ENVIRONMENTAL AWARENESS AND DIGITAL SUSTAINABILITY IN THE CONTEXT OF CRYPTOCURRENCIES AND BLOCKCHAIN TECHNOLOGIES: A STUDY AMONG INFORMATICS AND TECHNOLOGY TEACHER EDUCATION STUDENTS

CONSCIÊNCIA AMBIENTAL E SUSTENTABILIDADE DIGITAL NO CONTEXTO DAS CRIPTOMOEDAS E TECNOLOGIAS BLOCKCHAIN: UM ESTUDO ENTRE ESTUDANTES DE FORMAÇÃO DE PROFESSORES DE INFORMÁTICA E TECNOLOGIA

Stepan Hubalovsky*
* Faculty of Education (Pedagogická fakulta) at the University of Hradec Králové (UHK)
Hradec Kralove, Czech Republic
Orcid: https://orcid.org/0000-0002-1570-222X
stepan.hubalovsky@uhk.cz

Marie Hubalovska*
* Faculty of Education (Pedagogická fakulta) at the University of Hradec Králové (UHK)
Hradec Kralove, Czech Repubic
Orcid: https://orcid.org/0000-0002-9834-0278
marie.hubalovska@uhk.cz

The authors declare that there is no conflict of interest

Abstract

This study examines the level of knowledge and awareness of cryptocurrencies and blockchain technologies among pre-service teachers of Informatics and Technology, with a specific focus on the perception of their environmental impacts and attitudes toward sustainability in digital technologies. The research was conducted through a questionnaire survey (N = 110) that included items related to knowledge and use of cryptocurrencies, awareness of energy consumption and environmental effects of blockchain, and support for integrating sustainability into education. Descriptive statistics and inferential analysis (t-tests and Spearman correlations) were used to evaluate four research hypotheses. The findings indicate that students demonstrate generally positive attitudes toward sustainability in digital technologies; however, their actual knowledge of environmental consequences associated with cryptocurrencies and blockchain remains limited and fragmented. None of the tested hypotheses were statistically confirmed, suggesting that environmental attitudes are not closely linked to technological knowledge or cryptocurrency usage. These results highlight the need to incorporate topics such as digital sustainability, environmental informatics, blockchain, and

Resumo

Este estudo examina o nível de conhecimento e conscientização sobre criptomoedas e tecnologias blockchain entre futuros professores de Informática e Tecnologia, com foco específico na percepção de seus impactos ambientais e atitudes em relação à sustentabilidade em tecnologias digitais. A pesquisa foi conduzida por meio de um questionário (N = 110) que incluiu itens relacionados ao conhecimento e uso de criptomoedas, conscientização sobre o consumo de energia e os efeitos ambientais do blockchain, e apoio à integração da sustentabilidade na educação. Estatísticas descritivas e análises inferenciais (testes t e correlações de Spearman) foram utilizadas para avaliar quatro hipóteses de pesquisa. Os resultados indicam que os alunos demonstram atitudes geralmente positivas em relação à sustentabilidade em tecnologias digitais; no entanto, seu conhecimento real sobre as consequências ambientais associadas a criptomoedas e blockchain permanece limitado e fragmentado. Nenhuma das hipóteses testadas foi estatisticamente confirmada, sugerindo que as atitudes ambientais não estão intimamente ligadas ao conhecimento tecnológico ou ao uso de criptomoedas. Esses resultados destacam a
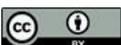
ethical technology use into teacher education curricula. The study also outlines implications for pedagogical practice and provides recommendations for future research, including longitudinal studies and the integration of project-based and simulation teaching methods.

Keywords: Cryptocurrencies. Digital Sustainability. Teacher Education. Environmental Awareness.

necessidade de incorporar tópicos como sustentabilidade digital, informática ambiental, blockchain e uso ético da tecnologia nos currículos de formação de professores. O estudo também destaca implicações para a prática pedagógica e fornece recomendações para pesquisas futuras, incluindo estudos longitudinais e a integração de métodos de ensino baseados em projetos e simulação.

Palavras-chave: Criptomoedas. Sustentabilidade Digital. Formação de Professores. Conscientização Ambiental.

1 INTRODUCTION

The rapid development of digital technologies and the expansion of decentralized systems have brought cryptocurrencies and blockchain to the forefront of both technological innovation and public debate. While blockchain has been widely recognized for its potential to transform financial services, digital identity systems, supply chain management, and education, the energy consumption and environmental impacts associated with some consensus mechanisms—particularly Proof of Work (PoW)—have become a subject of growing concern. Current research highlights significant carbon emissions, high electricity usage comparable to the annual consumption of medium-sized states, and considerable generation of electronic waste associated with cryptocurrency mining. These issues position blockchain within the broader discourse on digital sustainability, environmental responsibility, and ethical technology development.

Despite the increasing visibility of cryptocurrencies in media and society, empirical studies show that students, including those preparing for teaching in technology and informatics, often possess limited or superficial knowledge of blockchain principles and their environmental consequences. At the same time, sustainability is becoming a key priority in education policies, with frameworks such as Education for Sustainable Development (ESD) and DigComp 2.2 emphasizing responsible and environmentally aware digital practices.

Given that pre-service teachers will play a crucial role in shaping students' technological thinking, digital citizenship, and environmental responsibility, it is essential to explore how well they understand the environmental dimensions of emerging digital technologies. This study investigates the relationship between knowledge of

cryptocurrencies, perceived environmental impacts, and attitudes toward sustainability among future ICT and Technology educators. By addressing this research gap, the study aims to provide evidence-based recommendations for curriculum development, interdisciplinary approaches in digital education, and pedagogical strategies that support critical and responsible engagement with modern technologies.

2 THEORETICAL BACKGROUND

2.1 Cryptocurrencies and blockchain in the context of the digital economy

Cryptocurrencies represent a specific form of digital asset that leverages cryptography and a decentralized database – the blockchain – to ensure security, transparency, and immutability of transactions. Blockchain is a distributed ledger in which transactions are grouped into blocks, arranged chronologically, and linked together through cryptographic hashes, providing high resistance to data manipulation [1]. Over the past decade, blockchain technology has expanded beyond financial services into other sectors such as supply chain management, healthcare, education, and public administration [2].

The rapid growth of cryptocurrencies, led by Bitcoin and other major projects, has simultaneously raised questions regarding their social and environmental sustainability. While proponents highlight the potential for financial inclusion, new forms of ownership, and innovation within the digital economy, critics point out the high energy consumption, carbon footprint, and electronic waste associated with cryptocurrency production and operation [3],[4],[5],[6]. These aspects form the starting point for discussion about the role of cryptocurrencies within the context of sustainable development and ESG frameworks (Environmental, Social, Governance).

2.2 Energy intensity and environmental impacts of PoW

Most "first-generation" cryptocurrencies employ the Proof of Work (PoW) consensus mechanism, in which network security is ensured through competition among computational nodes solving highly complex cryptographic puzzles. This process results in exceptionally high electricity consumption, which in the case of Bitcoin has

consistently reached hundreds of terawatt-hours annually—comparable to the total energy usage of medium-sized countries [5],[7],[8]. Current estimates suggest that between 2021 and 2023, Bitcoin was responsible for approximately 60–90 Mt of CO_2 emissions per year, a level equivalent to the annual emissions of smaller European nations [5],[9],[10].

In addition to direct electricity consumption, PoW generates significant quantities of electronic waste. Specialized mining hardware (ASICs and high-performance GPUs) has a limited lifecycle and is frequently replaced by more efficient devices within 1.5–2 years, resulting in thousands of tons of e-waste annually [9],[11],[12]. Life-Cycle Assessment (LCA) studies indicate that the environmental impacts of cryptocurrency mining are not limited to the operational phase (electricity consumption), but also derive from raw material extraction, chip manufacturing, and device disposal [6],[11].

