ALMA MATER EUROPAEA UNIVERSITY

INTERNATIONAL SCIENTIFIC CONFERENCE
IT'S ABOUT PEOPLE 2024–2025

SUSTAINABLE DEVELOPMENT
Peer-Reviewed Proceedings Book

Editors: Tanja Bagar, Daniel Siter

MARIBOR, 2025

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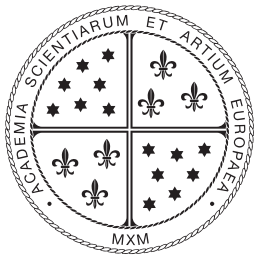

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PRESS

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PRESS

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IT'S ABOUT PEOPLE

2024: In Service of Sustainability and Dignity
2025: Social and Technological Resilience for Health and Sustainable Development

Peer-Reviewed Proceedings Book
SUSTAINABLE DEVELOPMENT

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EDITORIAL INTRODUCTION

In recent years, sustainability has become one of the most frequently used words in public discourse. While its importance is undeniable, its meaning is often stretched or oversimplified. True sustainability is neither a slogan nor a trend; it is a profound personal, scientific, social, and ethical commitment, a commitment to honour the visible and invisible world beyond ourselves. It requires us to look critically at our actions, to rethink established systems, and to respect the delicate balance that allows life to thrive.

As a researcher who has spent many years studying microorganisms and the invisible ecosystems that sustain both human and planetary life. To this day, I remain deeply in awe of their complexity. The deeper I explore the microscopic world, the more I am reminded of how extraordinary our own cells and bodies are and how closely their intricate balance mirrors the complexity of our planet. Both are remarkable, resilient systems, yet also fragile. Microorganisms teach us that even the smallest actors can shape entire environments. In a similar manner, research and scientific work, even when modest in scale, can contribute to meaningful transformations toward sustainability.

This volume brings together contributions from researchers who seek to understand how our societies, economies, and technologies can evolve in harmony with the natural world. The topics explored here are diverse and interconnected, ranging from mobility and novel waste-management technologies to food systems, the impacts of tourism and the construction industry, emerging extreme weather patterns, and sustainability reporting. This diversity demonstrates clearly how interdisciplinary collaboration can illuminate new pathways forward, offering innovative entrepreneurial models, frameworks for sustainable construction, and insights that advance our shared pursuit of a more resilient and responsible future. I am grateful to all the authors, reviewers, and colleagues who invested their expertise, time and care in this publication. Their work demonstrates that sustainability is not just a word or a trend, but a shared responsibility—one that calls for a deeply humbling understanding of the complexity of life's visible and invisible networks, an understanding that yields not only respect but awe.

I hope that the content of these proceedings strengthens our collective commitment to a future in which human progress and ecological integrity not only coexist, but grow together.

Assist. Prof. Tanja Bagar, PhD

2024

1.09 Objavljeni strokovni prispevek na konferenci
Published professional conference contribution

STARTUPS AS AN INNOVATIVE CONCEPT OF SUSTAINABLE ENTREPRENEURSHIP

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ABSTRACT

A big topic resonating in society in recent years is sustainability, which covers all areas of society's life, such as social, political, ecological, and entrepreneurial areas. But to make sustainability an essential part of our lives, it is necessary to abandon the usual concepts and focus on a different view of things and innovations that precede any change. Based on the knowledge about start-ups, which defines them as disruptors of old concepts, we can assume that startups, with their innovative approaches to solving issues, will play a crucial role in the sustainability of society. When we analyze the startup ecosystems, we can see that there are many leading startups in the eco scene, which are often at the forefront of innovation, so they can use their unique approach to making a positive impact on the environment and thus attract more people interested in the topic of sustainability. We used mixed methods in creating this paper. To define the concept of startups, sustainability, and sustainable innovation we analyzed various literature and research papers and to present the best overview of the studied issue we used descriptive methods to present the relevant information. The statistical issues were based on KMPG International and UtilityBidder Methodology, which we used for the presentation of the results of their research on sustainability by enterprises (KMPG International) and countries (UtilityBidder).

Keywords: *Startup, Sustainability, Entrepreneurship, Innovation, Environment*

1 INTRODUCTION

In recent years, we have seen the efforts of mankind for the sustainability of its activities with the aim of using renewable resources to an ever greater extent and gradually replacing non-renewable resources with them. This effort leads to the continuous development and improvement of innovative ideas to ensure the mitigation of humanity's impact on our planet. To make this possible, it is necessary to support research and development activities aimed in this direction and at the same time to support individuals who come up with such innovative ideas. At the moment, the biggest innovators are considered to be startups that deny established concepts and at the same time are considered "destroyers of old concepts". From a closer perspective, we can apply to startups the theory of creative destruction formulated by Joseph Schumpeter, which he came up with in 1942. Based on this theory is creative destruction characterized as innovations in the manufacturing process that increase productivity, describing it as the "process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one." Basically, the theory of creative destruction assumes that long-standing arrangements and assumptions must be destroyed to free up resources and energy to be deployed for innovation. To Schumpeter, economic development is the natural result of forces internal to the market and is created by the opportunity to seek profit (Kopp 2023). Creative destruction theory treats economics as an organic and dynamic process and is based on 4 principles: innovation, competition, entrepreneurship, and capital. As Kopp (2023) mentions, creative destruction can be seen across many different industries (for example: Technology, Media and Entertainment, Retail, Finance, and Energy). As all companies often strive to be better, many businesses seek new ways to disrupt the status quo and seek new paths to better business opportunities. Companies don't technically need to embark on creative destruction; however, by not doing so, they risk the occurrence of falling behind their competition.

This paper brings a look at startups and their role in sustainability. Our analysis of the examined issue is based on the opinions and research of several experts, both from the field of research and directly from practice, who deal with the given issue.

2 MATERIALS AND METHODS

The main goal of the article is to evaluate startups as an innovative concept of sustainable entrepreneurship. To reach the paper's objective and obtain an answer to this question, as Kondrla et al. (2023) say, it is crucial to identify what is significant to us and distinguish what is significant from irrelevant. Based on this opinion we used in this paper mixed methods. To define the concept of startups, sustainability, and sustainable innovation, we analyzed various literature and research papers. Descriptive methods were used to present the relevant information and provide the best overview of the studied issue. The statistical issues were based on KMPG International and UtilityBidder Methodology, which we used for the presentation of the results of their research on sustainability by enterprises (KMPG International) and countries (UtilityBidder).

