Objectives |  | Develop a Search Strategy |  | Conduct the Literature Search |
|  |  |  |  |  |
| Report  the  Results |  | Analyze and Synthesize Findings |  | Extract Data |  | Select Relevant Studies |

Figure – 2: Methodological approach of this paper

**Step 1: Define the Research Question and Objectives**

* **Identify the research topic:** This part is centered on the Environmental Impact and Challenges of Industrial Metaverse. This review therefore focuses on studies from 2020 to 2024 alike, so that the work can be compared to previous ones and validated.
* Formulate research questions: This section is focused on how to form research questions. The fast one covers the carbon footprint and energy use of the metaverse. The research analyzes the energy consumed by technologies that underlie the metaverse — cloud computing, virtual reality and artificial intelligence­—and associated global warming gas emissions. Secondly, the Metaverse can help decrease demand on physical resources and activities for a more sustainable environment. How Metaverse might be good for the environment -The answer demonstrates a way in which reducing tangible resources and activities could benefit the environment by using meta real estate.

**Step 2: Develop a Search Strategy**

* **Keywords and phrases:** This is used as phrases to help with better research. · Invoking State Qubit question broke down in detail for ease researching • Viewpoint The comparative area has been researched in depth for the review study metaverse, environmental impact, energy consumption & carbon footprint (CFP), Virtual Reality (VR) and Artificial Intelligence.
* **Databases and sources:** The databases included in this research are Google Scholar, and other sources books, conference papers, reports.

**Step 3: Conduct the Literature Search**

* **Search databases:** Keyword are environmental impact on metaverse, energy consumption of metaverse and carbon footprint of the metaverse. This keyword will assist in the task of searching for relevant paper on a first pass may help as well.
* **Screen results:** Review results on screen to see if relevant Titles and Abstracts relevance to the research question.
* **Retrieve full texts:** After screening titles and abstracts according to relevance with the research question derive the full-text versions of relevant articles and studies.

**Step 4: Select Relevant Studies**

* **Inclusion and exclusion criteria:** This section includes the relevant data and excludes some irrelevant variables to match the criteria of the research after comparing the research data with other studies.
* **Assess quality:** This section critically evaluates the methodological quality of the studies using standardized tools.

**Step 5: Extract Data**

* **Data extraction forms:** Standardized forms have been created to extract key information from each study, such as study design, sample size, methods, findings, and conclusions.
* **Organize data:** The extracted data has been compiled into a structured format, such as tables or spreadsheets.

**Step 6: Analyze and Synthesize Findings**

* **Thematic analysis:** The common themes, patterns, and trends are characterized to highlight the environmental impact of Metaverse. The selected studies include “Environmental Impact”, “Technological Integration”, “Sustainability”.
* **Narrative synthesis:** The results are reported in narrative form highlighting key points and connections among the studies.
* **Quantitative synthesis:** Meta-analysis for pooling the results of different studies has been done statistically.

**Step 7: Report the Results**

* **Structure the review:** The review is divided into subsections, including an introduction, methodology such as how and where you've gathered your sources for reading more on similar topic), with results & discussion encompassing these sections it will make a conclusion easier.
* **Critical appraisal:** The strengths, limitations, and implications of the reviewed studies have been discussed.

# Data Collection

We collect data for our study through data collection procedure. We use Systematic Literature Review (SLR) technique for data collection for our study. SLR is an academic procedure that focuses to identify and evaluate all applicable literature on a topic to draw conclusions regarding the topic at concern. SLR is a way to compile information on a research issue or topic. The SLR procedure is repetitive and visible for the purpose of ensuring maximum accuracy. Primary studies are the studies that are analyzed by SLRs which are also referred to as additional research. We use Conventional SLR because our study collects consequences related to specific research questions.

The approach utilized in this paper explains how we located the articles for our examination of the Industrial Metaverse and its role, applications, implementation, environmental impact and challenges. Our systematic approach involved initially an extensive literature search including but not limited to web science, IEEE Explore, ACM Digital Library, ScienceDirect, Springer Nature and Google Scholar. These databases are renowned for offering academic articles on the Industrial metaverse and related issues together.

The initial search queries were carefully designed to capture a broad range of relevant papers related to the industrial Metaverse applications and challenges. "Industrial Metaverse," "Deployment and Industrial Metaverse," "Environmental impact and Industrial Metaverse," "Challenges of Industrial Metaverse," and similar variations were the primary search terms we utilized. To enhance the retrieval of relevant literature, we made sure that our research searches included relevant terms.

Our initial searches turned up a sizable number of papers which are about 32 across the various databases. The selection procedure required patience when choosing articles and research papers according to specified requirements. A set of rules were put in place to ensure that only articles and papers that specifically addressed the research's main issues were taken into consideration for ensuring a strong link to the answers to the research questions.