Recent review studies conclude that PoW is among the most environmentally problematic digital technologies in terms of carbon footprint, energy demand, and waste generation [8],[11],[13]. In its recent report on the environmental impacts of digital assets, the OECD emphasizes that without regulation and a transition to less energy-intensive consensus mechanisms, cryptocurrencies may become a significant barrier to achieving climate targets [10].

2.3 Alternative consensus mechanisms and sustainable blockchains

In response to criticism of PoW, both research and industry practice have increasingly focused on more energy-efficient consensus mechanisms, particularly Proof of Stake (PoS), Proof of Space (PoSp), and their variants, including Proof of Space and Time (PoST). PoS replaces computational competition with an economic stake—the probability of creating a new block is determined by the amount of tokens "staked," which dramatically reduces energy consumption [14][15]. The transition of major projects such as Ethereum from PoW to PoS has resulted in more than a 99% reduction in energy usage, without significantly disrupting network functionality [15][16].

Proof of Space and Proof of Space and Time rely on a different source of "trustworthiness"—instead of computational power or financial capital, they utilize storage capacity and the temporal consistency of its use [2][17]. Although the energy requirements of these systems are orders of magnitude lower than PoW, they introduce

new challenges related to material intensity (HDD/SSD hardware demands) and circular ICT economy considerations [2][17][18].

Recent systematic reviews focused on energy-efficient blockchain consensus mechanisms indicate that a combination of architectural optimization, migration to PoS/PoST, and the integration of renewable energy sources forms the foundation for so-called sustainable blockchain ecosystems [1][16].

2.4 Regulation and sustainability framework of digital assets

At the macro level, the issue of the environmental impacts of cryptocurrencies and digital technologies has been receiving increasing attention from regulatory institutions. The OECD and other international organizations emphasize that emissions associated with cryptocurrency mining are no longer marginal and must be taken into account within climate policy frameworks [10][11].

The European context is shaped primarily by two key dimensions—regulation focused on digital assets and financial markets, and broader policies related to green and digital transformation. Regulations concerning digital assets (e.g., MiCA) are beginning to introduce requirements for transparency regarding energy consumption and environmental impacts, while the Green Deal and the EU taxonomy for sustainable investment place strong emphasis on decarbonization within ICT infrastructure and data centers [10][11].

This framework creates pressure not only on operators of blockchain networks, but also indirectly on educational institutions that prepare future professionals capable of understanding the interconnections between digitalization and sustainability.

2.5 Digital sustainability, Green IT, and education

The concepts of Green IT and sustainable informatization highlight the dual role of ICT: on the one hand, digitalization can contribute to more efficient resource utilization and emissions reduction, while on the other hand, it generates substantial energy and material burdens of its own [18].

Research in the field of Green ICT within higher education indicates that most universities still lack a systematically developed curricular framework that would help

students understand the environmental impacts of ICT—both at the infrastructure level and in relation to user behavior [19][20][21].

At the same time, an increasing number of studies examine how digital technologies can support Education for Sustainable Development (ESD). Systematic reviews demonstrate that digital tools and online environments can significantly contribute to the development of sustainability literacy, provided they are didactically well-designed and connected to real-world environmental challenges [22][23][24].

Special attention has been devoted to the carbon footprint of digital education—the massive increase in online teaching, cloud services, and media streaming during the COVID-19 pandemic led to increased energy demand for digital infrastructure, sparking a debate about the hidden digital carbon footprint of education [25].

Current studies focusing on pre-service teachers show that although they are aware that their digital behavior has environmental consequences, they often underestimate the specific energy requirements associated with different online activities and ICT devices [26].

2.6 Students' knowledge and attitudes toward cryptocurrencies and blockchain

Empirical research focusing on students' awareness of cryptocurrencies and blockchain has developed primarily within the fields of economics education and business schools in recent years. A number of studies indicate that while students demonstrate relatively high awareness of the existence of cryptocurrencies, their deeper understanding of blockchain technology, associated risks, and societal implications remains limited [26][27].

Across various countries, research has repeatedly shown that students obtain information about cryptocurrencies predominantly from social media, news outlets, and peers, whereas formal education plays a substantially smaller role [26].

Existing studies additionally reveal that students often perceive cryptocurrencies primarily as an investment opportunity or speculative asset, with environmental impacts viewed marginally or not considered at all [27].

However, there is a significant research gap in the context of teacher education. While studies are available on the role of ICT in environmental education, the use of digital technologies in ESD, or the integration of sustainability into informatics curricula

[23][24][27], systematic research connecting cryptocurrencies, blockchain, environmental impacts, and teacher preparation is virtually absent. This gap in the literature highlights the need to examine how pre-service teachers perceive the energy and environmental dimensions of modern digital technologies and the extent to which they are prepared to integrate these topics into their own teaching practice.

2.7 Research gap

Based on the review of the literature, several key points can be summarized:

- PoW cryptocurrencies represent a significant energy and environmental burden and are at the center of both regulatory and scientific debate concerning the sustainability of digital assets [5][7][10][11].

- Alternative consensus mechanisms (PoS, PoST, hybrid models) offer substantially more energy-efficient operation but introduce new questions related to material demands and the circular economy of ICT [1][2][16][18].

- In the field of education, the emphasis on digital sustainability, Green IT, and connecting ICT with the goals of sustainable development is increasing; however, implementation within curricula is uneven and often lacking systematic structure [21][22][23][24].

- Research indicates that students possess rather superficial knowledge about cryptocurrencies and blockchain, while the environmental dimension of this topic is perceived minimally [24][25][31].

- In the context of teacher education, the area of cryptocurrencies and their environmental impacts remains largely unexplored, despite the fact that this group will play a crucial role in shaping students' attitudes toward digital technologies and sustainability [25][26][27].

These findings demonstrate a clear need for empirical research focusing specifically on pre-service teachers of informatics and technology. It is necessary to investigate what knowledge they possess regarding cryptocurrency principles, how they perceive their energy and environmental impacts, and to what extent they are prepared to incorporate these topics didactically into their future teaching practice. This study addresses precisely this research gap.

3 RESEARCH OBJECTIVES

The aim of the research was to comprehensively examine the level of knowledge and understanding among pre-service teachers of informatics and technology in the field of cryptocurrency technologies, with particular emphasis on the principles of cryptocurrency operation, the differences between traditional mining (Proof of Work) and alternative methods such as farming (Proof of Space and Time), and their energy and environmental impacts. The objective also included assessing the extent of students' awareness of the ecological burden associated with the operation of blockchain networks, such as electricity consumption, CO_2 emissions, and electronic waste generation.

The research further examined students' attitudes toward the sustainability of digital technologies and identified relationships between the level of knowledge of cryptocurrency technologies, their actual use, and the degree of environmental sensitivity. The goal was to determine whether active use of cryptocurrencies influences attitudes toward sustainability, whether students of technical and ICT teaching programs demonstrate differing levels of knowledge, and whether correlations exist between awareness of environmental impacts and support for sustainable technological solutions. These objectives form the basis for future didactic and methodological proposals in the field of education related to digital technologies and sustainable development.

3.1 Research questions

The research formulated the following research questions:

1. **RQ**1: What is the level of knowledge among pre-service informatics and technology teachers regarding the principles of cryptocurrencies and their environmental impacts?
2. **RQ2**: Are there differences in knowledge and attitudes toward sustainability between students of informatics education and students of technology education?
3. **RQ3**: What is the relationship between the use of cryptocurrencies and the level of students' environmental sensitivity?
4. **RQ4**: Is the level of knowledge regarding the environmental impacts of blockchain technologies associated with support for the sustainable use of digital technologies?

3.2 Research conceptual model

The proposed research conceptual model is based on the assumption that personal experience with and use of cryptocurrencies may influence students' environmental attitudes. The model characterizes the relationships among four main constructs:

- **Field of Study** – comparison between pre-service informatics teachers and pre-service technology teachers.

- **Knowledge and Usage** – whether students understand the principles of cryptocurrencies and whether they actively use them in practice.

