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Environmental Sustainability of Metaverse: Perspectives from Romanian Developers

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Abstract: The metaverse is currently in the process of development and has applications in various fields, ranging from the gaming industry to art, communication, education, and fashion. Researchers regard the metaverse as the future of the internet, and, in this context, the impact of this new universe's development on the environment needs to be investigated to find viable solutions for its sustainability. We have discussed the economic and social sustainability consequences of the metaverse, and we have largely concentrated on the environmental effects. In conducting this research, we used a quantitative methodology mainly based on a structured questionnaire. We analyzed the impact of the metaverse on the environment from the perspective of professionals in the Romanian software development and programming industries. We selected this sample because the field is newly emerging and because they are experts on how the metaverse functions and evolves. We concluded that IT professionals believe that the new universe could have several negative impacts on the natural environment, such as increased power consumption or increased CO_2. emissions and the negative impact can be mitigated by adopting clear regulations and sustainable policies at the international level. This study aims to contribute to the long-term sustainability of the metaverse ecosystem by facilitating a comprehensive understanding of its functioning and evolution, as well as by addressing potential negative impacts on the natural environment. Additionally, the study seeks to make a scholarly contribution to advancing a sustainable metaverse by fostering informed decision-making processes and encouraging responsible practices within the industry. This research might be useful for technology companies, academics, and policymakers.

Keywords: metaverse; sustainability; environment; technology; virtual reality; augmented reality; extended reality; digitalization; artificial intelligence; e-waste; pollution

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1. Introduction

According to mainstream literature, the metaverse is the future of the internet [1], while others consider it to be the latest version of the internet that has grown out of the blockchain [2], and which is a universe combining virtual reality [3] and augmented reality elements, allowing the user an immersive experience. Specifically, the user does not remain a mere viewer, as in the current stage of the web, but they have experiential participation in a new virtual environment that will allow them to solve their tasks at work, benefit from their free time, or perform other types of activities. Therefore, it is a place where users meet in the virtual world, use virtual objects and digital currencies, and interact as they would in the real world [4]. After businessman Mark Zuckerberg announced that Facebook would become "meta" and that the company would focus on developing the metaverse, the term began to be used more frequently [5]. However, the concept is not new; we find it as early as 1992 in Neal Stephenson's novel Snow Crash [6], which describes a parallel universe similar to what the metaverse is now. The metaverse is a virtual space in Stephenson's book where users can connect through technology and interact with other people to work, buy goods, or socialize. Stephenson frames the metaverse as a virtual world inhabited by avatars of real people, and he did this at a time when Web 1.0 was just emerging [7]. Now,

as we are preparing for Web 3.0, we can see the metaverse as an extension of meetings on platforms such as Zoom, Classroom, or Teams. Lee (2021) features this new universe as an immersive 3D environment, a true artificial virtual community [8]. In contrast, Dahan et al. (2022) hypothesize that in the future, the metaverse could contain any digital element [9]. Tech companies such as Facebook (Meta), Nvidia, Roblox, and MultiversX (Figure 1) have announced their commitment to building the metaverse and are allocating significant funds to this effort, and each has its definition of what this entirely new virtual world represents.

Figure 1. Definitions of Metaverse [10–13].

Thus, each of these companies has its vision of the metaverse and will develop a segment for which it is well known. Meta or Roblox will target the metaverse of social media, communication, or entertainment. In contrast, NVIDIA will probably focus on machine learning. Virtual reality, augmented reality, extended reality, and mixed reality are likely to be included in the new universe, according to the vast majority of companies involved in the construction of the metaverse. Currently, the metaverse is in full development, and it is complicated to explain precisely what the whole universe will entail. The new virtual space is like the beginning of Web 1.0, after 1992, when nobody had any idea what the Internet would mean or what it would become. Experts [14–16] have proven the existence of several distinguishable features, such as the use of AI, VR, and AR technologies in the creation and interaction of this new world. (Figure 2). The virtual space that may be bought, owned, and sold is another component of the metaverse. The virtual monetary system and digital aspects, such as non-fungible tokens, are key components of the metaverse. However, to join the metaverse and interact in that area, one requires an avatar, a digital representation of the person designed for virtual communication and interaction. These aspects will be interconnected with artificial intelligence, which cannot be excluded from this system. In addition, during its evolution, the metaverse will integrate more components that will optimize the performance of this virtual world.

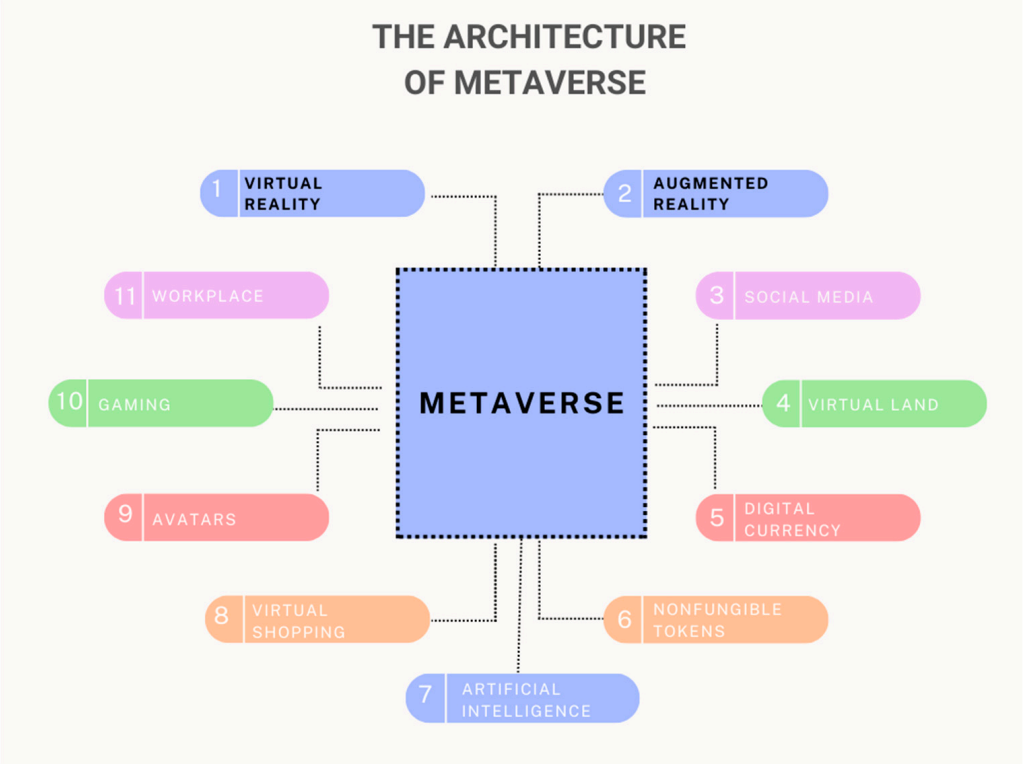

Figure 2. Architecture of metaverse. Data form: [1,14,17].

Even if most people view the metaverse as a stage in the future, this new virtual universe already exists, according to Microsoft CEO Satya Nadella [18]. Several companies are developing the metaverse, and interoperability will define this notion. Hence, it is essential that every user can transition across platforms [19]. These existing trends have been accelerated by the context generated by the COVID-19 pandemic, with work or homeschooling becoming accessible alternatives embraced by many people compared to earlier periods [20]. Considering the factors mentioned above, we can conclude that the metaverse will establish various virtual worlds and be capable of bringing about societal changes. This virtual environment will be connected to and sustained in the physical world; therefore, it is essential to understand its potential and actual environmental impact.