3 RESULTS

Olteanu & Fichter (2022), referring to several authors, stated that One key element in the facilitation of the multilevel challenge of sustainability transitions is the development, implementation, and diffusion of radically new or significantly improved goods/services, processes, or practices which, for example, reduce the use of natural resources or increase societal inclusion. Thus, environmental and social innovation is considered key for transformation processes toward sustainable development. As Gódány et al. (2021) say the socio-economic importance of entrepreneurship in the 21st century in relation to economic growth has become undisputable on local and global level both in terms of macroeconomic indicators, as well as the micro environment.

To better understand the whole concept of sustainability and its impact on entrepreneurship, we need to first understand the individual concepts so that we can later see the whole context of sustainable entrepreneurship and also startups and their role in the sustainability.

3.1 Sustainability and sustainable entrepreneurship

Sustainable practices support ecological, human, and economic health and vitality. Sustainability presumes that resources are finite, and should be used conservatively and wisely with a view to long-term priorities and consequences of the ways in which resources are used. In simplest terms, sustainability is about our children and our grandchildren, and the world we will leave them (UCLA 2023).

Sustainability requires an integrated approach that takes into consideration environmental concerns along with economic development. In 1987, the United Nations Brundtland Commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Today, there are almost 140 developing countries in the world seeking ways of meeting their development needs, but with the increasing threat of climate change, concrete efforts must be made to ensure development today does not negatively affect future generations (United Nations 2023).

Based on Mollenkamp (2023) sustainability, in the broadest sense, refers to the ability to maintain or support a process continuously over time. In business and policy contexts, sustainability seeks to prevent the depletion of natural or physical resources, so that they will remain available for the long term. The idea of sustainability is often broken down into three pillars: economic, environmental, and social—also known informally as profits, planet, and people. The concept of "economic sustainability" focuses on conserving the natural resources that provide physical inputs for economic production, including both renewable and exhaustible inputs. Kučera and Nemec (2022) stated that it is necessary to use efficiency approach, when limited input sources are being used. The concept of "environmental sustainability" adds greater emphasis on the life support systems, such as the atmosphere or soil, that must be maintained for economic production or human life to even occur and social sustainability focuses on the human effects of economic systems, and the category includes attempts to eradicate poverty and hunger, as well as to combat inequality.

Entrepreneurs have a responsibility to consider the future ramifications of social innovation and business strategy, and to practice business ethics that prioritize the long-term health of society at large. Nielsen predicted that by 2021 sustainable products will take up a quarter of retail shelf space and capture $150 billion in consumer spending. But some experts are saying that green capitalism isn't enough (Mulqueen 2022).

The terms sustainable entrepreneurship, social entrepreneurship and ecological entrepreneurship have become an international trend in recent years, all names are entrepreneurial approaches with which - depending on the focus – social or ecological problems are intended to be solved. With their entrepreneurship, the founders of the companies want to create social added value with their employees. Sustainable entrepreneurship has set itself the goal of the so-called green economy. The entrepreneurs want to operate their business in a sustainable, resource-saving and environmentally conscious manner - in such a way that their own actions have a positive impact on social and community coexistence. In sustainable entrepreneurship, the focus is not on maximizing profits, but rather on entrepreneurial activity for the benefit of society. Sustainable entrepreneurs also have to generate income in order to assert themselves in the market – but this is not the focus of their work. Rather, they want to develop new markets and sources of income with innovative business models – without harming people and the environment (BusinessPilot 2023).

Table 1: Checklist of points for setting goals and missions of sustainable entrepreneurship

Fair business practices	Work-Life – Balance
Fair remuneration	Sustainable corporate culture
Sustainable manufacturing processes	Commitment to the environment
Energy-efficient production	Further training offers
Social justice in the company	Corporate healthcare
Appreciative treatment of employees	

(Source: BusinessPilot 2023)

Companies designated as social businesses want to solve social or ecological problems and challenges through entrepreneurial activity. Conventional sustainability management serves existing companies for ecological and social optimization within market conditions. Non-profit projects, in turn, tend to subsequently correct sustainability problems that arise from state and market failures. However, sustainable entrepreneurship has a change in the market and society (Schaltegger 2017).

Figure 1: The influence of individual types of businesses on the market

Non Profit	Sustainable Entrepreneurship (incl. Social Business)	Profit-oriented Business
Dependent on donations	Cost coverage: reinvestment of profits in line with the founding goal	Profit maximization & cost coverage
Effect: rather retroactively correcting market results, but not changing the market	Effect: changing the market	Effect: Sustainability optimization within the given market conditions

(Source: Schaltegger 2017)

Sustainable entrepreneurs are sustainably responsible companies and public institutions such as cities and municipalities that actively and effectively contribute to greater climate and environmental protection with their successful organizations, pay attention to fair business practices, and are committed to society. They are successful organizations that create and secure numerous jobs and ensure the highest quality of their products and services, follow fair business practices and support their employees, for example by offering training and further education and fair remuneration. Sustainable entrepreneurs are tax-honest and pay their taxes and duties on time. They also give part of their success back to the community by supporting sustainable and social projects (Sustainable Entrepreneur 2023).

So when we talk about sustainability, we first of all mean the preservation of natural resources and the planet for future generations, while taking into account both economic, ecological, and social aspects. At the same time, we have to adapt our goals to these areas, both as a company and as individuals in our daily lives, and in recent years these goals have also come to the fore in the business environment, where we increasingly encounter the term sustainable entrepreneurship, social entrepreneurship, and ecological entrepreneurship. Whose goal is to create such conditions within the framework of business that will help not only the creation of sustainable jobs, or conditions for further education and remuneration, but at the same time, with part of their profits, they help the development of the community by supporting sustainable and social projects aimed at improving its social environment.

3.2 Startups and sustainability

Startups are companies or ventures that are focused on a single product or service that the founders want to bring to market (Grant 2022). Based on Gründer Platform (2023) a startup is when a company is founded with a novel business idea and high growth potential. Beyond this definition, startups also represent a certain, "disruptive" self-image: They question familiar processes and try out new things. In doing so, they demonstrate a keen nose for trends and what people want and need. "Just do it and learn from mistakes" – that is the motto that allows startups to pick up new developments faster than the competition and turn them into innovative products. The startup culture is therefore characterized by openness, a willingness to learn, and the willingness to question every belief. A foosball table in the hallway doesn't make a startup. However, flat hierarchies, short decision-making processes, trust in the abilities of each individual team member and a relaxed atmosphere do. Perhaps the most popular definition of a startup meaning is from Eric Ries, the creator of the Lean Startup methodology who defines a startup as a human institution designed to create a new product or service under conditions of extreme uncertainty (McGowann 2022). We can say that startups are companies that think big and who are not worried about making mistakes, because they are a basic prerequisite for their further development.