- **Perception of Energy Demand** – declared and subjectively perceived energy intensity of blockchain technologies.

- **Attitudes toward Sustainability** – attitudes toward reducing the energy consumption of digital technologies.

The conceptual model operationalizes the hypothesized relationships between cryptocurrency usage, knowledge, sustainability attitudes, and field of study.

3.3 Research hypotheses

Based on Research Conceptual Model the following hypotheses were formulated:

1. **H1**: Students who actively use cryptocurrencies demonstrate a lower level of environmental sensitivity than students who do not use cryptocurrencies.

2. **H2**: ICT students have a higher level of knowledge about cryptocurrencies than technology education students.

3. **H3**: A higher level of knowledge regarding the environmental impacts of cryptocurrencies is positively correlated with support for sustainability in digital technologies.

4. **H4**: There is a negative relationship between declared cryptocurrency usage and knowledge of their environmental impacts.

4 METHODOLOGY

The research was carried out in the form of an online questionnaire survey created in Microsoft Forms. The questionnaire consisted of 11 closed-ended questions.

Participation was voluntary and anonymous. Prior to completing the questionnaire, students were informed about the purpose of the research and provided consent for the data to be processed for scientific purposes.

The questionnaire was divided into four thematic sections:

1. Basic demographic characteristics of respondents (field of study, year of study, gender),
2. Knowledge and usage of cryptocurrencies,
3. Awareness of energy consumption and environmental impacts,
4. Attitudes toward sustainability and digital technologies.

The research sample consisted of students enrolled in the programs *Informatics Teacher Education* and *Technology Teacher Education* at the University of Hradec Králové. Participation was voluntary and anonymous.

4.1 Operationalization of variables

The operationalization of variables represents a key step in the research design, as it enables the translation of theoretical constructs (e.g., knowledge of cryptocurrencies, environmental sensitivity, support for sustainability, cryptocurrency usage) into measurable indicators based on specific questionnaire items. Individual variables were created by combining relevant questionnaire items and were subsequently processed statistically using descriptive statistics, correlation analysis, and comparative tests (t-tests).

The summary tables below present the set of operationalized variables, their definitions, corresponding questionnaire items, and the applied statistical evaluation methods. This procedure ensures transparent alignment between the research questions, hypotheses, and the analytical process.

Table 1

Overview of Closed-Ended Questionnaire Items, Question number, Possible Responses, and Coding Method.

Questionnaire Item	No.	Closed-Ended Response Options	Coding
Field of Study	Q1	Technology Teacher Education	0
		Informatics Teacher Education	1
How would you rate your knowledge of cryptocurrencies?	Q2	None	0
		Basic (I know what cryptocurrencies are)	1
		Intermediate (I understand how they work)	2
		Advanced (I actively follow or work with them)	3
Do you understand the basic principle on which most cryptocurrencies (e.g., Bitcoin) operate?	Q3	No	0
		Not sure	1
		Yes	2
Do you know the difference between cryptocurrency mining and farming?	Q4	No, I do not distinguish between them	0
		Partially, I am aware of some differences	1
		Yes, I clearly distinguish both principles	2
Were you aware that cryptocurrency mining has a significant impact on energy consumption and CO_2 emissions?	Q5	No	0
		I have heard about it, but I do not know the details	1
		Yes	2
How would you estimate the annual electricity consumption of the Bitcoin network?	Q6	I cannot estimate	0
		Approximately like a standard server or data center	1
		Like a large company	2
		Like a small country	3
Do you think blockchain and cryptocurrency technologies should follow principles of sustainable development (e.g., ESG)?	Q7	Strongly disagree	0
		Rather disagree	1
		I do not know / No opinion	2
		Rather agree	3

Questionnaire Item	No.	Closed-Ended Response Options	Coding
		Strongly agree	4
Teacher education should guide students toward responsible and environmentally conscious use of digital technologies.	Q8	Strongly disagree	0
		Rather disagree	1
		I do not know / No opinion	2
		Rather agree	3
		Strongly agree	4
Sustainability and efficiency should be key criteria in the development of new digital technologies.	Q9	Strongly disagree	0
		Rather disagree	1
		I do not know / No opinion	2
		Rather agree	3
		Strongly agree	4
Which of the following statements best describes the relationship between technology and ecology?	Q10	Ecological concerns are overrated.	0
		Technology should be evaluated solely based on performance.	1
		I do not know / No opinion.	2
		Sustainability should be as important as performance.	3
		Ecological concerns are underestimated.	4
Do you think the topic of "sustainability in digital technologies" should appear more frequently in informatics/technology education?	Q11	Rather not	0
		Rather yes	1
		Yes, definitely	2

Table 1 provides an overview of the closed-ended questionnaire items, including the response options and their coding for subsequent statistical processing. The items were coded either binarily (0–1) or as ordinal variables using a Likert scale (1–5). This coding enabled the conversion of respondents' declarative statements into numerical values suitable for statistical analysis. The table ensures transparency in the process of transforming raw questionnaire data into analysable variables.

Table 2

Operationalization of Research Variables V1–V4.

Definition	Variable	Questionnaire Items	Values / Coding
Field of Study	V1	SQ1	*0 – Technology Teacher Education*
			1 – Informatics Teacher Education
Knowledge of cryptocurrency principles and active usage	V2	SQ2 + SQ3 + SQ4	*0 – lowest level of knowledge and usage*
			7 – highest level of knowledge and usage
	KI: Knowledge Index	Mean (SQ2 + SQ3 + SQ4)	Continuous index based on averaged scores
Perception of blockchain energy demand	V3	SQ5 + SQ6	*0 – lowest perceived energy intensity*
			5 – highest perceived energy intensity
Attitudes toward sustainability in digital technologies	V4	SQ7 + SQ8 + SQ9 + SQ10 + SQ11	*0 – strongly disagree with sustainability*
			18 – strongly agree with sustainability
	SI: Sustainability Index	Mean (SQ7 + SQ8 + SQ9 + SQ10 + SQ11)	Continuous index based on averaged scores

Table 2 presents four key variables constructed through the combination of relevant questionnaire items: **V1 – Field of Study**, **V2 – Knowledge and Usage of Cryptocurrencies**, **V3 – Perception of Blockchain Energy Demand**, and **V4 – Attitudes toward Sustainability in Digital Technologies**. The table specifies the calculation method for each variable, the corresponding value range, and the questionnaire items from which each variable was derived.

The operationalized variables enabled the construction of composite indices reflecting respondents' knowledge of cryptocurrency technologies (**Knowledge Index, KI**) and their attitudes toward sustainability (**Sustainability Index, SI**). Each index was calculated as the arithmetic mean of relevant items, allowing quantitative comparison across respondent groups and subsequent statistical testing. Higher index values indicate a greater level of knowledge or stronger pro-sustainability attitudes.

These variables were subsequently used in hypothesis testing and allowed for the examination of relationships between technological knowledge, environmental sensitivity, and the behavioural aspects of students' engagement with digital technologies.

Table 3

Hypothesis Testing in Relation to Variables V1–V4, KI and SI.

Hypothesis	Description	Compared Variables	Test Type	Statistical Parameter
H1	Students who understand cryptocurrency principles and actively use cryptocurrencies exhibit a lower level of environmental sensitivity than students who do not use cryptocurrencies.	SI (V2 = 4,5,6,7) < < SI (V2 = 0,1,2,3)	Two-sample t-test	p-value $\alpha = 0.05$
H2	ICT students show a higher level of knowledge about cryptocurrencies than technology education students.	KI (V1 = 1) > > KI (V1 = 0)	Two-sample t-test	p-value $\alpha = 0.05$
H3	Higher knowledge of environmental impacts is positively correlated with support for sustainability in digital technologies.	Spearman's ρ (V3 vs V4) >> 0	Correlation analysis	Spearman's ρ
H4	There is a negative relationship between declared cryptocurrency usage and knowledge of environmental impacts.	Spearman's ρ (V2 vs V3) << 0	Correlation analysis	Spearman's ρ

Table 3 summarizes the statistical procedures used to test hypotheses H1–H4. Independent samples t-tests were applied to examine hypotheses H1 and H2, while correlation analysis was used to examine hypotheses H3 and H4.