The hypothesis of this study asserts that the development and widespread adoption of the metaverse may result in various adverse environmental effects, such as increased energy consumption and carbon dioxide emissions. However, through effective regulations and adopting sustainable practices, it is possible to mitigate these negative effects and promote the creation of an ecologically sustainable metaverse in the long run.

Our study aims to investigate the possible impacts of the widespread implementation of the metaverse on environmental sustainability. To achieve this objective, we will start with the following questions: What is the impact of the metaverse on environmental well-being, both in terms of potential negative impacts and possible benefits? What are the viable methods or approaches that can be used to ensure the sustained longevity and resilience of the metaverse?

This study has considered various factors, including pivotal elements that exert a substantial environmental impact on the metaverse, such as energy consumption, e-waste production, and pollution. This study also aims to investigate potential solutions to environmental challenges using innovative and sustainable technologies.

Following the introductory section, Section 2 presents an analysis that scrutinizes the impact of the metaverse on sustainability from three distinct perspectives: economic, social, and environmental. Even though the article focuses on environmental sustainability, it could only be analyzed by putting it in relation to the interdependence between the

three perspectives. The Sustainable Development Goals (SDGs) [21], established by the United Nations, have been employed as a comprehensive frame of reference in conjunction with academic literature in the relevant domain. The advantages and disadvantages of a metaverse concerning sustainability have been delineated. Following that, a comprehensive explanation was given about the materials utilized and the methodology employed. Subsequently, the results obtained through the questionnaire methodology were showcased, along with corresponding visual aids that aligned with the participants' answers. Ultimately, the article concluded with comprehensive discussions, conclusive findings, and potential avenues for future research in this field.

2. Metaverse and Sustainability

The metaverse is in full development and is being built at a time when global warming is among the world's most pressing issues [22,23]. Thus, all technological development endeavors must be environmentally conscious. In this sense, metaverse sustainability represents a complex problem currently being investigated and debated.

When discussing sustainability, we need to approach the subject from three perspectives: economic, social, and environmental [24]. The scientific evidence collected so far indicates that the metaverse will impact sustainability, influence the environment, have economic implications, and also affect the social sphere.

2.1. Economic Sustainability

From an economic point of view, the metaverse will create many opportunities. It will have numerous effects on companies developing this new environment and on people using the existing platforms in this virtual universe [25]. For companies, the metaverse will develop innovative marketplaces for digital goods [26], allowing them to sell physical objects through alternative channels to current commerce.

At the same time, it will be feasible to build new marketing methods that are considerably more effective than those already accessible [27]. In addition, firms using the metaverse can offer immersive experiences to improve user engagement, where consumers have the option to virtually test various items and services, which could lead to greater sales and, consequently, competition.

Emerging digital technologies, like online storefronts developed in the metaverse and virtual reality experiences, could help organizations innovate and improve their business models. For example, in the fashion business, the first steps have already been taken, and large companies are now active in this new universe and have produced their own NFTs, or digital apparel. Every corporation can design its own NFT in the metaverse, which might automatically lead to a rise in brand popularity and the creation of new sales opportunities [28]. New business models could be developed in the metaverse, such as medical consultations using virtual and augmented reality or selling real estate such as houses or land in this new environment.

Another aspect of metaverse sustainability that affects the economic side is related to the decrease of transit costs in retail, as this new universe would allow testing some things in the metaverse, which would lead to a reduction in the number of returned products.

Several organizations are now creating new business models in the metaverse, and many transactions are being carried out via the blockchain, using virtual currencies and, in particular, NFTs. This technique can lead to reduced transaction costs as fees that intermediaries might levy are eliminated [29]. This would also instantly reduce the number of complaints created by deceptive product displays and counterfeits, as the buyer would have direct access to the goods through the immersive experience.

However, the potential economic advantages could be overshadowed by various undesirable concerns, such as environmental challenges and social issues.

2.2. Metaverse and Social Sphere

Rapid technological progress, specifically in computers and the Internet, has generated significant repercussions in society [30]. Thus, the metaverse will significantly impact society as a whole, and sustainability in this respect is an important aspect to be considered in developing this new environment.

This concerns the capacity of the metaverse to provide users with a fair and inclusive virtual experience. From a social perspective, the sustainability of the metaverse is crucial to avoiding problems that may arise in this completely new virtual space. Already, researchers believe that the emergence of a metaverse will generate increasing disparities between social origins and broaden the divide between the wealthy and poor [31]. However, we cannot discuss the construction of a perfect virtual world because it could cause major problems in the real world with serious consequences [25]. The metaverse should, first and foremost, be accessible to all social groups in order to be socially sustainable. But implementing virtual or augmented reality technology requires the utilization of specialized eyewear, which incurs a high cost and poses accessibility challenges.

An additional concern is related to the possibility of isolation, and apprehensions have arisen regarding how individuals may engage with one another within the metaverse. Furthermore, there is a potential risk that individuals may be tempted to spend an excessive amount of time within the metaverse, thereby potentially impacting their relationships and interactions beyond the boundaries of this new universe. Simultaneously, the possibility of possessing a parallel identity in the metaverse may prompt certain individuals to abandon social interaction in their physical existence in favor of virtual socialization, potentially resulting in isolation and consequent psychological distress [32].

Another element of social sustainability is safety in the metaverse. In a virtual space that in the future could be accessed by anyone, there is a danger of hazards such as harassment, deception, and cybercrime. This is why strict measures such as two-factor authentication, data encryption, and monitoring of user activity are necessary. Just as there are now policies on using social networking sites, there will need to be explicit regulations against harassment and inappropriate behavior in the metaverse.

A mechanism should also be created so that incidents of this kind can be reported to a team to deal with such situations.

There is an intrinsic and undeniable link between economic sustainability, social sustainability, and environmental sustainability. People coexist in nature, utilizing the natural resources they require. How people live and use resources can damage the environment, resulting in pollution, climate change, and other issues.

2.3. Metaverse and Environment

There are several factors that the creators of this brand-new medium should consider to minimize its detrimental influence on the environment (Figure 3).

Many new electronic devices, such as virtual reality glasses and haptic gloves, are required to enter the metaverse [33], and a vast quantity of this equipment must be manufactured. To build devices that support metaverse technology, it is necessary to use rare materials and enormous quantities of plastic, which pose an environmental risk. Due to increasing CO_2. levels, the design and use of electronic equipment may impact climate change [34]. It takes energy to manufacture, transport, and distribute the equipment. In addition, the growth of Internet technology and applications is related to a rise in electrical power usage [35].

In addition to developing the technology, accessing it by users could require a large amount of energy and therefore generate significant carbon emissions. It would require storing massive amounts of data and constructing new data centers [36].

Another issue closely related to the development of Web 3.0 and the metaverse is e-waste, an environmental problem, especially in the current social environment. The growing demand for the latest technology has led to a significant increase in e-waste [37].