The purpose of the study, the primary concepts and the application of those concepts led to the criteria for inclusion and exclusion which were applied to determine the finalized literature selection in this study. A methodical screening procedure was applied to this study to include research papers or eliminate any duplicate or unnecessary research papers. Besides the literatures that related to the research questions, written in English, published within a particular time and focused on Industrial metaverse and its environmental impact and challenges were between the inclusion criteria. These included studies with excellent research designs, specific objectives and suitable data analysis. On the other side, literatures that were not written in English, were not that much relevant to the research questions, were published before a certain date or were not specifically about Industrial metaverse and its environmental impact and challenges were eliminated from the literature selection for this study and between the exclusion criteria.

After selecting the research papers, a review was performed and summarized findings from previous research papers on Industrial metaverse and its environmental impact and challenges. We analyzed encompassed papers that focused on the application of the Industrial Metaverse context and explored the associated challenges. We follow a guideline and some instructions which were created to examine the research papers to evaluate its validity and appropriateness. This approach ensured an accurate and smart analysis by making it possible to access important information required to deal with the research questions.

The inclusion criteria for our analysis encompassed papers that focused on the application of the industrial Metaverse context and explored the associated challenges.

* Initial Search: 105 studies identified.
* Title and Abstract Screening: 53 studies excluded.
* Full-Text Screening: 20 studies excluded.
* Included for Review: 32 studies.

A graph of blue bars

Description automatically generated

Figure – 3: Number of papers from different database

This form will help us to retrieve data which includes quantitative data and qualitative information from literature review to comprehend the environmental impact of metaverse.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Study Details   |  |  | | --- | --- | | Title of the Study |  | | Author(s) |  | | Year of Publication |  | | Journal/Conference |  | | DOI/Link |  | |
| Research Focus   |  |  | | --- | --- | | Main Research Question |  | | Hypothesis |  | | Objectives |  | |
| Methodology   |  |  | | --- | --- | | Research Design | qualitative, quantitative or mixed methods | | Data Collection Methods | literature review | | Sample Size and Characteristics |  | | Technologies Examined | VR/AR devices, data centers, blockchain | |
| Key Findings   |  |  | | --- | --- | | Environmental Metrics Reported | Energy Consumption, Carbon Footprint, Resource Usage | | Comparison Metrics | comparison with traditional internet usage, other digital technologies | | Mitigation Strategies Suggested | energy-efficient technologies, sustainable practices | |
| Discussion and Implications   |  |  | | --- | --- | | Summary of Findings |  | | Implications for Policy/Practice |  | | Recommendations for Future Research |  | |
| Gaps and Limitations   |  |  | | --- | --- | | Identified Gaps in the Study |  | | Limitations Noted by Authors |  | |
| Citations and References   |  |  | | --- | --- | | Key References Used |  | | Citations within the Paper |  | |

Figure – 4: Data collection form

Through analysis of the data form, we summarized the key findings across the studies, through an identification of common themes or patterns. In this way, we could compare different methodologies and results but also point out the voids or inconsistencies in the literature available to us in such a manner that meaningful data could be extracted to answer the research question.

# Ethical Issues

At the cutting edge of technological innovation, the industrial metaverse combines advanced technologies like virtual reality with IoT, AI, and blockchain to transform sweeping changes on any scale—from manufacturing operations right down to digital production facilities. Nevertheless, with these combinations comes ethical concerns which must be addressed properly for mindful development and application of them. One major ethical issue is how to maintain the privacy and security of data received from the diverse sources: IoT devices, sensors, user interactions in virtual environments. Responsible data collection, storage and employment are essential if future developments take place on a correct ethical basis. Tackling these issues requires robust data protection protocols and standards of conduct for data practices, including getting explicit user consent on what your data is for, anonymizing information where possible and obeying relevant regulations. Similarly crucial transparency is in the processes of data analysis. This will help to build trust among users and stakeholders. As well as ensuring that data integrity and performance remain high by establishing an unchangeable record of all transactions, blockchain technology improves transparency. One other key ethical consideration is data integrity - maintaining the integrity, accuracy and authenticity of research data. Stringent collection standards, peer review processes, validation checks, and statistical methods are all used to authenticate the reliability of data Conflict of interest issues and prevention of plagiarism are also important issues, requiring clear ethical guidelines and standards. Procedures used during the project included these policies on data collection, anonymous data and transparent methods of conducting analysis. Peer review validated the methodology of the research, while steps to prevent conflicts of interest also maintained a high ethical standard through training and adherence to guidelines set down. Proactively addressing these ethical issues ensures responsible and ethical development of the industrial metaverse, leveraging technological advancements for societal benefit. Continuous improvement of ethical standards fosters integrity and accountability in research and development within this evolving industrial landscape.

# Economic Decision

This research is intended to further explore and develop theoretical work. The objective of this study is to amplify understanding through theoretical models and conceptual frameworks. As such, a cost analysis was not conducted for the following reasons:

**1. Theoretical Emphasis:** The research aims to promote theoretical knowledge in the field, refine the meaning and scope of abstract concepts, and develop hypotheses for study using these as a ground-breaking work. Theoretical research often concentrates on thorough study of existing literature, the definition of new concepts and the study of possible implications for such theories.