5 RESULTS AND STATISTICAL PROCESSING

5.1 Graphical overview of descriptive results

The following graphs provide a visual overview of the descriptive results obtained from the questionnaire. They summarize the basic characteristics of the research sample and illustrate key findings related to students' self-reported knowledge, awareness of cryptocurrencies, perception of energy consumption, and attitudes toward sustainability in digital technologies.

Figure 1

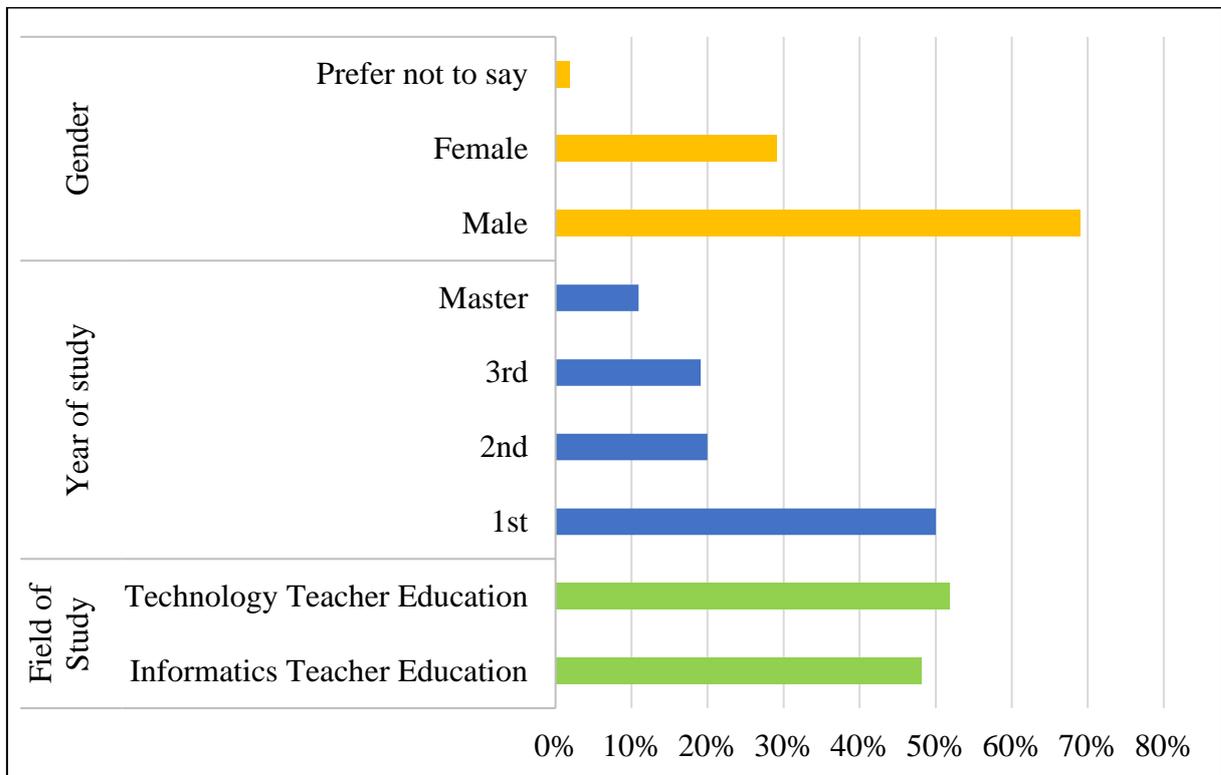Distribution of respondents by sample characteristics (field of study, year of study, and gender).

Figure 2

Distribution of respondents' self-reported knowledge and awareness of cryptocurrencies.
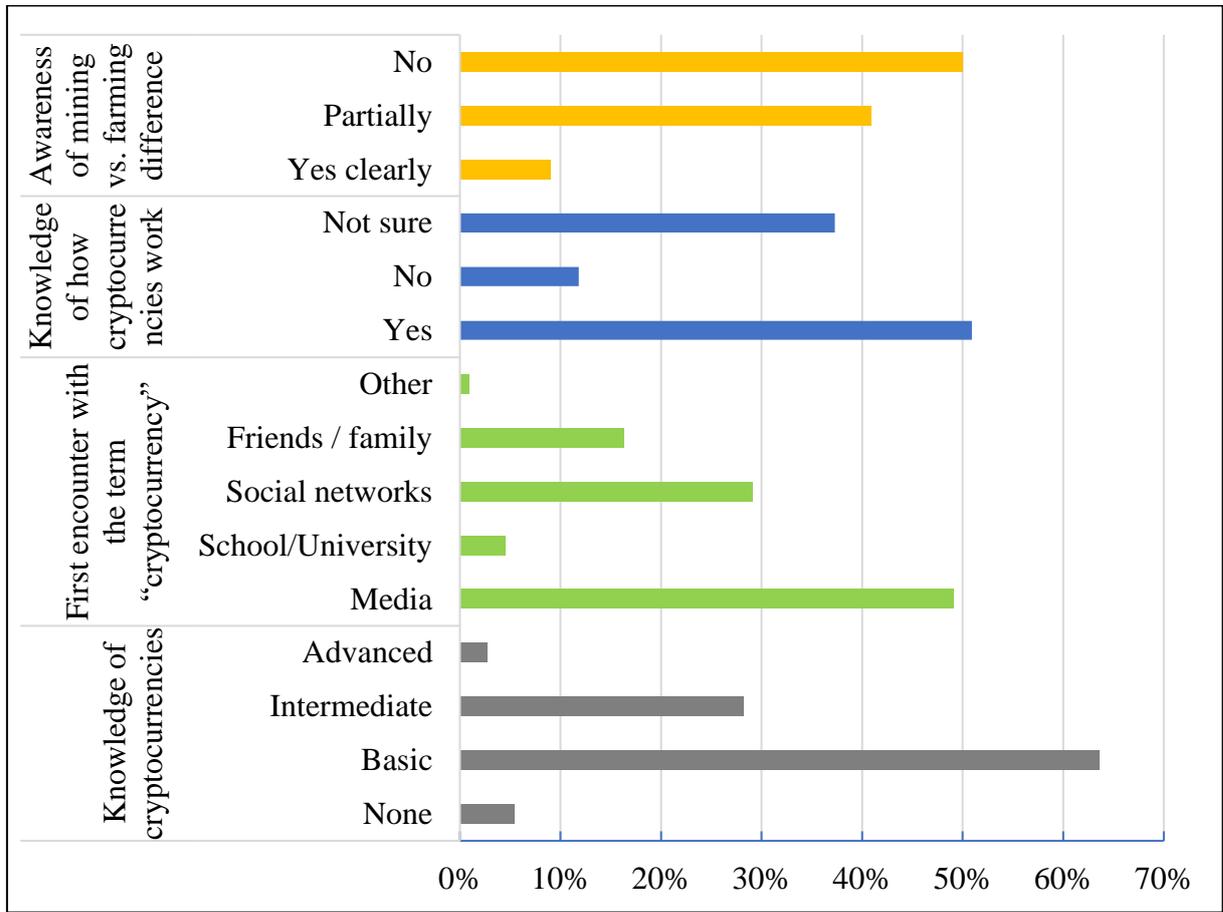