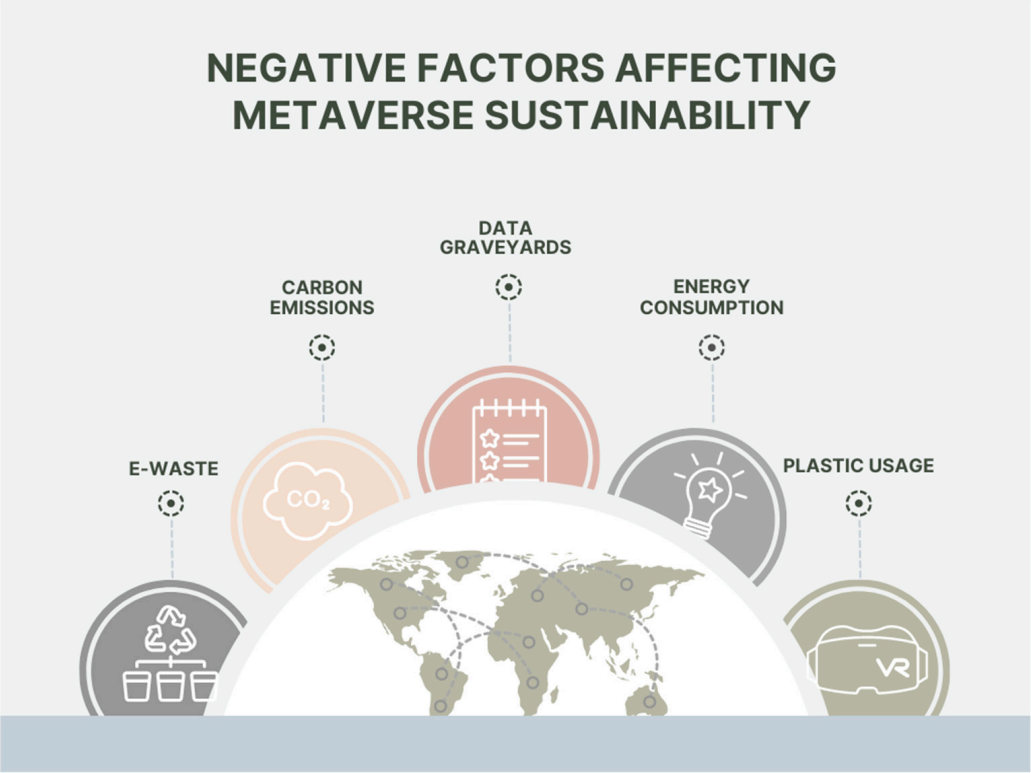

Figure 3. Negative factors affecting metaverse sustainability.

Some researchers see e-waste as a significant risk to the environment because, in many countries, including Romania, waste is thrown away haphazardly, and far too little is recycled. If not properly managed, this waste can pose a major risk to human or animal health and pollute the environment [38].

The Metaverse could also have positive effects on the environment, and one of these aspects is related to the reduction of real-world travel due to the opportunities for organizing business meetings in the new environment. In addition, the metaverse could encourage remote working, limiting pollution's effects [39]. Carbon emissions associated with transportation [40] and those associated with maintaining an office building could be reduced due to the metaverse. All this could contribute to improving air quality.

This study has been developed considering both the negative and positive effects of the metaverse on the environment.

3. Materials and Methods

Our research underpins a quantitative methodology to get a clearer picture of the sustainability of the metaverse. A survey based on the questionnaire method was carried out, and the target group was chosen only from among employees in the Romanian tech industry. Considering that the metaverse is a complex virtual environment involving software development, algorithm usage, structure design, and various other technical aspects, we selected respondents connected with one or more industry segments. Therefore, we have selected a sample of 108 professionals working in the IT industry, including experts in software development, hardware engineering, algorithm specialists, and other technical roles.

The structured questionnaire, created in Google Forms, was used to collect data, containing 11 closed questions and a section allowing respondents to freely express their thoughts on the research topic and better understand individual perspectives and experiences (Figure 4). A first draft of the questionnaire was sent to a small group of 15 people with expertise in the field to ensure the questions were clear (piloting the study), and subsequently, the final version was produced.

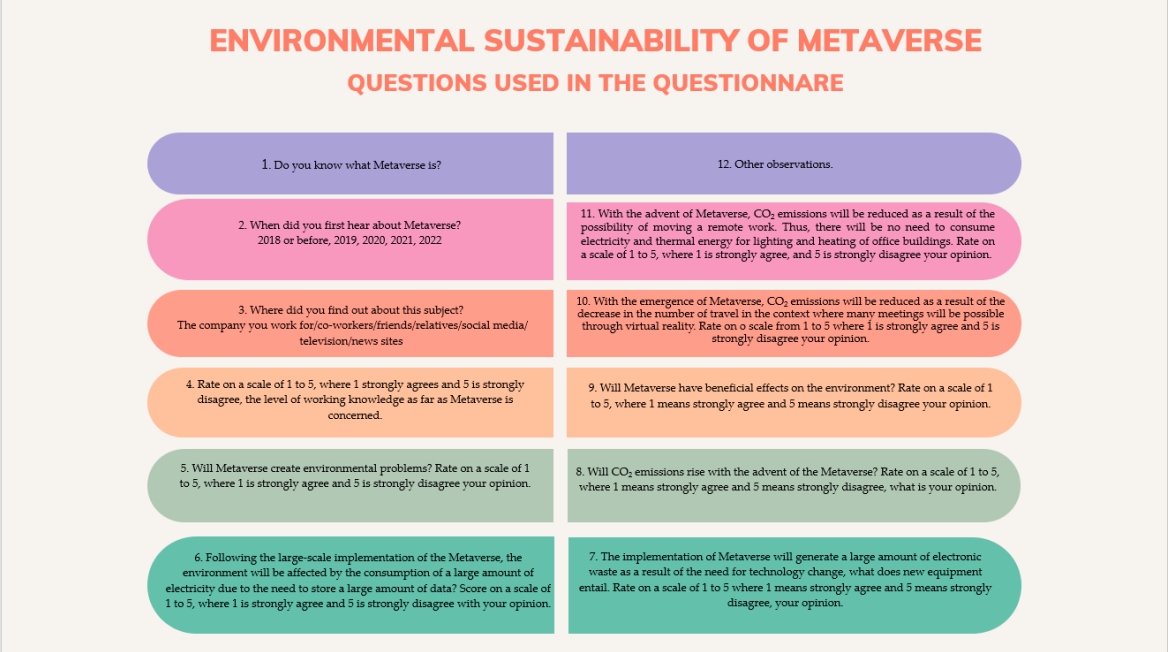

Figure 4. The structure of the questionnaire used in the research.

Eight questions required responses to be expressed on a linear scale from 1 to 5, where 1 represented their total agreement and 5 their total disagreement with the issues. We used different coding and assigned a value of 1 to total agreement and 5 to total disagreement.

To ensure that respondents fully understood the scale and the appropriate coding, we paid particular attention to explaining the questionnaire in detail. Clear instructions were provided at the beginning of the survey, where we clarified the meaning of each response option and pointed out that value 1 signifies total agreement, while value 5 indicates total disagreement.

The results have been properly interpreted, considering the coding used in the questionnaire.

The questionnaire was sent online to five tech companies in Romania. The selection of firms for participation in the study is based on several criteria. Firstly, medium- to large-scale companies were chosen to ensure an adequate sample size. Secondly, companies from various sectors, such as gaming development, automotive technology development, software development, and others, were included to gather insights from different domains and industries. Lastly, the geographic location was taken into consideration. The aim was to ensure representation from various geographical areas within the country. The surveyed employees work in software development, algorithm development, or gaming development.

The first question in the questionnaire clarified an essential aspect of interpreting the data obtained, namely that all respondents had heard of the metaverse and were familiar with this concept.

The study was carried out between November 2022 and February 2023.

For the quantitative analysis, the data collected through the structured questionnaire was analyzed using JASP, version number 0.17.2, an open-source statistical software. We used the Chi-square test to determine if there is a significant relationship between categorical variables, and through Cramer's coefficient, we measured the strength of that relationship.

The analysis aimed to highlight the relationship or association between respondents' perceptions of the environmental impact of the metaverse and their concerns about specific issues like electricity consumption, CO_2 emissions, and e-waste generation. By examining the correlation between these variables, we aimed to understand how these perceptions are related and to what extent they influence each other.