Impact startups are innovative new ventures that diffuse solutions at scale that have a sustainability net benefit. They play an important role in the sustainability transition as actors in the introduction and diffusion of sustainability innovation (Horne-Fichter 2022).

Kwon (2020) in his study states that the recent sustainability trend in terms of startups involves consumer-focused technologies, whereas basic and traditional technologies have diminished in focus.

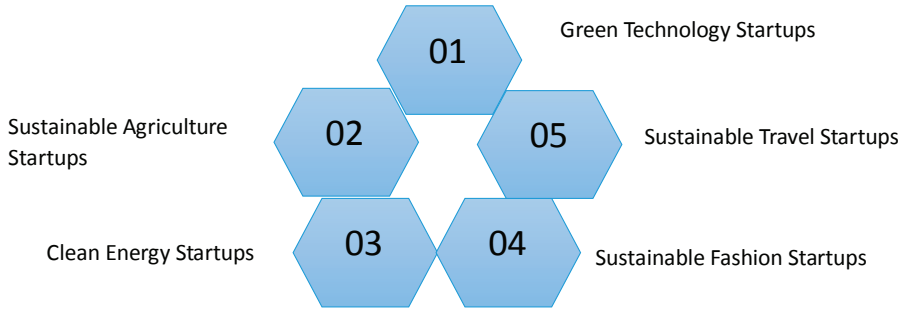
As Buchholz (2023) mentions the path to sustainable operations is a tricky one, laden with unexpected pitfalls, significant sacrifices, and lacking a unifying expectation of what 'sustainable' actually looks like in practice. Yet, getting a grip on emissions, waste, and renewable resources among other elements – not to mention all the associated policy and process changes – is of vital importance in the coming years. Startups often renowned for their ingenuity, scalability, and passionate problem-solving, are perfectly poised to take on the mantle of sustainable practice and generate innovative solutions. Uninhibited by legacy tech and embedded processes, startups are free to assess sustainability in more efficient, effective ways.

TRUIC Team (2023) points out, that green startups are on the cutting edge of new technology while also helping the world at large recover from years of overuse. While sustainability can help every human hope for a better future, these companies are taking action on green practices that will help everyone in the years to come.

Based on Kuckertz at all`s (2019) findings, the types of value creation in ecological startups, depending on the design of sustainable value creation, are shaped by and may result in a technologically-oriented, socially-oriented, or organizationally-oriented value creation type.

As FasterCapital (2023) indicates many startups are leading the way when it comes to sustainable business practices. There are also many benefits to being a sustainable startup. For one, it can help you attract and retain customers who are interested in supporting businesses that are doing their part to protect the environment. What›s more, sustainable business practices can help you save money by reducing your energy and waste costs. And, if you›re able to successfully implement sustainable practices into your business, you›ll be setting a good example for other businesses to follow. In the next picture we can see the most popular popular types of sustainable startups.

Figure 2: The types of sustainable startups



(Source: FasterCapital 2023)

3.3 Startups/sustainability and sustainable innovation

From business sustainable statistics (TravelPerk 2022) we can see, that although 90% of business leaders think sustainability is important, only 60% of companies have a sustainability strategy. 67% of companies have started using more sustainable materials, such as recycled materials and lower-emitting products. 66% are working to increase their energy efficiency. 57% of companies have started using energy-efficient or climate-friendly machinery, technologies, and equipment. 57% are also providing employee training on climate change/climate action. 49% are developing new climate-friendly products or services. 46% have begun requiring business partners across their supply chain/value chain to meet specific sustainability criteria. 44% are updating/relocating facilities to make them more resistant to climate impacts. 22.8% of Fortune 500 corporations have engaged with the UN's SDG (Sustainable Development Goals) framework. However, only 0.2% of these corporations have developed methods and tools to assess and evaluate the progress of their actions toward relevant SDGs. And more than 90% of CEOs state that sustainability is important to their company's success. When we go further and look at KPMG International (2022) statistics on sustainability, we can see that 96% of G250 companies (the World's 250 largest companies by revenue based on the 2021 Fortune 500 ranking) report on sustainability or ESG matters, and 64% of

the G250 acknowledge climate change as a risk to their business. 49% of the G250 acknowledge social elements as a risk to their business, with Western Europe as the leading region. 71% of N100 (Worldwide sample of the top 100 companies by revenue in 58 countries, territories, and jurisdictions) companies identify material ESG topics and fewer than half of G250 companies have leadership-level representation for sustainability.

To better understand these statistics we need first to understand the definition of sustainability, which is the base for these reactions of enterprises. Sustainability is the capacity to endure in a relatively ongoing way. Sustainable innovation means that companies seek out ways in which to sustain continuous innovation/improvement for company growth, competitive advantage, increased market share, etc. The right company structure can help make innovation a sustainable practice (Shields 2022).

"Innovations have become a driving force for the future opportunities of the companies." (Urbaníková et al. 2020). Šimelytė et al., (2021) state, that it involves developing and applying new technologies, processes, and systems enabling the efficient use of resources, waste reduction, and the creation of sustainable products and services.

By building sustainability into innovation, companies can create products, services, and processes that are good for both society and the organization. Innovation is vital for a company's survival and growth. Firms that don't innovate fall behind their competitors and ultimately go out of business. However, traditional forms of innovation may result in profitable products, services, and processes – but also harm employees or over-exploit natural resources. "Sustainable innovation" seeks to address those unintended social and environmental impacts. It implies that companies can provide products and services that are good for themselves and society in the long term. Sustainable innovation can be put into three broad categories: operational optimization, organizational transformation, and systems building (Lee 2021).

Figure 3: Categories of sustainable innovation

	Sustainable Business		
Approach	1. **OPERATIONAL OPTIMIZATION** „Eco-Efficiency"	2. **ORGANIZATIONAL TRANSFORMATION** „New Market Opportunities"	3. **SYSTEMS BUILDING** „Societal Change"
Innovation Objective	Compliance, efficiency • *„Doing the same things better"*	Novel products, services or business models • *„Doing good by doing new things"*	Novel products, services or business models that are impossible to achieve alone • *„Doing good by doing new things with others"* •
Innovation Outcome	Reduces harm	Creates shared value	Creates net positive impact
Innovation`s Relationship of the Firm	Incremental improvements to business as usual	Fundamental shift in firm purpose	Extends beyond the firm to drive institutional change

(Source: Lee 2021)

Based on PTC (2023) sustainable innovation is the act of continuously improving your products, processes, and workforce to create a brighter, more sustainable future—for your customers, your

employees, and the environment. Sustainable innovation also supports growth and profitability by facilitating product reuse and circularity and making business operations more efficient and safe.