Figure 3

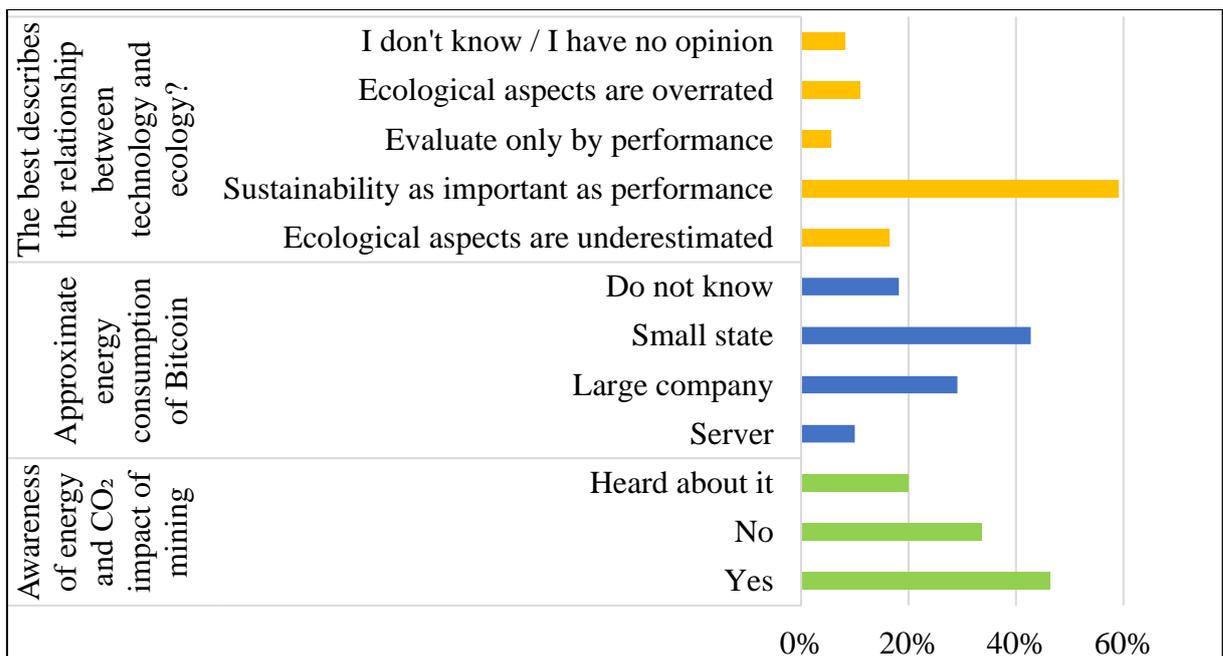*The distribution of self-reported knowledge of cryptocurrencies among respondents.*
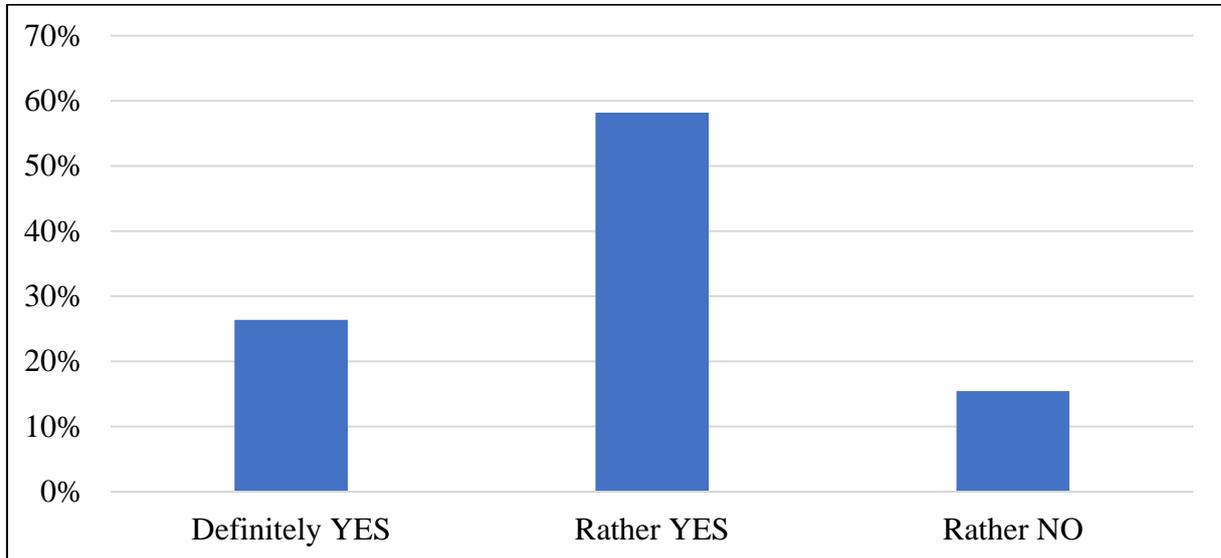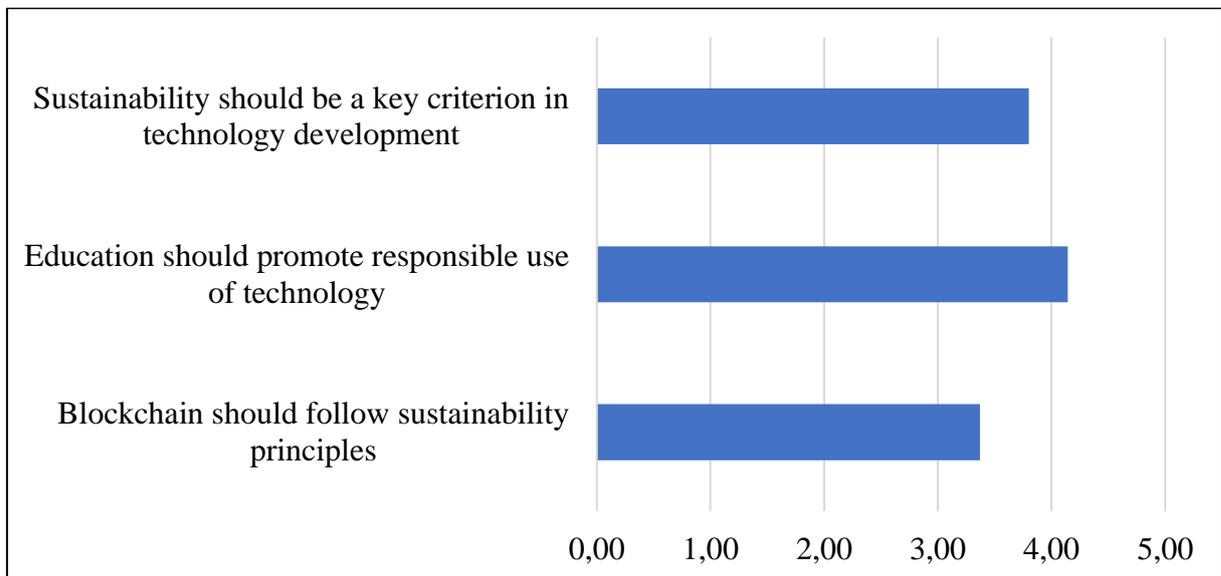
Figure 4

Attitudes toward sustainability in digital technologies and its relevance in CS/technology education.

Figure 5

Students' attitudes towards sustainability in digital technologies (mean values on the Likert scale: 1 = definitely disagree; 2 = rather disagree; 3 = no opinion; 4 = rather agree; 5 = definitely agree).

In summary, the visual analysis of the descriptive results reveals several notable trends within the research sample. The sample characteristics graph indicates a balanced

representation of study fields, a predominance of first-year students, and a majority of male respondents.

The results concerning knowledge and awareness of cryptocurrencies show that most students self-report only basic to medium levels of understanding, with active users forming a minority group.

In terms of environmental perception, students generally express strong positive attitudes toward sustainability in digital technologies and support the integration of sustainability-related content into computer science and technology education.

Despite these declared values, differences between knowledge levels, cryptocurrency usage, and sustainability attitudes remain relatively small, suggesting limited connection between professed attitudes and practical understanding of technological and environmental implications.

5.2 Hypotheses evaluation

The statistical analysis of the collected data was conducted using Microsoft Excel. The results of hypothesis testing are summarized in Table 4.