**2. Scope and Methodological:** The methodology employed in this study is rooted in qualitative analysis, which inherently differs from quantitative methods required for cost analysis. The emphasis is to make a critical analysis and argument by reason of theory, not to collect and analyze figures or statistics that would lead to some knowledge about costs.

**3. Resource Allocation:** Because of the theoretical nature of the research, funding and time went into conducting extensive literature reviews, developing theoretical models and participating in academic discussion. This did not extend to providing a financial analysis or econometric evaluations which would form the basis for cost estimates.

**4. Relevance and Application:** While practical implications and applications that result from the theoretical findings may be further researched in future, the present study sets no sights on the stage of implementation or operation where cost analysis is crucial. Future research could expand upon these theoretical foundations to include empirical studies which address cost implications and other practical considerations.

**5. Contribution to Knowledge:** The primary contribution of this research lies in its theoretical advancements and the generation of new insights within the academic field. In this way, questions which arise go on to provide channels for further inquiry. The findings themselves serve as a base from which to launch empirical studies, maybe all the way to a comprehensive cost analysis.

In summary, the omission of cost analysis is based on methodological concerns, the nature of the research itself, and its theoretical aims and intended contributions The assessment of economic feasibility and financial costs in future research astonishingly may enter this book or other publications as an appendix.

# Chapter 3

# Results and Analysis

# Results and Analysis

The carbon footprint associated with information and communication technology (ICT) arises from compute-related activities in data centers, data transmission via communication networks, and the production, use, and disposal of hardware devices like mobile phones.[5] All these ICT components rely on energy systems. As the metaverse gains prominence, it will necessitate technological enablers, potentially increasing electricity demand across the ICT landscape compared to a scenario without metaverse adoption. Matthew Ball’s proposed metaverse enablers—hardware, networking, payments, and compute highlight areas where significant electricity demand is expected. For instance, virtual reality (VR) hardware for metaverse access, differences in electricity demand between 5G and previous cellular network standards, energy-intensive consensus mechanisms in cryptocurrency networks, and the computing power required for artificial intelligence (AI) all contribute to this demand. However, the actual need for these technologies will vary based on metaverse use cases and technological advancements.

Advancements in technology have shown that increased computing power doesn’t always correlate directly with higher electricity requirements. A study found that despite a 2,600% increase in work performed by global cloud data centers from 2010 to 2018, energy consumption rose by less than 10%. This was attributed to the adoption of more efficient server hardware.[8] The relationship between computing power and electricity consumption isn’t always linear. Advances in technology have allowed for more efficient server hardware, resulting in improved performance without significantly increasing energy usage. This phenomenon is particularly evident in global cloud data centers, where workloads have surged dramatically, yet energy consumption has remained relatively stable. It’s a positive trend that highlights the importance of optimizing energy efficiency as we continue to rely on digital infrastructure. Building on this study, the International Energy Agency (IEA) finds that data center energy use has remained almost constant between 2010 and 2020, despite internet traffic globally expanding 15-fold, because of increases in the efficiency of data center infrastructure, servers, storage, network switches, and a growing percentage of cloud and hyperscale data centers.[9]

The environmental impact of the metaverse, despite being virtual, is significant. Virtual reality technology, data centers, and cloud services used in the metaverse require substantial energy. AI models and training processes contribute to this energy demand. However, the metaverse growth can also accelerate decarbonization and improve air quality by reducing air pollutant emissions and saving energy.

The metaverse emits greenhouse gases, similar to physical sectors. By 2050, the metaverse industry could potentially lower greenhouse gas emissions by 10 gigatons, decrease atmospheric carbon dioxide concentration, and reduce total domestic energy consumption significantly. To mitigate its impact, consider recycling e-waste, purchasing second-hand electronics, and streaming content in standard definition. While the metaverse offers endless possibilities, its environmental impact requires careful management and sustainable practices.

A graph of the number of global emissions

Description automatically generated with medium confidence

Figure – 5: Global trends in internet traffic, data centers workloads, data center energy use, and ICT-related GHG emissions from 2010–2020.

A graph of a number of years

Description automatically generated with medium confidence

Figure – 6: Trends in consumer electronics energy consumption in US homes (2006–2020)

**Decarbonization and Corporate Climate Action:** Major data center operators, including Google, Microsoft, and Amazon Web Services (AWS), are committed to using carbon-free electricity.

Their efforts are expected to lower the carbon intensity of electricity consumed by metaverse providers compared to the power sector average. However, these companies still rely on power purchase agreements (PPAs) while remaining connected to the broader grid.

**Data Communication Networks and Electricity Consumption:** The metaverse’s growth may significantly increase data traffic and speed requirements. Assessments of energy and greenhouse gas (GHG) implications should consider communication network emissions. These emissions are likely to contribute to a growing share of ICT-related emissions globally.

**Household Electricity Consumption:** As end-users access the metaverse using devices like VR headsets, household electricity consumption may rise. In the US, consumer electronics accounted for 12% of residential electricity consumption in 2020. Despite increased device usage, annual energy consumption has remained stable since 2006.