Sustainable innovation integrates environmental protection with the ability to create new products that satisfy our needs in the long term. Designing better and more sustainable technologies can bring many uncertainties in terms of usability, application, or costs. However, in the last decade, it is been clearer that we can only achieve economic development by focusing on the creation of technologies that do not harm natural ecosystems (Garcia 2022).

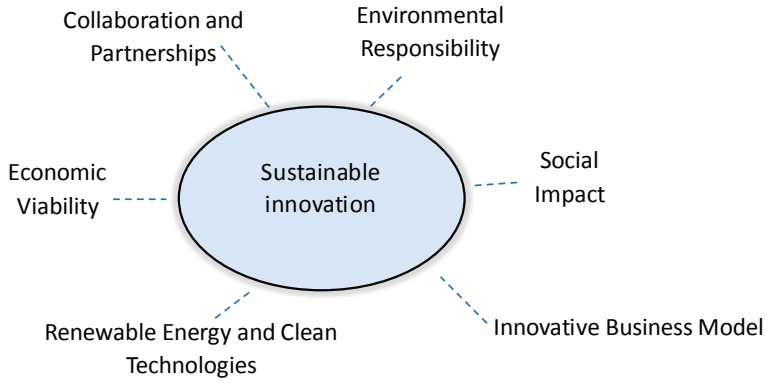
Table 2: Benefits of sustainability for companies

- Lowering costs by reducing the used inputs
- Building credibility and trust
- Improvement of the relationship among investors, customers, researchers and stakeholders
- Efficiency improvement
- Opens the way for innovation
- Customer needs are better understood

(Source: Garcia 2022)

The goal of sustainable innovation is to meet the needs of the present generation without compromising the ability of future generations to meet their own needs (Jain, 2022). We can see some key characteristics of sustainable innovation also in the next picture. As we can see sustainable innovation can be aimed at various fields of everyday life where every man can find scope for herself with the aim to help conserve existing resources for the next generations or to find creative and efficient solutions to address pressing challenges, such as climate change, resource depletion, pollution, inequality, and poverty.

Figure 4: Key characteristics of sustainable innovation



(Source: Jain 2022)

If we look more closely at the examples of sustainable innovations, we can see that they include Renewable Energy Technologies, Circular Economy Practices, Sustainable Agriculture, Sustainable Transportation and Social Enterprises (Jain 2022).

As we know from definitions, startups are innovative businesses and innovation is the core of their idea or solution. But on the other hand, there is the question "Why should be startups also sustainable?" The answer to this question was found by Trusca (2023), who mentions, that for startups caring about sustainability should be a priority for several reasons. Firstly, a sustainable product can differentiate the business from competitors and attract environmentally conscious customers and investors. These startups, are usually referred to as "green startups" and have a unique focus on sustainability while also having unique business models, incorporating a triple-bottom-line approach to decision-making. They aim to promote social good by utilizing technology to develop eco-friend-

ly products and services and have involved established sustainability standards, such as the Global Reporting Initiative (GRI) or the Sustainability Accounting Standards Board (SASB) in their internal practices and policies.

By the top sustainable startups of 2023, presented by Chomsky (2023), we can see that they brought to the market not just a positive impact on making a positive impact on the environment through their work, but also cutting-edge technology and innovative approaches. For example, Amp Robotics uses AI and robotics in waste management and recycling, Coral Vita has developed a groundbreaking method of growing corals in a controlled environment using microorganisms. REEF Technology is revolutionizing parking and mobility by integrating renewable energy sources, like solar panels and green hydrogen production facilities, to power its operations and reduce carbon emissions and Windscape AI uses smart technology to predict the wind's speed, which can help to figure out how fast the wind will blow, what helps make clean energy from the wind more affordable and efficient for the wind farms. By these examples of sustainable startups better known as "green startups", we can see, that these enterprises bring together modern technologies with the traditional fields of green ecology and they also help effectively use conventional sources.

As the findings of Bregnballe–Karppinen's (2020) research indicate, startups have created solutions the literature defines as impossible to develop. Hence, it may be concluded that they are urgently needed to drive the change as they can do what is otherwise perceived as impossible. They also mention that the disruptive solutions startups bring to the field of their activity are essential for a better future and these novel inventions startups bring are vital in order to address the exponentially increasing environmental challenges.

When we go further and will see which destinations between the OECD countries are the best for sustainable startups, based on the Methodology of UtilityBidder (they analyzed each OECD country across six separate factors, compiling the data into a single "Sustainable Startup Score", which they used to create the ranking), we can see that the top country is Switzerland with its 7,81 Sustainable startup score. In second place is the United Kingdom and the third place belongs to Sweden (6,75 score). With a closer look we can also see, that among the top 10 destinations, there are all European countries ranging from 7,81 to 6,00 sustainable startup scores.

Table 3: Top 10 countries for sustainable startups

Country	Startups per 100.000 people	Eco commuting provision score / 10	National recycling rate	Rail passenger kilometres per capita	Transport CO_2 emissions per capita (tonnes)	Proportion of energy from renewables	**Sustainable startup score / 10**
1 Switzerland	9,4	2,8	30,07%	1670,8	1,67	33,08%	7,81
2United Kingdom	10,1	5,32	25,97%	355	1,41	19,34%	7,08
3 Sweden	6,9	1,35	19,91%	760	1,46	53,31%	6,75
4 Luxembourg	11,7	9,38	29,98%	460	7,41	10,85%	6,33
5 Latvia	5,3	2,09	34,03%	198,1	1,6	26,91%	6,21
6 Estonia	23,4	1,33	27,36%	241,1	1,69	15,27%	6,18
7 Netherlands	6,2	1,84	27,88%	624,1	1,48	14,38%	6,16
8 Ireland	8,8	3,19	29,92%	163,4	1,99	20,13%	6,1
9 Austria	3,5	1,7	40,60%	943,2	2,44	36,61	6,03
10 Denmark	7,3	1,36	11,31%	1103,1	1,89	43,04%	6

(Source: UtilityBidder 2024)

On the other side are the worst OECD countries for sustainable startups where first place belongs to Mexico with just 2 sustainable startup score, in second place we can find Turkey (2,87), and in third place is Poland with a 3,21 sustainable startup score, further followed by Chile (3,23), Greece (3,28), Japan (3,37), South Korea (3,38), Czech Republic (3,93), Israel (4,01) and United States (4,36).

To improve their position in the framework of sustainability, as Kučera et al. (2023) mention, the

countries should learn from examples of best practices, identify successful strategies that can be adapted or replicated in their own conditions, and which could possibly improve the ratio between the inputs and outputs, based on benchmarking and learning from leaders.