The analytical procedures followed standard statistical principles to derive meaningful insights from the collected data.

The questionnaire method was doubled by direct and indirect observation by the authors, who critically examined, before writing the questionnaire, both reports issued by the European Union [41] and UN bodies [42] on the impact of technological development on the environment.

4. Results

The survey of 108 developers and software engineers revealed that all respondents knew what the metaverse was. About 40% of respondents mentioned that they had heard of the metaverse before 2021 (Figure 5), and this highlights that they have been interested in the technological process over the past few years and can provide valuable answers about the impact of the metaverse on the environment. The data collected indicated that 9.3% had learned about the metaverse from their workplaces.

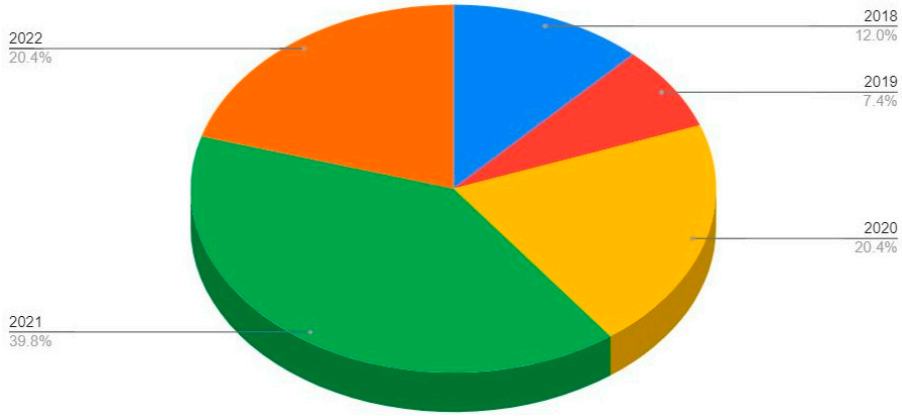

Figure 5. Year in which survey participants first encountered the term "metaverse".

Regarding the level of metaverse working knowledge (Figure 6), for the closed-ended question on a linear scale from 1 to 5, the calculations indicate that the biggest share of respondents know how to work on the metaverse because they selected options 1, 2, or 3, which together amount to 63%. Options 4 and 5 added together indicate that 37% of the respondents do not have knowledge of how to work with this technology, i.e., they are not yet familiar with the procedures by which this new universe is constructed.

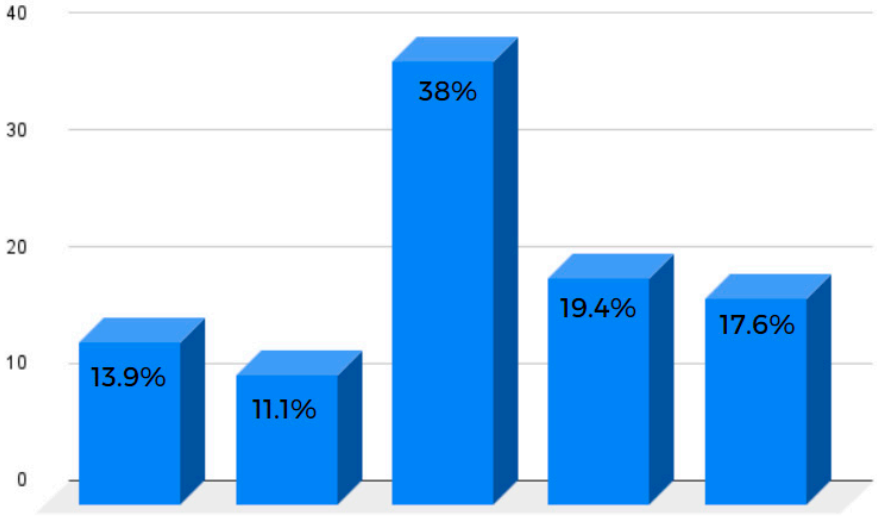

Figure 6. Respondents' level of working on the metaverse.

Developers and software engineers were questioned about whether the metaverse would damage the environment (Figure 7). Admittedly, the majority of respondents (28.7%) selected 3 on a scale from 1 to 5, where 1 represents total agreement and 5 is total disagreement in response to a question, with a 1 to 5 linear response range. The data indicates that the majority of respondents are neutral about the environmental impact of the metaverse. Nevertheless, by adding 1, which means total agreement, to 2, which is an almost total agreement, we have a percentage of 33.4%, which indicates that about one-third of the respondents believe that the metaverse will cause real problems about the environment. At the same time, 14.8% scored 4, meaning that they disagree. Only 23.1% of people believe that the Metaverse will have no impact on the environment.

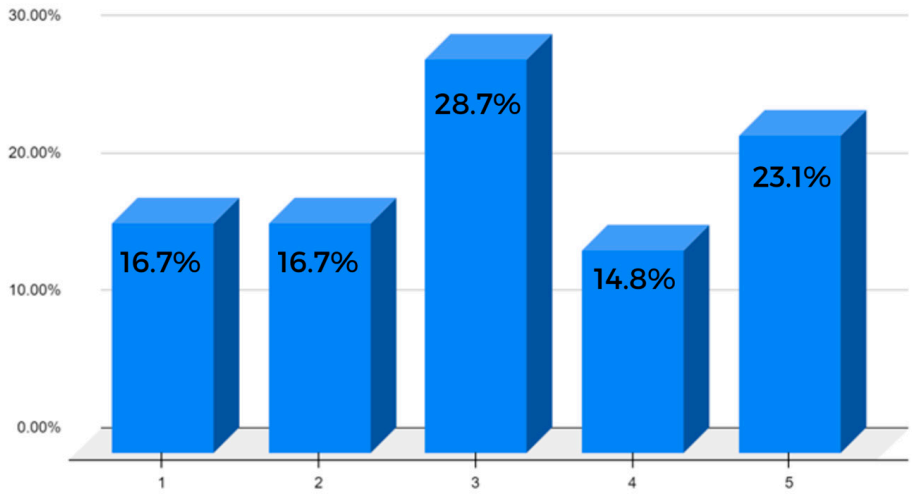

Figure 7. Will the metaverse cause environmental problems?

Regarding the statement that the metaverse will require a large amount of power and will affect the environment due to storing a large amount of data (Figure 8), 22.2% of the surveyed tech industry employees in Romania rated it as 1, i.e., total agreement, which reveals that these respondents believe that the environmental impact will be high; 19.45% scored 2, i.e., they agree, which suggests that these respondents believe that the environmental impact will be serious; 22.2% scored 3, i.e., neutral; 16.7% scored 4, i.e., disagree. Respondents who disagree may hold the belief that the metaverse's power requirements will not be as substantial as suggested, or they may believe that technological advancements will mitigate the environmental impact. On the other hand, 19.45% scored 5, i.e., they strongly disagree, which points out that these respondents strongly believe that the metaverse will not affect the environment through high power consumption and the need for the storage of a large amount of data being completely miscalculated. They strongly assert that the estimation of these effects is completely misguided or inaccurate.

Thus, all this data suggests that the technology underpinning the metaverse can be associated with significant consumption of electrical power. In the present time, the processing, transportation, and storage of data rely on electricity consumption. Furthermore, the functioning of the metaverse necessitates the utilization of servers and data centers to uphold and regulate virtual reality. Additionally, to maintain optimal functionality and control the temperature, a significant amount of energy must be expended, necessitating an additional supply of electrical power. The utilization of the metaverse has the potential to result in heightened internet traffic, necessitating the expansion of infrastructure to accommodate the increased demand. And the use of electrical power has the potential to yield noteworthy ecological consequences.