**Climate Impact and Behavioral Change:** To assess the overall climate impact of the metaverse, we must consider its benefits. The COVID-19 pandemic showed how behavioral changes (e.g., remote work, virtual events) reduced emissions. Studies indicate an 8.8% drop in emissions during the first half of 2020 compared to 2019. The metaverse’s energy and GHG implications involve a complex interplay of data centers, communication networks, and household consumption. Balancing environmental impact with the metaverse’s benefits will be crucial.

The metaverse has the potential to enhance environmental sustainability by reducing the demand for physical resources and activities.Virtual Meetings and Collaboration instead of traveling for meetings, people can participate virtually in the metaverse. This reduces the need for transportation, saving fuel and lowering emissions. The metaverse enables remote work and virtual classrooms. Fewer people commuting to offices and schools means reduced traffic congestion and pollution. In the metaverse, digital goods (e.g., virtual clothing, accessories) replace physical ones. This reduces the production and disposal of physical items. And also metaverse platforms can prioritize energy-efficient data centers and servers, minimizing their environmental impact. Designers and engineers can simulate and test products virtually, reducing the need for physical prototypes and materials. Virtual concerts, events, and experiences can replace physical gatherings, reducing resource-intensive setups. In summary, the metaverse promotes a shift from physical to digital experiences, potentially benefiting the environment.

A graph of energy consumption

Description automatically generated

Figure – 7: Expected effects of a metaverse diffusion on global emissions by sector compared to a scenario without a metaverse diffusion

The proposed solution is offering a roadmap for developing a more sustainable metaverse. Developing a more sustainable metaverse requires a multi-faceted approach that addresses the various environmental challenges identified. Here’s a detailed roadmap:

Table – 3: Roadmap of sustainable Metaverse

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Short-term**  **Goals**  **(1-2 years)** | **Medium-term****Goals** **(3-5 years)** | **Long-term**  **Goals**  **(5+ years)** |
| 1. **Energy Efficiency and Renewable Energy Integration** | * **Energy Audits** * **Optimization of Current Technologies** | * **Transition to Renewable Energy** * **Green Data Centers** | * **Net-Zero Emissions** * **Decentralized Energy Solutions** |
| 1. **Sustainable Hardware Development** | * **Eco-friendly Materials** * **E-waste Management Plans** | * **Modular Hardware Design** * **Extended Producer Responsibility (EPR)** | * **Circular Economy Practices** * **Innovative Recycling Technologies** |
| 1. **Software and Platform Optimization** | **Code Optimization** and **Resource Allocation** | **Virtualization and Cloud Computing** and **Edge Computing** | **AI and Machine Learning** and **Interoperability Standards** |
| 1. **Community and Policy Engagement** | **Stakeholder Collaboration** and **Public Awareness Campaigns** | **Incentives for Sustainability** and **Educational Programs** | **Global Standards and Regulations** and **Sustainable Ecosystems** |
| 1. **Monitoring and Continuous Improvement** | **Baseline Metrics** and **Regular Reporting** | **Performance Dashboards** and **Feedback Loops** | * **Adaptive Strategies** * **Longitudinal Studies** |

### 1. ****Energy Efficiency and Renewable Energy Integration****

Short-term goals For Energy Efficiency and Renewable Integration (years 0-5) include an energy audit, optimization of current technology Energy audits for data centers/metaverse infrastructure. Apply software-based optimizations and move to more power-conscious algorithms to minimize the computational burden.

Industry Medium-term Goals (3-5 years): Transition to Renewable Energy & Green Data Centers Establish partnerships with renewable energy sources for powering your data centers by solar, wind or hydro sciences Develop or convert to stable datacenters which are LEED (management in Energy and Environmental Design) compliant, use advanced cooling mechanisms such as liquid chilling & free-air cooling.

Long Term Goals (5yrs+): Net-Zero Emissions, decentralized energy solutions. Invest in carbon offset projects and build renewable energy infrastructure so that the Earth has net-zero carbon emissions. The metaverse needs decentralized energy: develop batteries and renewable-powered microgrid for local hubs.

### 2. ****Sustainable Hardware Development****

Short-term Goals (1-2 years) include Eco-friendly Materials and E-waste Management Plans. Short-term Goals (1-2 years) Eco-friendly Materials, E-waste Management Plans. Supporting the use of recycled and biodegradable materials for VR headsets, servers, etc. Implement e-waste collection and recycling programs, new or in partnership with electronic manufacturers. Modular Hardware Design and Extended Producer Responsibility (EPR)Medium-term Goals (3–5 years) Facilitate expanded availability of modular hardware that is easy and allows for replacement or repair without the need to make whole unit replacements. Put in EPR policies to ensure that product manufacturers are responsible for the lifespan of their products down to end-of-life disposal. Circular Economy Practices (Long-term Goals [5 years]) Innovative Recycling Technologies 27 Transition to a circular economy model by building products with reuse, refurbishment and recycling in mind.