4 CONCLUSIONS

As Yiğit (2021) mentions innovation has the mission of serving sustainable development as well as increasing national income. As it is already known from the definitions of startups, they are businesses that are based on an innovative approach and thinking and they often act as disruptors of conventional concepts, which helps them discover innovative approaches and bring new and revolutionary concepts to markets. So based on these opinions, we can say, that startups are sustainable innovators who bring the innovative concept of sustainable entrepreneurship to life. As we can further see the enterprises are aware of the need for sustainability in their production, but not all of them integrate this concept into their processes. Based on statistical data we can see that there exists some percentage of enterprises, who are aware of the need for sustainability in their production, but not all of them integrate this concept into their processes. They associate sustainability with increased costs and are unwilling to risk changes to established practices, fearing that this could put them at a disadvantage in the market. However, this attitude is short-sighted, because as we have the opportunity to constantly observe, not only the thinking of entrepreneurs and businesses is changing, but also the thinking of end customers, who are beginning to notice the so-called "ecological footprint" of the products they buy and are beginning to place more and more emphasis on this fact, which causes a change in the purchasing behavior of consumers. This is precisely why we can see that sustainability-oriented startups, i.e. so-called "green startups" have great opportunities for application on the market and at the same time bring an innovative perspective to solving the sustainability problem and show other businesses the possible direction and method of applying the concept of sustainability for them as well. And that is also the reason why we can observe a constant increase in sustainable-green startups.

REFERENCES

1. Bregnballe, Sif, and Laura Karppinen. 2020. Startups as the green innovators of the pharmaceutical industry. Exploring the necessary transformation to a circular economy. Master thesis. Available at: https://research-api.cbs.dk/ws/portalfiles/portal/62185766/825303_Thesis_w._cover.pdf (October 2023)
2. Buchholz, Lucy. 2023. Top 10: Sustainable Startups of 2023. Available at: https://sustainabilitymag.com/articles/top-10-sustainable-startups-of-2023 (October 2023)
3. BusinessPilot. 2023. Sustainable Entrepreneurship. Available on: https://gruenderplattform.de/green-economy/sustainable-entrepreneurship (October 2023)
4. FasterCapital. 2023. The Types of Startups that are Leading the Way in Sustainability. Available at: https://fastercapital.com/content/The-Types-of-Startups-that-are-Leading-the-Way-in-Sustainability.html#The-Types-of-Sustainable-Startups (November 2023)
5. Garcia, K. 2022. Why is Sustainable Innovation Important for the Future?. Available on: https://waitro.org/articles/why-is-sustainable-innovation-important-for-the-future/ (October 2023)
6. Gódány, Zsuzsanna, Renáta Machová, Ladislav Mura, and Tibor Zsigmond. 2021. Entrepreneurship Motivation in the 21st Century in Terms of Pull and Push Factors. In: *TEM Journal* 10 (1): 334-342. Available at: https://www.ceeol.com/search/article-detail?id=935914 (October 2023)
7. Grant, Mitchel. 2022. What a Startup Is and What's Involved in Getting One Off the Ground. Available at: https://www.investopedia.com/terms/s/startup.asp (November 2023)
8. Gründer Plattform. 2023. Gründe dein eigenes Startup und mach dein Ding. Available at: https://gruenderplattform.de/startup-gruenden (November 2023)
9. Horne, Jannic, and Klaus Fichter. 2022. Growing for sustainability: Enablers for the growth of impact startups – A conceptual framework, taxonomy, and systematic literature review. *Journal of Cleaner Production* 349: 131163. doi: 10.1016/j.jclepro.2022.131163
10. Chomsky, Raf. 2023. Top 10 Sustainable Startups of 2023. Available at: https://sustainablereview.com/top-10-sustainable-startups-of-2023/ (November 2023)
11. Jain, Nick. 2022. What is Sustainable Innovation? Definition, Examples and Best Practices. Available at: https://ideascale.com/blog/sustainable-innovation/ (November 2023)
12. Kondrla, Peter, Radoslav Lojan, Patrik Maturaknič, Yulia N. Biryukova, and Ernel G. Mastrapa. 2023. The Philosophical Context of Curriculum Innovations with a Focus on Competence Developmentjournal of Education Culture and Society. *Journal of Education, Culture and Society* 14(2): 78-92.
13. Kopp, Carol. 2023. Creative Destruction: Out With the Old, in With the New. Available at: https://www.investopedia.com/terms/c/creativedestruction.asp (October 2023)
14. KPMG International. 2022. Big shifts, small steps. Survey of Sustainability Reporting 2022. Available at: https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2023/04/big-shifts-small-steps.pdf (October 2023)
15. Kuckertz, Andreas, Elisabeth S.C. Berger, and Anja Gaudig. 2019. Responding to the greatest challenges? Value creation in ecological startups. *Journal of Cleaner Production* 230:. 1138-1147. https://doi.org/10.1016/j.jclepro.2019.05.149 (October 2023)
16. Kučera, Jozef, and Juraj Nemec. 2022. Allocation of Public Funds from The State Budget to The National Sports Associations in Slovakia. *Scientific Papers of the University of Pardubice - SciPap* 30(1): 1405. https://doi.org/10.46585/sp30011405 (October 2023)
17. Kučera, Jozef, Emilia Zimková, Juraj Nemec, and Miroslav Nemec, 2023. A comparative analysis of the efficiency of public funding policies for sports in the European Union. Cogent Social Sciences 9(2). https://doi.org/10.1080/23311886.2023.2280335 (October 2023)
18. Kwon, Oshung. 2020. A study on how startups approach sustainable development through intellectual property. *Sustainable Development* 28(4): 613–625. https://doi.org/10.1002/sd.2012 (November 2023)
19. Lee, Ju Young. 2021. *What is Sustainable Innovation?* Available at: https://nbs.net/what-is-sustainable-innovation-and-how-to-make-innovation-sustainable/ (October 2023)
20. McGowan, Emma. 2022. What Is a Startup Company, Anyway? Available at: https://www.startups.com/library/expert-advice/what-is-a-startup-company (October 2023)