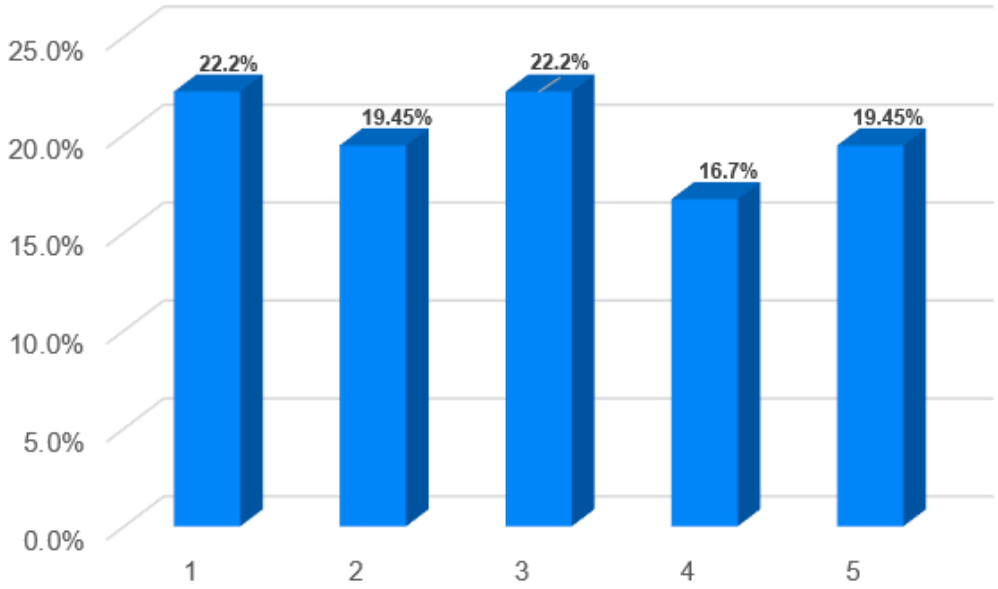

Figure 8. Metaverse will require a large volume of power due to the storage of a huge volume of data.

In a context where United Nations statistics [43] indicate that a noteworthy portion of the energy utilized in the digital domain is derived from non-renewable sources, potentially resulting in greenhouse gas release and the consequent impact on the climate. For example, the process of energy production has the potential to result in the release of supplementary emissions of gases and other pollutants. Conversely, heightened electricity consumption may necessitate the construction of supplementary power facilities to cater to worldwide energy demands. The construction of such facilities in natural areas or on agricultural land could potentially have adverse effects on ecosystems and local communities.

Also, the production of components and equipment required for accessing the metaverse will necessitate a substantial quantity of electricity. And when new equipment hits the market, old equipment goes to waste.

Additionally, the target audience was questioned about whether or not the implementation of metaverse technology would generate a substantial amount of electronic waste. On a scale from 1 to 5, with 1 indicating total agreement and 5 indicating total disagreement, respondents were asked to rate their level of agreement or disagreement. The response distribution shows that a sizeable proportion of the respondents were concerned about the potential for electronic waste to be generated by metaverse technology, with 15.7% agreeing and 22.2% mostly agreeing. However, the biggest share of respondents (30.6%) were relatively neutral about the topic.

We used the Chi-square test and Cramer's coefficient to study the existence and association between variants measured on the scale. As mentioned in the methodology, to determine these correlations, we used JASP software. We paired question number 6 from the questionnaire with "Metaverse will require a large amount of energy due to storing a large amount of data?" (series 1. Figure 9) with question number 7: "Will the Metaverse implementation generate a large amount of e-waste? (series 2, Figure 9).

The high values of the Chi-Square test (X^2 = 121.922) and the Cramer coefficient (V = 0.529) suggest a strong correlation between these two variables (Table 1).

Table 1. Results of Chi-Square Test and Cramer's V between questions 6 and 7.

Test	Value	df	*p*
X^2 (chi-square)	121.922	16	<0.001
N	109		
Phi-coefficient	NaN		
Cramer's V	0.529		

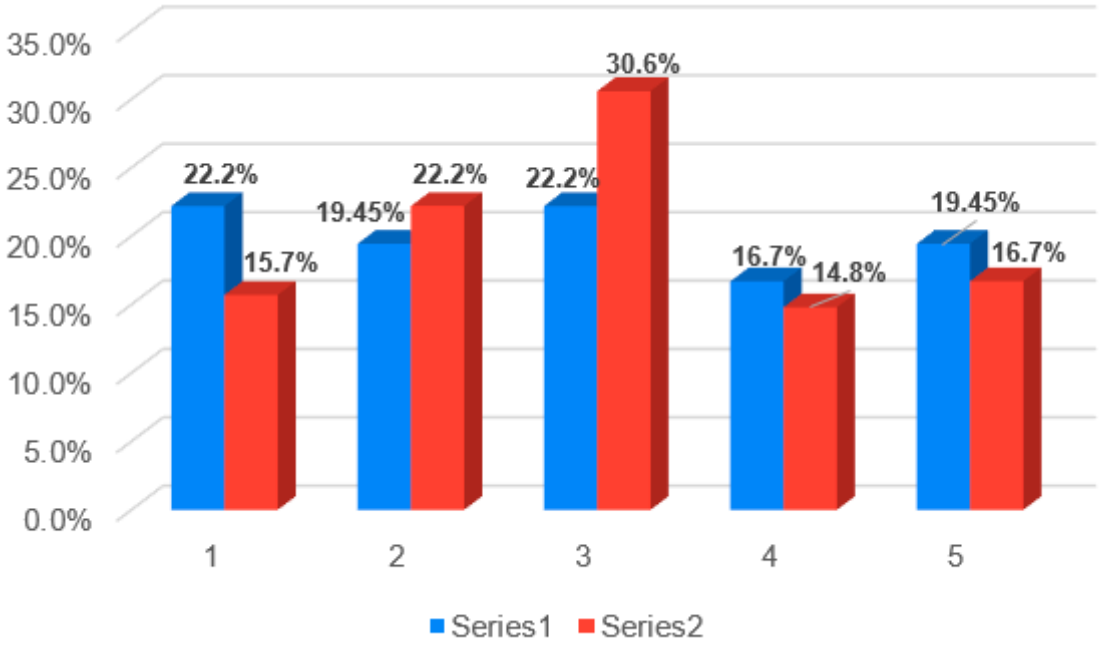

Figure 9. Series 1. Metaverse will require a large amount of energy due to storing a large amount of data. Series 2. Will the Metaverse implementation generate a large amount of e-waste?

In terms of interpreting these results, we can conclude that there is a significant relationship between respondents' perceptions of the metaverse environmental impact in terms of electricity consumption and waste generation. Those who believe that the metaverse will harm the environment because of its high electricity consumption are more likely to believe that this new universe will generate a large amount of waste.

Linking this interpretation to sustainability in general, people concerned about the potential negative impacts of the metaverse in terms of electricity consumption and CO_2 emissions may also be more aware of human activities' consequences for climate change and pollution.

The concerns of IT employees about e-waste pollution are justified when considering statistical data. Over 50 million tonnes of e-waste from end-of-life equipment are generated worldwide annually [44]. Therefore, the issue of e-waste has attracted IT employees' attention and also the attention of international organizations, government institutions, and environmental NGOs because of the adverse effects it can cause on the natural environment.