### 3. ****Software and Platform Optimization****

Code optimization and resource allocation Short-term Goals (1-2 years) make the metaverse application code more efficient and less resource demanding. Use dynamic resource allocation method to maximize utility on computational resources. Medium-term Goals (3-5 Year): Virtualization and Cloud Computing, Edge Computing apply virtualization and cloud computing to turn resources up (or down) in accordance with demand, thus minimizing idle energy consumption. Use edge computing for data processing nearer to the point where it is created, so that large amount of data transmission is not required, and energy use can be cut. Of course, there are long-term (5+ years) goals ranging from AI and Machine Learning to Interoperability Standards. Leverage AI and machine learning to forecast future needs, while simultaneously optimizing resources in real-time improving efficiency even further. Design and apply interoperability standards that allow for different metaverse platform resources to be shared behind the scenes, saving in redundancy efforts.

### 4. ****Community and Policy Engagement****

Stakeholder Collaboration & Public Awareness Campaigns (Short-term Goals 1-2 years) Negotiate with stakeholders (labour, environmental groups, government officials and corporations) regarding sustainability goals. Create more than just Play to Earn campaigns, but also environment-related ones educating people on the direct impact of metaverse and how it will only be able to exist if sustainable process is integrated into the system being used by both users and game developers.

Medium Term Goals (3-5 years) — Sustainability Incentives, Education Programs. When it comes to the metaverse development, therefore encourage policies that give companies financial incentives for being environmentally friendly. Create courses and certifications for sustainable development in the digital sphere

Long-term Goals (5+ years) include Global Standards and Regulations and Sustainable Ecosystems. Work towards the establishment of global standards and regulations for environmental sustainability in digital environments. Foster sustainable digital ecosystems by promoting circular economy principles and responsible consumption within virtual environments.

### 5. ****Monitoring and Continuous Improvement****

Baseline Metrics and Regular Reporting (1-2 Years) are short-term goals. Define initial metaverse-related energy use, carbon emissions and e-waste in a standardized way. • Set reporting mechanisms that help track progress against sustainability goals.

Longer Term Goals (3-5 years): Performance Dashboards and Feedback Loops Develop dashboards for real-time monitoring of sustainability KPIs Establish feedback loops with users and stakeholders to collect input, while always working on tightening initiatives for sustainability.

Long (5+ years) term goals: Adaptive Strategies and Longitudinal Studies. Create adaptive strategies, which consider the fact that both technology and environmental factors are likely to evolve. Give it time, conduct studies longitudinally to see how the metaverse is wrecking or improving our planet and change your strategies accordingly.

The move offers a full plan for building out the more sustainable metaverse, which includes ways to tackle near-term and long-haul challenges. By focusing on energy efficiency, sustainable hardware, software optimization, community engagement, and continuous improvement, the metaverse can be developed in an environmentally responsible manner that minimizes its ecological footprint.

# Accuracy and Verification

The robust methodological approach, as exemplified by an integrative literature review, is what gives credibility to the research findings. By gaining data from more reliable sources and doing a more thorough analysis of the data, this approach means well-founded conclusions. Key methods supporting accuracy include data triangulation in which cross-referencing multiple data sources checks that findings are accurate and reliable. In addition, use of peer-reviewed articles and studies enhance the credibility of the data. Furthermore, examining case studies and real-world applications of the industrial metaverse provides concrete evidence of its environmental impact. Taken together these methods guarantee that research findings are not only accurate, but they are also practical and relevant to implement.

The roadmap for a more sustainable metaverse is suggested above. With the systematic literature review gaining way-beyond a detailed picture of both the positive and negative environmental impacts of the metaverse. Its results showed that while the metaverse has the potential to reduce physical travel and promote digital economies, it also produces major problems in terms of energy consumption and e-waste. To meet these needs, green technologies and sustainable practices must be implemented. These findings and proposed solutions connect the aims of the research directly with the data collected, giving a roadmap toward a more sustainable metaverse.

In the industrial metaverse, proposed systems ' points of failure include scalability problems: greater metaverse expansion requires a capacity for managing the increased data load effectively. Also, despite impressive efficiency gains, many people continue to worry about the high energy consumption of AI and blockchain technologies. Interoperability also presents a challenge: ensuring seamless integration between various IoT devices and platforms is far from straightforward. It is essential to address these potential points of failure for environmentally sound and sustainable industrial metaverse formation.

There are several important trade-offs involved in the implementation of sustainable practices within the industrial metaverse. One such significant trade-off relates to cost and sustainability. That is, despite a high initial cost incorporating renewable energy and energy-efficient technologies pays for itself in terms of benefits both financially and environmentally in the long run. Another major trade-off is between performance and energy efficiency: keeping high performance while reducing energy consumption requires the optimization of algorithms and investment in more efficient hardware. Furthermore, enhancing security can sometimes complicate matters for the users, necessitating those systems designed be both intuitive and secure. Understanding customer behaviors and business requirements is vital in negotiating these trade-offs. Assuming for instance, industries with a strong focus on sustainability might be more likely to adopt green technologies despite higher initial costs, when those industries focus on rapid growth, they will put scalability and performance first.