Table 4

Summary of hypotheses testing results

Hypothesis	Assumption	Result values		p-value	Interpretation
H1	SI(V2=4,5,6,7) < SI(V2=0,1,2,3)	**SI(V2=4,5,6,7) = 10,91**		**0,164**	Not significant
		SI(V2=0,1,2,3) = 11,49			
H2	KI(V1=1) > KI(V1=0)	**KI(V1=1) = 2,34**		**0,050**	Not significant
		KI(V1=0) = 2,96			
H3	Spearman's ρ (V3 vs V4) >> 0	**Spearman's ρ (V3 vs V4) = 0,075**			Not significant
H4	Spearman's ρ (V2 vs V3) << 0	**Spearman's ρ (V2 vs V3) = 0,350**			Refuted

5.2.1 Evaluation of Hypothesis H1

Hypothesis H1 assumed that students who understand the principles of cryptocurrencies and actively use them would demonstrate a lower level of environmental sensitivity than students who do not use cryptocurrencies.

Based on the calculation, the following mean values of the **Sustainability Index** (SI) were obtained:

- Students who understand and use cryptocurrencies: **SI = 10.91**
- Students who do not know / do not use cryptocurrencies: **SI = 11.49**

The difference between the means corresponds to the expected direction - students who use cryptocurrencies demonstrate a lower level of environmental sensitivity. This result thus supports Hypothesis H1 at the level of descriptive statistics.

However, based on statistical testing, the obtained p-value was **p = 0.1636**, which does not exceed the statistical significance threshold of **α = 0.05**.

Interpretation of Results

The results indicate a trend consistent with Hypothesis H1 - cryptocurrency users show lower environmental sensitivity on average. However:

- the difference between the groups is not statistically significant, and
- the hypothesis cannot be confirmed, because the difference may be due to chance.

One of the main reasons for the insignificant difference may be the relatively small sample size, which limits statistical power and increases the likelihood that the observed difference is influenced by random variation.

Another possible explanation is the **heterogeneity of motivations for cryptocurrency use** - some users may be driven by economic incentives (profit, investment), while others may engage with cryptocurrencies experimentally or out of academic interest. These differing motivations may influence sustainability attitudes in different directions.

Low awareness of the environmental impacts of cryptocurrencies may also play a role, which was evident across the entire sample. If most students are unaware of the substantial differences in energy demand between PoW and alternative consensus mechanisms (e.g., PoS or PoST), they may exhibit similar attitudes regardless of cryptocurrency usage.

The results therefore suggest that even among cryptocurrency users, there may be **insufficient connection between technological behavior and environmental responsibility**, reinforcing the need for education on sustainability within digital technologies.

Future research should expand the sample size and include more detailed diagnostic questions on specific types of cryptocurrencies and user motivations. It is also advisable to conduct longitudinal studies to monitor how knowledge and attitudes develop over time.

5.2.2 Evaluation of Hypothesis H2

Hypothesis H2 assumed that students of **Informatics teacher education** would demonstrate a higher level of knowledge about cryptocurrencies than students of **Technology teacher education**. To test this assumption, the composite variable **Knowledge Index** (KI) was used, based on questionnaire items related to understanding cryptocurrency principles, distinguishing between mining and farming, and awareness of the environmental impacts of blockchain technologies.

The results are as follows:

- Students of Technology Teacher education: **KI = 2.96**
- Students of Informatics Teacher education: **KI = 2.34**

The results show that **technology teacher education students achieved a higher KI score than informatics teacher education students** - an opposite outcome to what hypothesis H2 proposed.

The statistical comparison of the two groups (t-test based on data distribution) was **p = 0.0502**, which is only slightly above the statistical significance threshold of $\alpha = 0.05$, however the difference is not statistically significant, and therefore Hypothesis H2 cannot be confirmed.

Interpretation of Results

Although the trend indicates that technology education students report a higher level of cryptocurrency knowledge than informatics education students, the difference is not statistically significant. This suggests that the **level of knowledge in both groups is generally low** and relatively comparable, which may reflect a lack of formal instruction on cryptocurrency technologies or varied personal experience across individuals.

One possible explanation is that **technology students may have greater experience with technical hardware and computing infrastructure**, which could include awareness of cryptocurrency mining in relation to computing performance, graphics cards, or energy consumption. In contrast, informatics students may focus more on programming, software development, and didactic applications of ICT, which does not necessarily imply deeper knowledge of blockchain or cryptocurrency systems. Another factor may be **the small and unevenly distributed sample size**, which reduces statistical power.

The result may also reflect strong variability in **personal interest and informal learning, as cryptocurrency-related topics are largely outside the standard university curriculum and knowledge acquisition tends to occur informally**. The results highlight the need for systematic education on the sustainability and technological foundations of cryptocurrencies within teacher preparation programs.

5.2.3 Evaluation of Hypothesis H3

Hypothesis H3 assumed that a higher level of knowledge regarding the environmental impacts of cryptocurrencies and blockchain technologies would be positively correlated with support for sustainability in digital technologies. In other words, students who possess a deeper understanding of ecological aspects should also demonstrate stronger support for sustainability principles in the digital domain.

To verify this assumption, **Spearman's rank correlation was applied**, as it is suitable for ordinal variables and does not require the assumption of normal data distribution.

The result of the correlation analysis is $\rho = 0.075$, which means the hypotheses is not confirmed.

Interpretation of Results

The identified correlation is very weak and statistically insignificant. Therefore, Hypothesis H3 cannot be confirmed - no demonstrable relationship was found between the level of knowledge about the environmental impacts of blockchain (Knowledge–Environment Index) and support for sustainability in digital technologies (Sustainability Attitude Index).

Although the trend indicates a very slight positive correlation, its magnitude is negligible and cannot be considered meaningful.

There are several factors that may account for the weak correlation:

- **Low knowledge level across the entire sample** — most students reported only minimal or partial awareness of the environmental impacts of cryptocurrencies, reducing variability and limiting the ability to detect correlations.

- **Declarative rather than internalized sustainability attitudes** — respondents may express support for sustainability due to social desirability or general ecological values without connecting them to technological contexts.

- **Absence of curriculum-based education** — sustainability in digital technologies and environmental impacts of cryptocurrencies are not systematically included in study programs, thus support for sustainability may be intuitive rather than informed.

- **Lack of linkage between theory and practice** — results suggest that students struggle to connect technological behaviour (e.g., cryptocurrency use) with environmental responsibility, which aligns with the findings of Hypothesis H1.

Hypothesis H3 was not confirmed. The research demonstrates that the relationship between knowledge of environmental impacts and support for digital sustainability is extremely weak and insignificant. This finding highlights **the need to strengthen educational activities in environmental informatics and digital ethics** in order to foster a conscious and responsible generation of future teachers.

5.2.4 Evaluation of Hypothesis H4

Hypothesis H4 assumed that there would be a negative relationship between declared cryptocurrency usage and the level of knowledge regarding the environmental impacts of blockchain technologies. In other words, **students who actively use cryptocurrencies were expected to demonstrate lower awareness of their environmental consequences**, potentially due to economic motivation.

To examine the relationship between the variables, Spearman's rank correlation was employed, which is appropriate for ordinal data and does not require the assumption of normal distribution.

Correlation analysis result is ρ = 0.3503. **The value is positive rather than negative, contrary to the hypothesis**. The correlation is moderate, although due to the small sample size it should be interpreted with caution.

Interpretation of Results

The result contradicts the original expectation. Rather than showing lower levels of environmental awareness, the data indicate that:

- cryptocurrency users tend to have higher awareness of environmental issues,
- their engagement with cryptocurrencies is not driven solely by economic motivations but may be associated with deeper involvement in technology-related topics,
- these students are likely exposed to technological and economic media sources where the topic of mining energy consumption is frequently discussed.