The category of e-waste includes electronic devices that have either reached the end of their useful lives or are obsolete and no longer viable. According to a report by the United Nations International Centre for Environmental Technology [45], the annual e-waste production per individual is estimated at around 6 kg.

The exponential increase in users accessing the metaverse means new electronic devices are being purchased, resulting in old electronics being thrown away.

So, entry into the metaverse could contribute to increased demand for new equipment. As the new universe emerges, accessing it will involve using gadgets that support this emerging technology.

In this context, recycling e-waste is a crucial environmental solution due to the presence of hazardous materials that have the potential to contaminate the environment and need to be collected appropriately.

Materials such as plastics and other non-biodegradable components have the potential to persist in the environment for long periods of time.

In addition, it should be noted that recycling this particular category of waste can involve a significant financial investment. For example, at the European Union level, the disassembly and disposal of such equipment requires special procedures that must comply with environmental conservation regulations.

The recycling procedure involves specific methodologies to extract valuable substances and mitigate environmental contamination. To address the potential negative environmental impact of the metaverse in terms of e-waste generation, it is imperative that metaverse developers proactively consider sustainable technologies. An example of this would be creating sustainable and environmentally friendly equipment that can be used over an extended period of time. In addition, individuals need to recognize the adverse effects of e-waste and behave responsibly when disassembling and disposing of previously used electronic devices. The solution to this problem could come precisely from the metaverse. Environmental organizations, public institutions, and universities have the potential to create educational programs in the metaverse about e-waste recycling that are accessible and understandable to the general public. Such initiatives could raise awareness of the harmful effects of e-waste.

The issue of e-waste and electricity consumption has been found to contribute to environmental pollution and increased carbon dioxide levels. With this in mind, participants were surveyed to assess their attitudes toward this issue.

The majority of tech industry employees interviewed believe that the development of the metaverse will lead to an increase in CO_2. emissions. Thus, out of the five options, the distribution of responses is as follows: 14.8% answered (1), 12% answered (2), 35.2% answered (3), 14.8% answered (4), and 23.1% answered (5).

For an in-depth analysis and interpretation, we analyzed the correlation between question 6 (series 1. Figure 10) of the questionnaire and question 8 (Series 2. Figure 10).

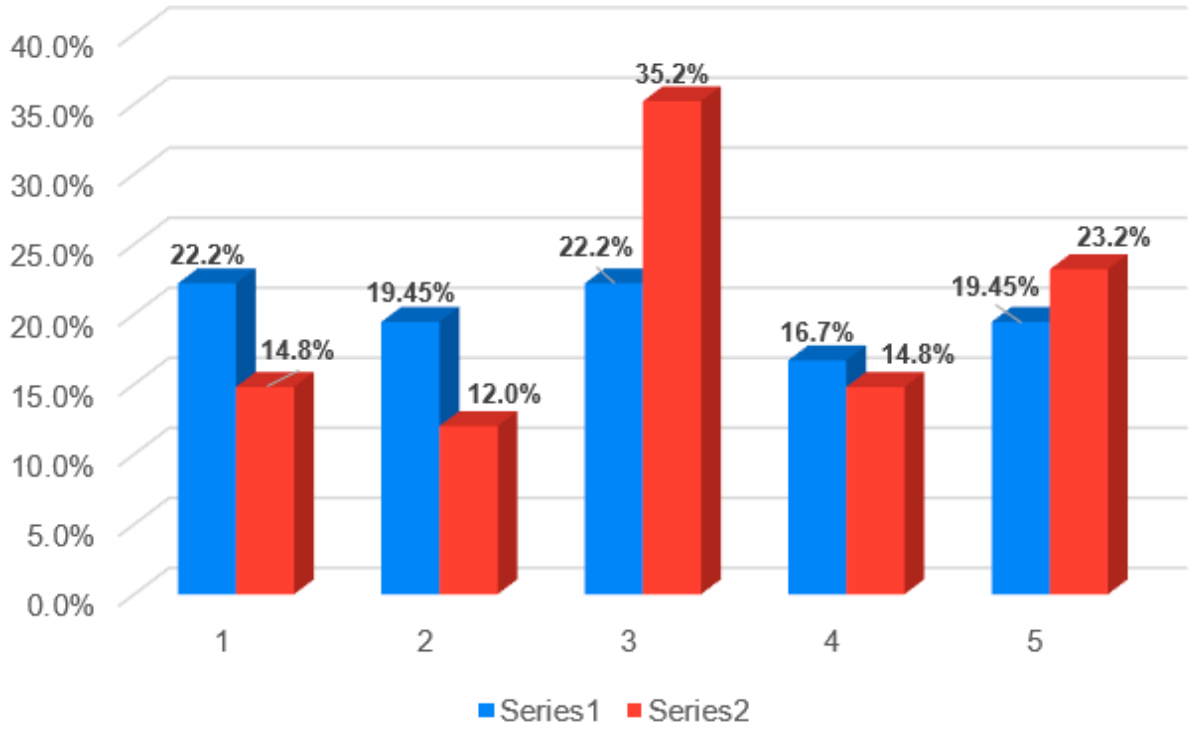

Figure 10. Series 1. Will Metaverse cause environmental problems due to high electricity consumption? Series 2. Will Metaverse harm the environment due to CO_2 emissions?

The results of our analysis (Table 2) indicate a significant correlation between question number 6 used in the questionnaire, "Will Metaverse cause environmental problems due to high electricity consumption?" and question number 8: "Will Metaverse harm the environment due to CO_2 emissions?".

Table 2. Results of Chi-Square Test and Cramer's V between questions 6 and 8.

Test	Value	df	*p*
X^2 (chi-square)	130.462	16	<0.001
N	109		
Phi-coefficient	NaN		
Cramer's V	0.547		

Chi-Square test values (X^2 = 130.462) and Cramer's coefficient (V = 0.547) suggest a strong association between these two questions.

Interpretation of these results indicates that respondents who believe that the metaverse will cause environmental problems due to high electricity consumption are also likely to believe that it will harm the environment due to CO_2 emissions.

Our results suggest that there is a strong link between perceptions of electricity consumption and concern about CO_2 emissions in terms of the environmental impact of the metaverse.

This association implies that these respondents recognize the connection between electricity consumption, CO_2 emissions, and the potential environmental risks associated with the metaverse.

High electricity consumption from non-renewable sources will lead to greenhouse gas emissions, which can contribute to climate change, such as global warming. The production of large quantities of electricity involves polluting factors that affect air quality and soil and can negatively affect the entire ecosystem. The generation of electricity involves exploiting natural resources, especially fossil fuels, which can result in the degradation of natural habitats. Both flora and fauna could be negatively impacted. So developers and users must acknowledge the potential consequences of the metaverse on the environment and implement measures to mitigate its effects.

A significant correlation was also found by correlating questions 7 and 8 of the questionnaire (Table 3).

Table 3. Results of Chi-Square Test and Cramer's V between questions 7 and 8.

Test	Value	df	*p*
X^2 (chi-square)	109.373	16	<0.001
N	109		
Phi-coefficient	NaN		
Cramer's V	0.501		

The high values of the Chi-Square test (X^2 = 109.373) and Cramer's coefficient (V = 0.501) indicate a strong association between respondents' perceptions of the environmental impact of the metaverse in terms of electricity consumption and e-waste generation.

Interpretation of these results suggests a significant relationship between respondents' perception of the environmental impact of the metaverse in terms of CO_2 emissions and their concern about e-waste generation. Those who believe that the metaverse will cause environmental problems through high electricity consumption are also more likely to believe that it will generate a large amount of e-waste due to the need to change technology and use new equipment.