# Impact Analysis

The industrial metaverse is changing the industrial areas in ways that go beyond human imagination at the same time, this technology is still in its infancy and has a big impact on the environment. Environmental impact is any positive or negative change in environmental quality resulting from human intervention which can shift the natural balance of processes in a system [20] and [21]. To achieve sustainable development, this must be assessed if the goal of sustainable development is to be reached. Industrial system control increasingly involves fully connected ecosystems due to sustainability mandates. At present, the aim of most affluent nations is to achieve net zero between 2040 and 2060. This means that businesses must overcome the conundrum of continuously enhancing their economic performance yet attaining zero net environmental impact.

Table – 4: Environmental impact of Metaverse

|  |  |
| --- | --- |
| **Positive Impacts** | **Negative impacts** |
| Reduced Need for Physical Travel such as business travel, Meetings and Conferences which reduce carbon emissions | Increased Energy Demand relies heavily on large-scale data centers and servers. Increased Server Demand with Scale. Cooling and Heat Emission from Data Centers |
| Sustainable Work and Remote Collaboration | Environmental Impact of Infrastructure Expansion and Resource-Intensive Device Manufacturing |
| Reduced Physical Resource Consumption | Rely on non-renewable energy sources |
| Promotion of Sustainable Practices such as Environmental Awareness and Education, Eco-friendly Campaigns and Virtual Protests | Require a massive amount of electricity to function. High-performance servers and the hardware needed for immersive experiences (like VR/AR) demand a lot of power |
| Reduced Physical Infrastructure Requirements | Rely heavily on energy-consuming processes. For example: Proof-of-Work (PoW) systems. |
| virtual replicas of physical environments that can be used to model and monitor environmental conditions in real-time. | Metaverse has increased demand for high-tech devices with short life cycles which contribute to e-waste |
| Digital Preservation of Cultural and Environmental Heritage that allow future generations to experience and learn from these spaces. | Environmental Blind Spots in Virtual Economies and Insufficient Carbon Offset Measures |

**Energy Consumption and Efficiency**: To set up the backbone of metaverse, these enormous data centers store and process vast amount of needed for virtual worlds. Electricity to power servers and keep them cool consumes a lot of electricity in such a setup that each data center has. [22] High-speed internet connection is thus an indispensable factor of the metaverse, for all its communication and interactivity requirements to be met. The energy needed for this infrastructure - the routers transporting data packets around cyberspace, switches sharing information among computers on their local network and transmission towers which propagate radio waves from one place to another - adds up to general consumption. Devices such as VR headsets, computers, and mobile devices, and to a lesser degree PDAs, consume energy as the metaverse is entered. As the metaverse continues to expand, more devices will be needed and usage times lengthened initiatives towards women recycling. No later than next year, estimates expect that energy either makes up or forms a bigger proportion of the total as we go step by step into future success with 3D graphics. High performance GPUs (Graphics Processing Units) are brains behind both personal devices and datacenters, meaning their use equates to heavy energy consumption. Energy consumption is not insignificant if the metaverse uses blockchain for transactions, NFTs (Non-Fungible Tokens) or other decentralized applications. Blockchain operations, particularly those spinning on proof-of-work mechanisms as is the case with Ethereum, have high energy requirements [1].

Well before major deployments hit the scene, studies show that the number of energy flows in DAG operations was found to be the highest. The daily energy usage of networking, storage and supercomputers is included in the TRUBA dataset. According to the findings of a forthcoming TRUBA study, future energy use will decrease; and as the same research shows, it's not all bad news... What 's more encouraging is that our analysis demonstrates that TRUBA's energy use is down somewhat lacking something; yet cloud servers are being introduced in increasing numbers for deep learning operations. [23] To achieve net zero across the board you must ensure that the underlying structure of your metaverse runs on renewable energy.

**E-waste and Device Lifecycles:** As the metaverse becomes more popular, VR headsets, augmented reality (AR) glasses, gaming PCs, and smartphones needed to access it leads to a higher turnover rate for these devices. As new, more advanced models arrive, old devices are often thrown away, increasing e-waste. [24] Data centers supporting the metaverse are constantly upgrading their hardware as storage and processing demands rise. With this perennial upgrading comes a lot of e-waste: obsolete servers, storage devices, and networking equipment. Old routers, switches, and other network hardware are part of the e-waste generated when the metaverse needs more robust bandwidth. If these are replaced with updated and more capable models, they too become part of the problem. The metaverse will accumulate many kinds of Internet of Things (IoT) devices to enrich interactive capabilities and interconnections. When these simply fall into obsolescence or become unworkable, they will contribute to overall e-waste.