21. Mollenkamp, Daniel Thomas. 2023. What is Sustainability? How Sustainabilities Work, Benefits, and Example. Available at: https://www.investopedia.com/terms/s/sustainability.asp (November 2023)
22. Mulqueen, Tina. 2022. What is sustainable entrepreneurship, and why does it matter? Available at: https://www.entrepreneur.com/leadership/what-is-sustainable-entrepreneurship-and-why-does-it/354955 (October 2023)
23. Olteanu, Yasmin, and Klaus Fichter. 2022. Startups as sustainability transformers: A new empirically derived taxonomy and its policy implications. In *Business Strategy and the Environment* 31(7): 3083–3099. Available at: https://onlinelibrary.wiley.com/doi/full/10.1002/bse.3065 (November 2023)
24. PTC. 2023. What Is Sustainable Innovation? Why Is It Important?. Available at: https://www.ptc.com/en/solutions/sustainable-innovation (November 2023)
25. Shields, Kerri. 2022. Sustainable Innovation. In: *Leading Innovation.* Available at: https://ecampusontario.pressbooks.pub/leadinginnovation/chapter/chapter-5-sustainable-innovation/ (November 2023)
26. Schaltegger, S. 2017. *Sustainable Entrepreneurship als Treiber von Transformation.* Available at: https://www.zukunftsinstitut.de/artikel/sustainable-entrepreneurship-als-treiber-von-transformation/ (November 2023)
27. Šimelytė Agne, Manuela Tvaronavičienė, Rasmus B. Holmen, and Arunas Burinskas. Knowledge and technology transfer as driving force for social innovations. *Polish Journal of Management Studies* 23(2): 512-536. doi: 10.17512/pjms.2021.23.2.31
28. Sustainable Entrepreneur. 2023. Nachhaltig verantwortungsvoll. Available at: https://sustainable-entrepreneur.at/ (October 2023)
29. TravelPerk. 2022. *68 Business sustainability statistics (relevant in 2023)*. Available at: https://www.travelperk.com/blog/business-sustainability-statistics/ (November 2023)
30. TRUIC Team. 2023. 30 Environmental Startups That Will Inspire Entrepreneurs to Go Green. Available at: https://startupsavant.com/startups-to-watch/environmental (November 2023)
31. Trusca, Anca. 2023. Assessing the Sustainability Impact of Startups. A Guide for Entrepreneurs. Available at: https://www.innoq.com/en/articles/2023/04/assessing-the-sustainability-impact-of-startups/ (November 2023)
32. UCLA. 2023. What is Sustainability? Available at: https://www.sustain.ucla.edu/what-is-sustainability/ (November 2023)
33. United Nations. 2023. Sustainability. Available at: https://www.un.org/en/academic-impact/sustainability (November 2023)
34. Urbaníková, Marta, Michaela Štubňová, Viera Papcunová, Jarmila Hudáková. 2020. Analysis of innovation activities of Slovak small and medium-sized family businesses. *Administrative Sciences* 10(4): 1–19. Doi: 10.3390/admsci10040080.
35. UtilityBidder. 2024. Sustainable Startup Destinations. Available at: https://www.utilitybidder.co.uk/compare-business-energy/sustainable-startup-destinations/ (Januar 2024)
36. Yiğit, Sema. An Empirical Perspective on the Relationship Between Innovation Performance and Sustainable Development. *EGE AKADEMİK BAKIŞ / EGE Academic Review* 21(2):47-57. doi: 10.21121/eab.874020.

1.08 Objavljeni znanstveni prispevek na konferenci
Published scientific conference contribution

PRESENTING THE SUSTAINABILITY MODEL OF CONSTRUCTION PROJECTS: A META-SYNTHESIS APPROACH

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ABSTRACT

Prioritizing sustainability in construction has become a common goal among governments, industry professionals, and academics. The main objective of sustainable construction is to minimize the negative impact of construction on the environment and promote a better quality of life while paying attention to economic issues. This research aims to present a sustainable model for construction projects, considering the economic, social, and environmental dimensions. To achieve this goal, the study has conducted a qualitative analysis of the research results in this field. By applying the meta-synthesis method, we analyzed 45 out of 257 identified articles for this purpose. Our study identified 139 indicators to assess the sustainability of construction projects. Of these, 36 indicators pertain to the environment, 44 to the economy, and 59 to social factors. Among the identified indicators, safety on the site was the most frequently mentioned (22 repetitions), followed by hygiene (16 repetitions), energy efficiency (16 repetitions), employee training and development (16 repetitions), and water consumption and conservation (15 repetitions). Among the current research, innovations are identifying indicators and dimensions of sustainable construction using the meta-synthesis qualitative research method.

Keywords: *Sustainability, Sustainable Development, Sustainable Construction, Meta- Synthesis*

1 INTRODUCTION

Among all industries, the construction industry has the greatest impact on its environment. Construction projects allocate huge resources of capital; therefore, they play a key role in achieving sustainable development. It is estimated that the construction industry ecosystem contributes 13% to the world's gross domestic product (GDP). Meanwhile, building and construction account for 36% of global energy consumption and 39% of energy-related carbon dioxide (CO2) emissions (Kiani Maviet al. 2021). Traditional construction methods are no longer able to cope with increasing pressure to comply with environmental standards and commit to social responsibility (Fatourehchi and Zarghami 2020). Construction organizations are looking for approaches to transition from traditional to sustainable construction methods that help them achieve their business goals without distorting the environment (Ershadi and Goodarzi 2021). Over the past decades, the construction sector has been heavily criticized for its poor sustainability performance. This gives the construction industry a unique opportunity to contribute to improving global sustainability capability (Stanitsas 2021). For this reason, this paper has considered a leap in research conducted in this field in the last few years (Kiani Mavi et al. 2021). This issue shows the necessity of discussing sustainability in construction projects. The existing research literature shows different approaches in this field that tend to help in this direction. Researchers have recognized the importance of developing effective strategies to improve the sustainability of a construction project (Stanitsas et al. 2021). In order to address sustainability issues in construction projects, an understanding of the relevant indicators is required, however, the existence of a comprehensive approach as well as the classification of indicators that will help sustainable project management in construction projects according to the Triple Bottom Line (TBL) scenario, as a gap in the literature still exists (Stanitsas et al. 2021). Obviously, identifying the mentioned indicators and assessing sustainability is only half of the equation, the other half is how to modify the project, which is not required according to the sustainability standard. This is the area of tactics and solutions to improve sustainability in construction projects (Kiani Mavi et al. 2021). According to the stated contents, sustainable construction should increase the quality of social, economic and environmental functions by determining the current level of sustainability and identifying weak points and as a result improving them (Hendiani and Bagherpour 2019).

2 PURPOSE AND GOALS

The purpose of this article is to present a model for sustainability for construction projects to deal with environmental, economic, and social challenges related to the construction industry. The global construction sector plays an essential role in economic development, but at the same time, it is one of the main factors of environmental destruction and resource consumption (Fathalizadeh et al. 2021). Considering these concerns, the main goal of our proposed model is to provide a systematic framework that can be used to consider sustainability throughout the life cycle of construction projects.