This implies that they are aware of the detrimental consequences of electronic waste, such as resource depletion, pollution, and the inefficient use of materials.

Therefore, subjects such as electricity consumption and environmental impact are taken into consideration when people form their opinions about the effects of the metaverse on CO_2 emissions.

The Metaverse has the potential to exert a notable adverse effect on the environment, yet it also presents notable advantages.

Concurrently, the positive effects on the environment were contextualized to provide an overview of the topic. In response to the question of whether the metaverse will

have positive effects on the environment (Figure 11), 12% of respondents indicated whole agreement, 17.6% almost total agreement, 37% neutrality, 19.4% disagreement, and 13.9% total disagreement.

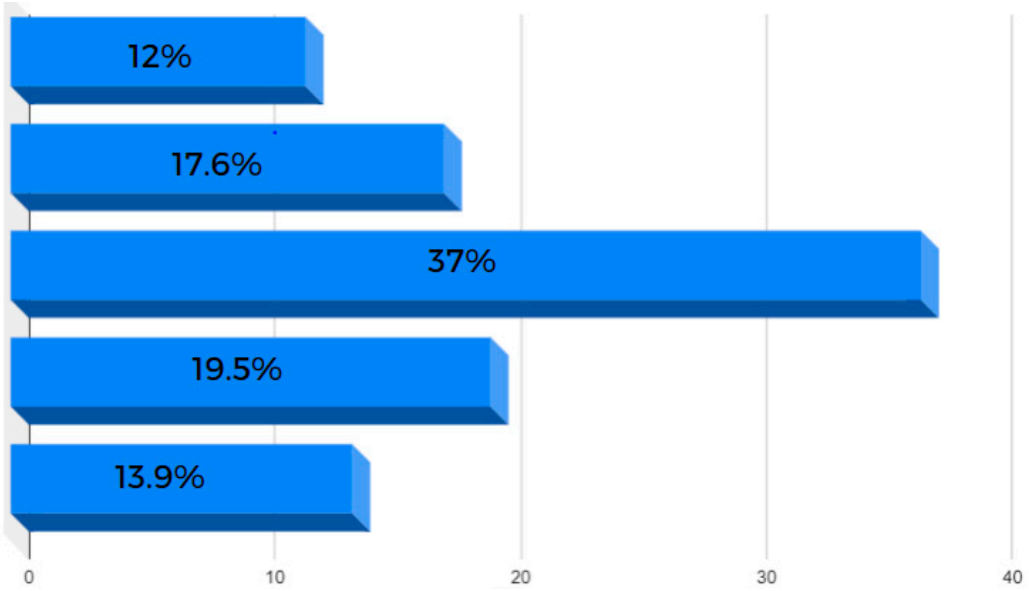

Figure 11. Metaverse will have beneficial effects on the environment.

The Metaverse is a significant consumer of electricity; however, its implementation has the potential to mitigate energy consumption. One potential solution is to transfer certain tasks to the metaverse while substituting physical offices with virtual ones. The consumption of energy resources by office buildings for various purposes such as heating, cooling, lighting, and maintenance is considerable. However, transitioning the workplace from the physical office to the metaverse has the potential to eliminate this need, leading to a substantial reduction in energy consumption.

Respondents were also asked about their opinions regarding the potential reduction in CO_2 emissions with the introduction of the Metaverse, considering the decrease in travel and the ability to conduct meetings and remote work through virtual reality (Series 1, Figure 12). Most respondents, 37%, expressed a neutral stance towards this aspect. Similar results were obtained for the question of whether CO_2 emissions would be reduced with the advent of the Metaverse due to eliminating the need for electricity and thermal energy consumption in office buildings for lighting and heating purposes (Series 2, Figure 12).

Results of the association analysis between question number 10 "With the advent of the metaverse, CO_2 emissions will be reduced as a result of less travel as many meetings can be done via virtual reality" and question number 11 "With the advent of the metaverse, CO_2 emissions will be reduced as a result of the possibility to work remotely. This will eliminate the need to use electricity and heat for lighting and heating office buildings", indicates a significant association between the two questions (Table 4).

Table 4. Results of Chi-Square Test and Cramer's V between questions 10 and 11.

Test	Value	df	*p*
X^2 (chi-square)	243.334	16	<0.001
N	109		
Phi-coefficient	NaN		
Cramer's V	0.747		

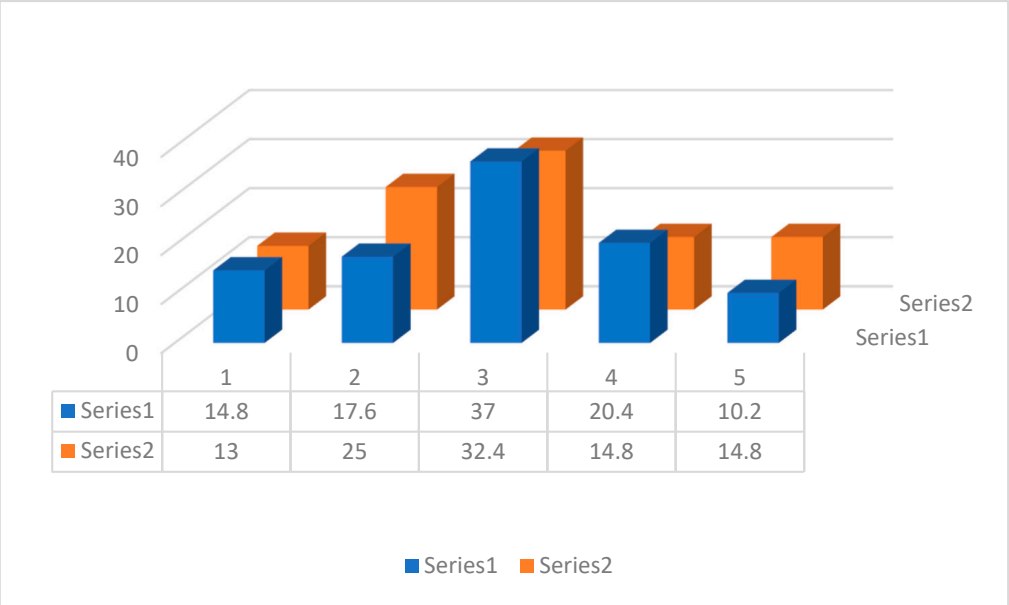

Figure 12. Series 1 With the advent of the metaverse, CO_2 emissions will be reduced as a result of less travel as many meetings can be done via virtual reality, Series 2. With the advent of the metaverse, CO_2 emissions will be reduced as a result of the possibility of working remotely. This will eliminate the need to use electricity and heat for lighting and heating office buildings.

High Chi-Square test values ($X^2 = 243.334$) and Cramer's coefficient ($V = 0.747$) suggest a strong association between respondents' perceptions of CO_2 reduction in the context of the metaverse and the potential benefits of reducing energy consumption in offices.

Interpretation of these results shows that there is a significant correlation between respondents' perceptions of reduced CO_2 emissions as a result of metaverse implementation and their views of the benefits of working remotely and virtual meetings. Those who believe that the metaverse can reduce CO_2 emissions by reducing travel and the possibility of working remotely are more likely to agree that it can bring benefits in terms of reducing electricity and heat consumption in office buildings.