The threats posed by e-waste are real, and these risks are heightened by the disorganized waste market that breaks most of what is recyclable out of e-waste. Such lethal materials as lead, cadmium, beryllium, mercury, and brominated flame retardants are present in every piece of electronic junk. Illogical disposal of electronics and other devices runs the risk of such injurious elements seeping into waterways, polluting the air, and wrecking our land. The amount of worn-out, discarded electronics goes up with the ever-growing global demand for electronics. In addition to the US $38 billion per year being lost by businesses due to e-waste treatment, the Phillips report predicts that by 2030, e-waste will account for 8% of the world's total GHG emissions and 4% of its primary energy use as well. Each year, about 50 million tons of e-waste are generated, more than has ever existed in those huge balloon structures. However, only 17.4% of e-waste is recycled on a global basis [26], exacerbating both environmental and health problems in economically developing countries. Through the abandonment of upstream essential raw materials such as iron, copper, gold, companies are annually an average of US $57 billion is passed up in opportunity costs by e-waste. By adopting circular models, companies can lessen their environmental footprint and tap into new economic opportunities while addressing critical e-waste issues.

**Carbon Footprint of Blockchain Technologies**: The incorporation of blockchain into the Metaverse promotes energy demands and such things as NFTs (Non-Fungible Tokens), not to speak of other decentralized applications. Blockchain operations are generally seen as energy guzzlers, especially those based on proof-of-work mechanisms. Within the Metaverse, the virtual economies (often backed by blockchain technologies like NFTs and cryptocurrencies) come with substantial energy costs. Energy wastage on blockchain networks is a major issue, especially those using proof-of-work consensus techniques. According to studies, mining bitcoin consumes as much energy as small countries. This creates a large carbon footprint. Miners quickly found that graphics processing units were better suited for finding PoWs than central processing units. However, as blockchain mining is highly energy-intensive and causes carbon dioxide emissions, the environmental impact of blockchain technologies on gaming must be considered. GameFi platforms should explore environmentally friendly solutions, such as proof-of-stake consensus algorithms, to reduce their carbon footprint and support the sustainable growth of the gaming industry [27].

**Potential for Reducing Carbon Footprint through Virtualization:**  Virtual environments in the metaverse can replace physical activities that have a high environmental cost. For instance, virtual meetings, conferences, and even events like concerts in the metaverse can eliminate the need for travel, significantly reducing greenhouse gas emissions from flights, car trips, and other transportation methods.

In the Early findings suggest that the metaverse could play a positive role in reducing carbon footprints by providing virtual alternatives to real-world activities, such as business travel, tourism, or large-scale physical events. This creates an opportunity for corporations, individuals, and governments to embrace the metaverse as a tool for sustainability by shifting high-emission activities to virtual environments. The metaverse can serve as a powerful tool for environmental advocacy, but more research is needed to assess its effectiveness in driving tangible, positive environmental actions.

The industrial metaverse is increasingly being used to do away with pollution effecting activities. This includes such things as commuting to work and the off WhatsApp. Because today a virtual meeting place gather. town, a virtual space platform that is offering a novel method of conducting online meetings unlike anything before it even has over 4 million clients. The platform provides a 2D environment where users can interact with one another in live time, just as if they were located at the same place [28] and [29].

**Reduction in pollution generated by activities:** The metaverse can be employed to create different scenarios for an entity like a city, and a factory in other to investigate the impacts on energy use. To observe how various scenarios affect their energy consumption, set up an entity identical to a factory through the industrial metaverse. For example, the digital twins of industrial metaverse can help to reproduce real conditions in a cheap and safe way. That is the case with Hellenic, one of the largest Coca-Cola bottlers where Microsoft deployed industrial metaverse capabilities. Hellenic has nearly 55 locations throughout Europe and service 29 local markets. In Greece one production line is responsible for cranking out 90.000 Coca-Cola bottles an hour. Microsoft used sensor data to construct digital twins that allowed production workers to immerse themselves in the models. The plant claimed, after just 12 weeks, to have reduced its energy consumption by more than 9 percent.

**Recycling Programs and Reduction in the consumption of physical objects**: A Third Industrial Revolution introduces the need for robust and sprawling network infrastructures to function. Outdated routers, switches and other networking hardware quickly become obsolete and are replaced with new, more capable equipment which adds to environmental pollution through e-waste production.

The possible consequences of virtual consumption should also be taken into account just as we think about how it might affect the environment. Although so-called virtual spaces can be designed to outlast physical ones, the energy use and emissions implications of this are not yet clear [30]. Manufacturers can make devices designed for durability and upgradability to increase equipment life. This reduces the frequency of equipment replacement and subsequent e-waste produced. With the industrial metaverse, we might very well find that it is possible to consume much less materialistically. 21% of consumers have conveyed their wish to engage in digital activities for the future, so that physical consumption decreases [31]. Encouragement to develop environmentally sound design criteria such as using recyclable materials and reduced deployment of hazardous substances in electronic devices can mitigate the environmental impact of e-waste.