Several factors may explain this unexpected result:

- **Active cryptocurrency users often follow specialist sources, discussion forums, and technological news** where PoW vs. PoS/PoST environmental impacts are debated.
- **Higher knowledge may stem from specialized interest**, not from general environmental attitudes.
- **Cryptocurrency users may be more technically oriented**, which supports their understanding of consensus mechanisms and energy efficiency differences.
- **The sample may not have included extreme speculative users** for whom environmental considerations are irrelevant.

The result may therefore suggest that awareness of environmental impacts does not discourage users from engaging with cryptocurrencies and may instead motivate them to explore alternative technologies perceived as more sustainable (e.g., PoS or PoST).

Hypothesis H4 was not confirmed, as the identified correlation was positive rather than negative. The research indicates that cryptocurrency usage may be associated with a higher level of awareness of environmental impacts, which represents an interesting and potentially important finding.

This insight highlights the need for further research to examine whether:

- environmental awareness leads to a preference for more sustainable consensus mechanisms (PoS, PoST),

- experience with cryptocurrencies supports the development of critical technological thinking.

6 DISCUSSION OF RESULTS

The findings of the research provide a comprehensive insight into the level of knowledge among pre-service informatics and technology teachers regarding cryptocurrencies, their perception of the environmental impacts of blockchain technologies, and their attitudes toward sustainability in the field of digital technologies. This discussion interprets the statistical results in relation to the formulated hypotheses and situates them within a broader pedagogical and societal context.

6.1 Level of knowledge and awareness of cryptocurrencies

The analysis showed that the overall level of knowledge among respondents is relatively low. Although cryptocurrencies and blockchain are currently widely discussed in the media, most students reported only basic familiarity and limited practical experience. Active use of cryptocurrencies appeared to be a minority phenomenon, likely influenced by perceived investment risk, insufficient information, and limited understanding of technological principles. This finding is consistent with previous studies (e.g., [24]), which indicate that students' knowledge of modern digital technologies is often fragmented and not systematically developed during teacher preparation programs.

6.2 Interpretation of hypotheses

Hypothesis H1 assumed that students who actively use cryptocurrencies would demonstrate a lower level of environmental sensitivity compared to students who do not use cryptocurrencies. The analysis indeed showed a lower Sustainability Index value among cryptocurrency users (SI = 10.91) compared to those who do not use them (SI = 11.49). However, the difference was statistically insignificant (p = 0.1636), and therefore the hypothesis cannot be confirmed. A possible explanation may lie in the fact that the use of cryptocurrencies is often motivated by economic factors (e.g., investment profit) rather than technological understanding or environmental responsibility. In addition,

environmental issues are not commonly associated with blockchain technologies in education or media discourse, meaning that users may not be aware of the significant differences in energy consumption between highly energy-intensive PoW and energy-efficient PoS/PoST systems. These results highlight the need to systematically integrate environmental informatics and digital sustainability into teacher education.

Hypothesis H2, which assumed a higher level of cryptocurrency knowledge among ICT students compared to technology students, was also rejected. The analysis revealed the opposite trend—technology education students achieved a higher Knowledge Index (M = 2.96) than ICT education students (M = 2.34), although the difference was statistically insignificant (p = 0.0502). This result may be explained by the orientation of ICT programs toward pedagogy, theoretical informatics, and programming, whereas technology programs are more frequently focused on hardware, energy systems, and physical technologies, which may spark greater interest in the practical aspects of blockchain. The absence of cryptocurrency and blockchain-related topics in ICT curricula may therefore explain lower familiarity with the topic.

Hypothesis H3, which predicted a positive correlation between knowledge of environmental impacts and support for sustainability in digital technologies, was not confirmed. The Spearman correlation coefficient was very low ($\rho = 0.075$), suggesting that respondents express positive attitudes toward sustainability in general, but without clearly linking those attitudes to technological aspects of the digital economy. This indicates an educational gap—students support environmental values on a declarative level but struggle to apply them to concrete technological systems such as blockchain or cryptocurrency infrastructure.

In the case of **Hypothesis H4**, which predicted a negative relationship between cryptocurrency use and knowledge of environmental impacts, the observed trend was the opposite. The correlation coefficient ($\rho = +0.350$) suggests that cryptocurrency users demonstrate a somewhat higher level of environmental awareness, leading to the hypothesis being rejected. This finding may be interpreted as indicating that cryptocurrency users are driven to engage with economic and technological parameters—especially when comparing consensus mechanisms. The growing presence of PoS and PoST models in media narratives reinforces the idea of more sustainable alternatives, potentially increasing awareness among active users. Current social and economic factors

such as the energy crisis may also contribute to heightened sensitivity to issues related to electricity consumption.

Overall, it can be stated that the relationship between technical education, cryptocurrency usage, and environmental literacy is more complex than initially assumed. Although students express declarative support for environmental sustainability, the connection between environmental themes and digital technologies remains weak. The results therefore confirm the need for **interdisciplinary education** in the areas of digital sustainability, blockchain, and environmental informatics, and open space for further research and curriculum development within the context of ICT education.

6.3 Implications for educational practice

The results of the research indicate that although pre-service informatics and technology teachers express generally positive attitudes toward sustainability in digital technologies, their knowledge of the specific environmental impacts of modern technologies and their ability to work with cryptocurrencies is low and does not correspond to their declared value-based positions. This has important implications for the preparation of future teachers in ICT and technical education.

First, it is evident that current curricula insufficiently address topics related to digital sustainability, blockchain technologies, and environmental informatics. The digital transformation of education and rapid technological development require future teachers to understand not only the functionality of digital technologies but also their long-term environmental and societal implications. Integrating these topics into teaching could support the development of critical and systemic thinking in students.

Second, linking environmental education with informatics can be effectively supported by project-based and experimental learning approaches, for example through practical tasks focused on measuring the energy consumption of ICT devices, simulating blockchain processes, or calculating the life cycle of technologies (LCA). Such activities can strengthen algorithmic thinking, data interpretation skills, and connect classroom content to real societal challenges.

Third, the findings confirm the need to systematically develop digital citizenship competences, especially in the context of technological ethics, energy management, awareness of the impacts of digital infrastructure, and the ability to make responsible

technological decisions. These topics are in line with the DigComp 2.2 framework, which emphasizes "sustainable use of digital technologies" and "critical assessment of the impacts of digitalization."

Fourth, it is desirable to support collaboration across study fields and create an interdisciplinary educational model that connects informatics, technical education, environmental studies, and economics. The results show that students possess different perspectives and experiences depending on their study background, and therefore cross-disciplinary dialogue may foster deeper understanding of complex technological issues.

In conclusion, the research confirms the need to update instruction toward modern technological topics (blockchain, IoT, decentralized systems, energy efficiency of digital infrastructure), which will play a key role in the future of technical and ICT education.

6.4 Research limitations

Although the research produced valuable insights into the levels of knowledge among pre-service informatics and technology teachers regarding cryptocurrencies and environmental sustainability, several limiting factors must be acknowledged.

First, the sample size was relatively small and not evenly distributed across the student groups. This may limit the generalizability of the results to a broader population of pre-service technology and informatics teachers.

Second, the data were collected through a self-report questionnaire, which is susceptible to response bias, particularly in areas related to technological competence or environmental ethics. It is therefore possible that declared attitudes and knowledge do not fully reflect respondents' real abilities and skills.

Third, the study employed relatively simple statistical procedures (descriptive statistics, mean comparison tests, correlation analysis) and did not utilize more advanced analytical techniques such as structural equation modelling, regression analyses, or factor analysis. This methodological choice reflects the pilot nature of the study.

Fourth, the questionnaire did not include all potential variables that may influence the relationship between knowledge of cryptocurrencies and environmental sensitivity, such as socioeconomic status, personal investment experience, or motivations for using cryptocurrencies.

Finally, the research captured only current knowledge and attitudes, not changes over time. A longitudinal approach would enable assessment of the impact of educational interventions and the development of student opinions throughout their studies.