An additional advantage of implementing this technology would be the mitigation of environmental pollution resulting from vehicular congestion on roads. The adoption of the metaverse and the reduction of commutes to physical offices may present a feasible approach to mitigating environmental consequences. Furthermore, this option has the potential to decrease the number of external trips. Also, conferences and educational events in the metaverse offer substantial environmental benefits compared to traditional physical gatherings. Hosting events in the metaverse eliminates the requirement for large-scale infrastructure and venue setups. Physical conferences often entail energy-intensive lighting and sound systems and the consumption of various resources. This significantly reduces waste generation, energy consumption, and the overall environmental impact associated with organizing and hosting events. So the metaverse has the potential to facilitate the creation of intelligent urban areas that employ advanced technological systems to optimize resource utilization and mitigate ecological harm.

The questionnaire also included a section where respondents had the opportunity to freely express their opinions regarding the sustainability of the metaverse. After analyzing the comments, various views and concerns about the concept of the metaverse can be observed. Some respondents stress the importance of recycling and proper management of e-waste, including obsolete or defective components. They raised the point that laws and regulations need to be formulated in a way that promotes recycling and provides a framework for corporate responsibility in this regard. It is also pointed out that some components can be reused or recycled in other devices to extend their useful life. However, it is stressed that it is important to understand the long-term impact of the metaverse concept and how

it will interact with other emerging technologies, such as blockchain. Some users express concern that the move to a virtual environment could hurt social interactions and lead to a loss of authentic human connections. In conclusion, the discussions and comments raised various issues and questions related to the metaverse, including environmental impacts, social implications, e-waste management, and interaction with other technologies.

5. Discussion

The metaverse will have multiple utilities [46], and it could completely change the way we interact and communicate at this time when information is transmitted at an astonishing speed [47]. Moreover, it can provide solutions to the labor crisis in certain geographical areas without generating problems related to overpopulation, transportation, integration, etc. [48]. Hence, technology is booming, and artificial intelligence, the metaverse, and other emerging tools cannot be deterred. At the same time, concerns about sustainability have spread, and there has been a strong focus on environmental protection. It is therefore highly important that all these digital innovations be based on sustainability. The metaverse, like any digital technology, can make its mark on the environment, and the impact can be major if action is not taken at the right time.

For example, major companies developing the metaverse [49–53] have announced that they are actively engaged in developing sustainable technologies, optimizing the hardware and software used to reduce energy consumption and carbon dioxide emissions, as well as using solar or other renewable energy sources. All these sustainable policies can have significant implications for reducing negative environmental impacts. At the same time, much depends on government policies and the role of authorities in developing and managing the metaverse [54]. In addition, a possible international agreement in this respect could limit the negative environmental impact.

We can also identify several environmental benefits of the metaverse, as we have shown in this study. Remote working and meetings in the metaverse could reduce CO_2 emissions.

In addition, the educational aspect should also be considered, which we shall address as a further research direction. Virtual applications can be developed to educate people about the impact of human actions on the environment. Furthermore, platforms can be built in the metaverse through which users can learn about sustainability, thus encouraging sustainable consumption patterns. Hence, the article presents a comprehensive analysis of the sustainability challenges and opportunities associated with the development and adoption of the metaverse. It identifies several key areas that require attention and solutions to ensure the sustainable and beneficial evolution of the metaverse. The findings indicate that optimizing energy consumption, transitioning to renewable energy sources, and proper electronic waste management are crucial aspects of the metaverse's sustainability. The article also highlights the importance of social responsibility, transparency, and collaboration among stakeholders in developing common standards and regulations to address the environmental issues associated with the metaverse. Furthermore, the article suggests that education and awareness play a crucial role in promoting the sustainability of the metaverse. By educating users and developers about their impact on the environment and encouraging responsible practices, the negative impacts of the metaverse can be reduced. Overall, the article's analysis provides relevant information for technology companies, academics, and decision-makers, contributing to the development and adoption of viable solutions for metaverse sustainability. The article's findings are essential for ensuring that the metaverse evolves into a sustainable and beneficial environment for society and the environment.

This study has limitations related to the timing of the study when the metaverse is still in its infancy. As technology is developing rapidly, its impact on the environment could also change in the future. Another mention concerns the fact that the questionnaire method applied only to one social category could be subjective in a context where employees in the IT industry are generally in favor of technological progress and may tend to act as

mediators on the subject. Thus, future research is necessary to include, first and foremost, the perspective of the industry that is developing the metaverse. Additionally, the present study will be complemented by incorporating the views of the population to understand their perception of this aspect, with a particular emphasis on the educational dimension regarding the sustainability of the metaverse.

6. Conclusions

The metaverse has the potential to have an impact on the environment. The data collected during our research raises concerns about several issues. For example, the constant technology change will inevitably lead to a significant amount of e-waste, as old devices will not be able to support the new platforms and new equipment will be needed. E-waste can contain toxic substances and damage the environment and people's health. Another problem that the metaverse could cause for the environment is related to high energy consumption. The Metaverse could negatively impact the environment from an energy point of view, as it will use encryption technologies to maintain the security and integrity of the data and store all the information. This is likely to lead to increased power consumption and, therefore, increased carbon dioxide emissions, especially if the source of electricity comes from fossil fuels.

Adopting sustainable policies enables the mitigation of all negative effects. Instead of energy-intensive apparatus, for instance, developers may opt for environmentally friendly solutions, such as using energy from renewable sources with minimal environmental impact.

Additionally, users of this new technology can be educated on sustainable practices. Through education, they can be encouraged to use energy-efficient equipment and not overburden devices.

Moreover, recycling and waste disposal technologies can be utilized to reduce environmental impacts.

Consequently, although we envision a virtual world, the use of this technology could have real-world implications, and only rigorous regulations could limit the effects. Thus, international organizations such as the UN, together with authorities with decision-making power on environmental protection policies, can play an important role in reducing the negative impact. International treaties and legislation could impose certain environmental standards and strict requirements on the resources used to sustain the metaverse. Clear rules could be set for the use of renewable energy sources such as solar or wind. In addition, standards could be imposed for technological efficiency. This could include the use of low-energy technologies. Establishing policies to recycle waste from electronic equipment could also limit the negative effects of the metaverse.

To sum up, setting regulations could help reduce the negative impact of the metaverse on the planet and protect the environment for generations to come.

Companies and industries can play a crucial role in educating consumers about sustainable technology as part of their efforts to adopt environmentally friendly policies. For example, companies can launch awareness campaigns focused on promoting sustainable technology and its benefits to consumers. They can also transparently label their products, providing clear information on the sustainability features of their products. This may involve labeling products with relevant eco-certifications and sharing information on responsible use and recycling. Additionally, companies can collaborate with research institutions and universities to develop and promote sustainable technologies. Partnerships of this kind can facilitate the academic exchange of experiences and contribute to the development of green solutions to address environmental challenges.

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Institutional Review Board Statement: Before starting our research, we received a recommendation from the Committee of the University of Craiova that it is not necessary to obtain a written agreement for our research, as it does not pertain to gender or equity, and it is anonymous research. Our research evaluated the impact of the metaverse on the environment using the questionnaire method. We have taken appropriate measures to protect the confidentiality of the subjects and the anonymity of the collected data. In addition, we have ensured the informed consent of the subjects and respected their rights and freedoms. Additionally, we have respected relevant international ethical standards. Therefore, we believe that our research has been conducted in accordance with adequate ethical standards.

Informed Consent Statement: Written consent was not requested because the responses were anonymous, but informed consent was obtained from all subjects involved in the study.

Data Availability Statement: These are the data in the google forms: questionnaire structure and results. https://forms.gle/pj4DLjBRRdSeCQJM8 (accessed on 6 July 2023). https://docs.google.com/spreadsheets/d/10nqul8w9kCfgyZDPq9moDGVTiSkwkd2p5tNS-Tx72ZU/edit?resourcekey#gid=113156659 (accessed on 6 July 2023).

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