**Climate Change Awareness and Environmental Activism in the Metaverse:** Educating consumers about the environmental impact of e-waste and the importance of proper disposal and recycling may be helpful in decreasing the amount of e-waste produced by people. Manufacturers can also provide takeback programs where customers who want to dispose of an old appliance may return it for recycling or proper destruction, often in exchange for a discount on any new product they buy in return for what can only be described as asocial behavioral key measure of the pollution caused by an entity can help improve systems of reward or penalties as well as encourage environmentally low-carbon lifestyles. While the flow of carbon in the real world is extremely complex, it is feasible to achieve this in the metaverse by creating fungible digital assets on the blockchain. Tokenization makes it possible to trade carbon credits, and carbon markets are created online where voluntary credits may be distributed as goodness-knows how many are used every year. The credits represent emissions that may be rescued from things like forest conservation and measures to store carbon such as soil regeneration and land use management changes. Pointing out the advantage of a more mature Wild West than Western civilization is to itself, will influence both organic growth and sustainable development.

The Reseed Company's platform sets an example for this kind of practice because it uses blockchain technology to monitor carbon stock management from registration through validation and verification. This enables farmers to generate additional income, while affording investors the possibility of a return on their investment. In the final analysis, enterprises ought to move to cloud service techniques and renewable energy sources take up the burden of responsibility for resource consumption; furthermore, we must create a culture that thinks about how products affect the environment and bequeath a green business legacy

Industrial Metaverse has found that it will have various influences on the environment through energy consumption, electronic waste and pollution, which is both positive and negative. However, a large proportion of industrial metaverse applications seem to be having a beneficial impact on the environment and so are now becoming more manageable in terms of sustainability based on this broad-stroke survey general result. Ultimately, businesses need to consider switching to cloud services and energy sources that come from renewable sources in order to achieve sustainability in the Industrial Metaverse. Beyond this, they should also be asking about how products affect the environment and developing a circular economy. 

# Conclusion

The industrial metaverse is a virtual space that is used in industrial sectors to create a virtual interconnected network of real-life hardware, processes, and systems with their digital replica. The industrial metaverse offers a realistic perspective on how manufacturers might put the metaverse into practice, namely by recreating actual events in a virtual environment. The Industrial metaverse is driven by a variety of emerging technologies such as the industrial Internet of Things, Artificial intelligence, mixed reality (AR/VR), Blockchain, cloud computing, edge-computing, digital twin as well as 3D printing and scanning. Several use cases range from industrial design and engineering, supply chain management and logistics, manufacturing operations and maintenance, training, as well as Research and development. Despite being in its early stages of development, the IM has already seen significant real-world implementations by businesses like General Motors (GM), Coca-Cola (HBC), and auto Original Equipment Manufacturers (OEMs). The environment is already being impacted by the IM deployments in both positive and negative ways, via energy consumption, the creation of e-waste, and pollution in certain cases.

Overall research, however, indicates that most industrial metaverse applications have a positive environmental impact and subsequent trend toward sustainability. With the help of IM, we can conduct tasks that would typically require us to be physically present in the real world such as traveling to conventions and concerts, going to work, attending international congresses, and so forth in a fully virtual setting from the comfort of our homes or offices. By doing this, we can drastically lower the tons of greenhouse gases that come from our regular car, train, or airplane travel. Furthermore, on the positive side General Motors (GM) has been using Process Simulate from Siemens to create an ergonomically efficient production line in a short period. GM must update its production line regularly to accommodate for design changes of existing vehicles and the production of new cars. For efficiency, engineers work remotely with virtual reality devices to immerse themselves in the designs. It helps understand manual assembly, hand clearances, operator movements, and the operator’s line of sight. With this information, engineers can identify a problem at an early stage and solve it before the issue occurs in real life. Moreover, IM enables interaction with real-time energy consumption data to enhance their comprehension of energy usage patterns, allowing them to make informed choices regarding their energy consumption.

We begin the conversation about the metaverse's effects on climate change. We anticipate that a metaverse dissemination will lead to higher emissions from energy generation compared to a scenario without one, given the rise in GHG emissions caused by data centers, communication networks, and ICT gadgets. Simultaneously, we anticipate that a metaverse dissemination can lower emissions in the transportation and building sectors by digitizing or substituting virtual activities for emitting ones. All things considered; we anticipate that a metaverse diffusion may lessen emissions than it produces. By sector, the anticipated consequences are summed up in Figure 5.

The metaverse, which combines the physical and digital worlds, is a rapidly growing industry with potential benefits for climate change mitigation. Based on a review of 90 studies, the metaverse’s adoption could reduce global surface temperature by up to 0.02 °C by the end of this century and lower greenhouse gas emissions by 10 gigatons of CO₂ equivalent during its expansion period in the United States. Additionally, it may improve air quality by reducing air pollutant emissions by 10–23% and saving 10% of nationwide energy use by 2050. However, uncertainties remain, and further research is needed to assess its net climate effects comprehensively. Beyond emissions, water use, waste production, and social aspects should also be considered. Policymakers, investors, and stakeholders have an opportunity to shape a sustainable metaverse through governance mechanisms and informed decisions.

However, metaverse shows promise, it’s essential to address potential challenges and ensure inclusivity as it evolves. High upfront costs and infrastructure barriers could exclude certain population groups, and careful monitoring is necessary to align technology trends with net-zero goals.

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