3 METHODS

There are various methods for reviewing qualitative findings. Meta-synthesis is one of the methods used in this field (Noblit and Hare 1988). Meta-synthesis is research that evaluates another conducted research. For this reason, metacomposition is called evaluation of evaluations. Meta-synthesis is a type of research about another research. Meta-synthesis can be considered the systematic study and review of past research (Sandelowski et al. 2007). The main purpose of this method is to create reliability of the output of findings and theorizing. This method deals with the systematic study of findings (Walsh and Downe 2005). Various models have been proposed for performing Meta-synthesis, among these models, the following can be mentioned:

1. The three-stage model of Noblit and Heyer is the oldest Meta-synthesis model;
2. Walsh and Dunn's six-stage model;
3. The seven-stage model of Sandelowski and Barroso is the most comprehensive Meta- synthesis model.

In this research, due to the comprehensiveness of the Sandelowski and Barroso model, this model is considered. Sandelowski and Barroso presented their seven-step model for Meta- synthesis research as follows (Figure 1):

Figure 1: Steps of meta-synthesis method

(Source: Sandelowski et al. 2007)

3 RESULTS

In this part, the analysis of the investigated method and the implementation of the relevant steps have been discussed.

Step One: Expressing the research question

According to the main purpose of this research, what is the answer to the question? The researcher seeks to identify the main indicators and categories affecting the sustainability of construction projects. Also, in response to the question *when*, considering the novelty of the research problem and the increasing attention of other researchers in the last five years, the collection of articles from the last five years has been considered as the source for identifying the mentioned indicators. In addition, due to the validity of articles published in international journals, in this research, the collection of articles from WoS and Scopus databases has been considered by the researcher for content analysis. Finally, considering the comprehensiveness of Sandelowski and Barroso's model and the acceptability of this model, the researcher will advance his meta-combination work according to the stages of this framework.

Step Two: Systematic texts searching

In this step, the researcher conducts a systematic search of published articles to determine valid, reliable, and relevant documents in the appropriate time frame. First, relevant keywords are selected. These words are listed in the table (Table 1) below.

Table 1: Keywords used in searches

Database	Title
WoS And Scopus	Environmental sustainability Social sustainability Economic sustainability Sustainability indicators
	Construction construction industry construction project
	Project management

The purpose of this step is to determine valid, reliable, and relevant documents in a suitable period.

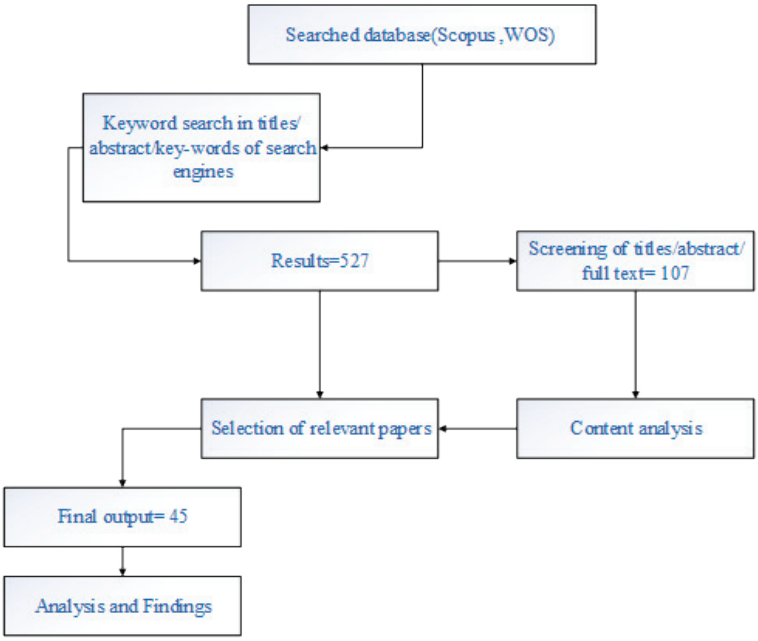
Step Three: Reviewing and selecting the appropriate texts

After identifying the research keywords, a collection of articles containing them is assembled. These articles are screened based on things such as title, abstract, content, and research method, and the final articles are identified and selected.

Table 2: Literature Screening and Inclusion Criteria

Non-acceptance criteria	Acceptance criteria	Criteria
Irrelevance	Related	Research objectives
Inaccessibility	Availability	Accessibility
No specific framework	With a clear framework	Clear expression
Non-English	English	Language
Articles before 2018	Articles from 2019 onwards	Time
Other	Articles published in Scopus, WoS	Database

Figure 2: Research trend chart



Step Four: Extracting the required data from texts

After choosing the appropriate articles, now we have to identify the relevant indicators based on the questions considered. Research questions:

1. What are the main sustainability indicators of construction projects?
2. What are the main indicators of the social dimension of the sustainability of construction projects?
3. What are the main indicators of the economic dimension of the sustainability of construction projects?
4. What are the main indicators of the environmental dimension of the sustainability of construction projects?

In the current research, a total of 139 codes were identified from the selected articles based on the meta-composite approach, whose frequency is based on sustainability dimensions: 36 codes for the environmental dimension, 44 codes for the economic dimension, and 59 codes for the social dimension. It is noteworthy that the frequency of identified codes regardless of their repetition was 573 codes.

Table 3: Examples of identified codes

freq	codes	
16	Energy efficiency	Resource management and energy consumption
11	Using environmentally friendly primary energy sources and renewable energy	
4	Eco-efficiency	
4	Sustainable maintenance	
3	Consistent and predictable load	
6	Construction water quality impact	Management of water resources and consumption
15	Water use and conservation	
7	Recycling water & Water saving	

Step Five: Analyzing and combining the results

The fifth step in Meta-synthesis is analysis and composites. For this purpose, the researcher has categorized the identified codes and themes based on modeling from the relevant research background. In the meta-combination approach, the codes and themes collected from the articles are categorized based on the researcher's understanding and intuition of the subject under investigation. This process continued until there were no more codes without related themes and categories.

Step Six: Quality control of the results

According to the Kappa coefficient value for codes identified after direction, this index is accepted, and the result is considered significant. Kappa coefficient is referred to as internal reliability evaluation criterion. Researchers believe that if the value of the coefficient is greater than 0.6, this coefficient has a relatively good value (Landis and Koch 1977).

Table 4: Kappa coefficient

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.890	.106	3.904	<.001
N of Valid Cases		19			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

(Source: Authors' own work)

Step Seven: Presenting the results

At the end, the results of Meta-synthesis are presented in Table 5. In the Meta-synthesis stage of three main areas, 10 general indicators, 33 sub-indices and 139 guidelines were extracted. It should be noted that the guidelines are the identified codes.