6.5 Recommendations for further research

Based on the results of the study and the identified limitations, several directions for subsequent research can be proposed:

- **Expansion of the research sample** - it is recommended to conduct a larger-scale study involving multiple universities and a broader representation of study programs in order to generalize the results at national or international level.

- **Longitudinal research on the impact of educational interventions** - it would be valuable to implement an experimental design to examine how students' knowledge and attitudes change after completing a targeted module (e.g., Digital Sustainability, Blockchain in Technical Education).

- **Integration of simulation-based and project-based learning methods** - we propose developing a simulation model of the energy impacts of blockchain technologies (e.g., in Excel VBA) and analysing its effect on the development of algorithmic thinking and understanding of sustainability.

- **Expansion of variables and psychometric validation of the questionnaire** - including factors such as technological self-efficacy, economic motivation, trust in digital systems, or value orientation may refine the structure of identified relationships.

- **International comparative study** - comparing the results with data from other countries may help identify cultural and educational differences in relation to this issue.

- **Use of more advanced statistical methods** - there is potential for applying Structural Equation Modelling (SEM), exploratory and confirmatory factor analysis, or logistic regression to achieve deeper interpretation of relationships between variables.

7 CONCLUSION

The research focusing on the knowledge of pre-service informatics and technology teachers regarding cryptocurrencies, their environmental impacts, and attitudes toward sustainability in digital technologies demonstrated that awareness of this issue is generally limited and often fragmented. Although most respondents declared a positive attitude toward environmental protection and support for sustainability principles, this orientation was not reflected in a higher level of knowledge about the environmental implications of blockchain technologies nor in a critical perspective on their energy consumption.

Statistical hypothesis testing did not confirm the anticipated relationships between cryptocurrency usage, knowledge of their functioning, and environmental sensitivity. Differences between users and non-users of cryptocurrencies were not statistically significant, and the correlation between knowledge of environmental impacts and support for sustainability was very weak. These findings suggest that students' environmental attitudes are not determined by technological knowledge, but rather influenced by other factors such as personal values or general ecological orientation.

From an educational perspective, the results highlight the need for the systematic integration of topics related to sustainable digitalization, environmental informatics, and technology ethics into the preparation of future ICT and technology teachers. Strengthening such content may contribute to shaping a generation of educators capable of reflecting on the broader social and ecological consequences of digital technologies and promoting responsible use of modern computing systems.

Future research should expand the study to a larger and more diverse sample of respondents, incorporate longitudinal measurements, and experimentally examine the effects of educational interventions—such as project-based learning, simulation models (e.g., VBA, Python), case studies, and practical experiments related to measuring the energy consumption of technologies. Such approaches may help improve understanding of the relationships between knowledge, attitudes, and real behavior in the context of digital sustainability.

ACKNOWLEDGEMENT

REFERENCES

[1] Narayanan, A., Bonneau, J., Felten, E., Miller, A., & Goldfeder, S. (2016). *Bitcoin and cryptocurrency technologies: A comprehensive introduction*. Princeton University Press.

[2] Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*. Retrieved form https://bitcoin.org/bitcoin.pdf.

[3] Krause, M. J., & Tolaymat, T. (2018). Quantification of energy and carbon costs for mining cryptocurrencies. *Nature Sustainability, 1*(11), 711–718.

[4] de Vries, A. (2020). Bitcoin's energy consumption is underestimated: A market dynamics approach. *Energy Research & Social Science, 70*, 101721.

[5] Stoll, C., Klaaßen, L., & Gallersdörfer, U. (2019). The carbon footprint of Bitcoin. *Joule, 3*(7), 1647–1661.

[6] Truby, J. (2018). Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies. *Energy Research & Social Science, 44*, 399–410.

[7] Li, W., Andreina, S., Bohli, J. M., & Karame, G. (2017). *Securing proof-of-stake blockchain protocols*. In E. Proust (Ed.), *Data Privacy Management, Cryptocurrencies and Blockchain Technology – ESORICS 2017 and CBT 2017 Workshops*, Lecture Notes in Computer Science, vol. 10436, pp. 297–315.

[8] Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The energy consumption of blockchain technology: Beyond myth. *Business & Information Systems Engineering, 62*(6), 599–608.

[9] Office of Science and Technology Policy. (2022). *Climate and energy implications of crypto-assets in the United States*. The White House. Retrieved from https://bidenwhitehouse.archives.gov/wp-content/uploads/2022/09/09-2022-Crypto-Assets-and-Climate-Report.pdf.

[10] European Parliament & Council of the European Union. (2023, May 31). *Regulation (EU) 2023/1114 on markets in crypto-assets (MiCA)*. Official Journal of the European Union, L 150, 40–205. Retrieved from https://eur-lex.europa.eu/eli/reg/2023/1114/oj/eng.

[11] European Securities and Markets Authority. (2024, March 25). *Final report on draft technical standards under the Markets in Crypto-Assets Regulation (MiCA) – First package.* ESMA. Retrieved from https://www.esma.europa.eu/sites/default/files/2024-03/ESMA18-72330276-1634_Final_Report_on_Draft_Technical_Standards_under_MiCA_First_Package.pdf.

[12] European Commission. (2022). *EU taxonomy for sustainable activities*. Retrieved from https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en.

[13] European Commission. (2019). *The European Green Deal*. Retrieved form: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640.

[14] Jiang, S., Li, Y., Lu, Q., Hong, Y., Guan, D., Xiong, Y., & Wang, S. (2021). Policy assessments for the carbon emissions of Bitcoin blockchain operation in China. *Nature Communications, 12*, 1938.

[15] Truby, J., Brown, R. D., Dahdal, A., & Ibrahim, I. (2022). *Blockchain, climate damage, and death: Policy interventions to reduce the carbon emissions, mortality, and net-zero implications of non-fungible tokens and Bitcoin. Energy Research & Social Science, 88*, 102499.

[16] Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., McCallum, P., & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews, 100*, 143–174.

[17] Murugesan, S., & Gangadharan, G. R. (2012). *Harnessing green IT: Principles and practices*. Wiley.

[18] Hilty, L. M., & Aebischer, B. (2015). *ICT Innovations for Sustainability*. Springer.

[19] Mishra, D., & Mishra, A. (2020). Sustainability inclusion in informatics curriculum development. *Sustainability, 12*(14), 5769.

[20] Shahzad, M. F., Xu, S., Lim, W. M., Hasnain, M. F., & Nusrat, S. (2024). Cryptocurrency awareness, acceptance, and adoption: The role of trust as a cornerstone. *Humanities and Social Sciences Communications, 11*(1), 1-14.

[21] UNESCO. (2021). *Education for Sustainable Development: A roadmap*. Paris, France: UNESCO. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000374802.

[22] Bascopé, M., Perasso, P., & Reiss, K. (2019). *Systematic Review of Education for Sustainable Development at an Early Stage: Cornerstones and Pedagogical Approaches for Teacher Professional Development. Sustainability, 11(3),* 719.

[23] Voogt, J., & Pareja Roblin, N. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies, 44*(3), 299–321.

[24] Carretero, S., Vuorikari, R., &–Punie, Y. (2022). *DigComp 2.2: The Digital Competence Framework for Citizens*. Publications Office of the European Union. Retrieved from https://publications.jrc.ec.europa.eu/repository/handle/JRC128415.

[25] Hasan, S. Z., Ayub, H., Ellahi, A., & Saleem, M. (2022). A moderated mediation model of factors influencing intention to adopt cryptocurrency among university students. *Human Behavior and Emerging Technologies*, 2022, 9718920.

[26] Alomari, A. S., & Abdullah, N. L. (2023). *Factors influencing the behavioral intention to use cryptocurrency among Saudi Arabian public university students: Moderating role of financial literacy. Cogent Business & Management*, 10(1), 2178092.

[27] Hossain, M. I., & Steigner, T. (2024). Addressing the environmental impact of Bitcoin mining: Balancing innovation and sustainability. *arXiv preprint* arXiv:2411.08908.

Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

How to cite this article (APA)