Table 5: Results of Meta-synthesis

Project									
Direction		Execution				Results			
Leadership and sustainable value creation	Goals and strategies	Resource and energy management	Stakeholders	Project oriented processes	Product oriented processes	Environmental results	Social results	Economic results	Project product results

According to the provided image, the meta-synthesis process in this research has led to the extraction of a comprehensive framework comprising three main areas, 10 general indicators, 33 sub-indices, and 139 guidelines. This hierarchical structure demonstrates a systematic approach to integrating and organizing sustainability criteria in project management. As Goel et al. (2019) note, the effective integration of sustainability into construction project management requires the identification and structuring of key dimensions and indicators. This finding also aligns with the research of Hatefi and Tamošaitienė (2018), who emphasize the importance of developing sustainable criteria for construction project assessment. The approach employed in this analysis, where the guidelines are directly derived from the identified codes, ensures the precision and transparency of the extraction process. According to Hashemi et al. (2021), the proper selection of sustainability indicators is the foundation for informed decision-making at various stages of the project lifecycle. Ultimately, this comprehensive framework not only provides an assessment tool but also represents a step towards achieving "project management for positive social impact," as promoted by Goel et al. (2020).

4 DISCUSSION

Integrating sustainability in project and project management is an approach that has received increasing attention from academic researchers in recent years. To implement the principles of sustainability at the project level, researchers have identified key success indicators and factors; However, the identification of the aforementioned indicators only leads to the identification of factors affecting the sustainability of projects, while the main goal of integrating sustainability in projects is to improve their performance level from the perspective of compliance with the principles of sustainability. According to what has been said, the need for a model that can be used to measure the sustainability of the project and determine their level of sustainability, to identify the improvement leaders and use the contract is felt. The current research has presented a model to fill the gap, this model introduces the dynamic approach to improve the sustainability of construction projects by considering the three main dimensions of orientation, implementation, and results.

5 CONCLUSION

The model presented in the results dimension by expressing the economic, environmental, and social results expected from the projects that are concerned with the integration of sustainability, as well as the expected results from the product of these projects, provides a view of what should be realized in the end. But this is not the end of the work, this model in two dimensions of orientation and implementation at two strategic and operational levels has expressed how to implement projects to comply with the principles of sustainability and obtain sustainable results.

REFERENCES

1. Ershadi, Mahmoud, and Fateme Goodarzi. 2021. Core capabilities for achieving sustainable construction project management. *Sustainable Production and Consumption* 28(10): 1396-1410.
2. Fathalizadeh, Ali, M. Reza Hosseini, A. J. Gilbertus Silvius, Ali Rahimian, Igor Martek, and David J. Edwards. 2021. Barriers impeding sustainable project management: A Social Network Analysis of the Iranian construction sector. *Journal of Cleaner Production* 318: 128405.
3. Fatourehchi, Dorsa, and Esmaeil Zarghami. 2020. Social sustainability assessment framework for managing sustainable construction in residential buildings. *Journal of building engineering* 32: 101761.
4. Goel, Ashish, L. S. Ganesh, and Arshinder Kaur. 2019. Sustainability integration in the management of construction projects: A morphological analysis of over two decades' research literature. *Journal of Cleaner Production* 236: 117676.
5. Goel, Ashish, L. S. Ganesh, and Arshinder Kaur. 2020. Project management for social good: A conceptual framework and research agenda for socially sustainable construction project management. *International journal of managing projects in business* 13(4): 695-726.
6. Hashemi, Hassan, Parviz Ghoddousi, and Farnad Nasirzadeh. 2021. Sustainability indicator selection by a novel triangular intuitionistic fuzzy decision-making approach in highway construction projects. *Sustainability* 13(3): 1477.
7. Hatefi, Seyed M., Jolanta Tamošaitienė. 2018. Construction projects assessment based on the sustainable development criteria by an integrated fuzzy AHP and improved GRA model. *Sustainability* 10(4): 991.
8. Hendiani, Sepehr, and Morteza Bagherpour. 2019. Developing an integrated index to assess social sustainability in construction industry using fuzzy logic. *Journal of cleaner production* 230: 647-662.
9. Kiani Mavi, Reza, Denise Gengatharen, Neda Kiani Mavi, Richard Hughes, Alistair Campbell, and Ross Yates. 2021. Sustainability in construction projects: a systematic literature review. *Sustainability* 13(4): 1932.
10. Noblit, George W., and R. Dwight Hare. 1988. *Meta-ethnography: Synthesizing qualitative studies.* Vol. Newbury Pa, 38-56.
11. Sandelowski, Margarete, Julie Barroso, and Corrine I. Voils. 2007. Using qualitative meta summary to synthesize qualitative and quantitative descriptive findings. *Research in nursing & health* 30(1): 99-111.
12. Stanitsas, Marios, Konstantinos Kirytopoulos, and Vrassidas Leopoulos. 2021. Integrating sustainability indicators into project management: The case of construction industry. *Journal of Cleaner Production* 279: 123774.
13. Walsh, Denis, and Soo Downe. 2005. Meta synthesis method for qualitative research: a literature review. *Journal of Advanced Nursing* 50(2): 204-211.
14. Landis, J. Richard, and Gary G. Koch. 1977. An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics* 33(1): 159-174.

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1.09 Objavljeni strokovni prispevek na konferenci
Published professional conference contribution

SUSTAINABLE TOURISM PLANNING TO ENSURE THE QUALITY OF LIFE OF LOCAL RESIDENTS - THE TOURISM 4.0 EXPERIENCE

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ABSTRACT

The tourism industry faces a critical challenge: balancing economic growth with environmental protection and social well-being. Sustainable tourism planning, which prioritizes local residents' quality of life, offers a promising path forward. This article explores the integral role of innovative tools, new technologies and data analytics in this process.

Innovative technologies can effectively monitor tourism's impacts, ensuring informed decision-making that minimizes negative environmental and social consequences. They enable the development of smart tourism systems that optimize resource use, reduce negative impacts and enhance visitor experiences. Furthermore, they empower collaboration among different stakeholders, including local communities, businesses, and government administration, fostering inclusive and sustainable tourism development.

This article explains how innovative tools and multiple data sources can be leveraged to gather real-time and other (e.g. historic, statistical etc.) data on tourist flows, in order to plan efficiently and make informed decisions. Moreover, it shares experiences of digital innovation of cultural heritage (CH) and Tourism 4.0's achievements. By integrating technologies and data analytics into sustainable tourism planning frameworks, destinations can create a future where tourism not only thrives economically but also protects the environment, enriches local communities, and fosters a high quality of life for residents.

Keywords: *Sustainable tourism planning, Quality of life of local residents, Innovative technologies, Data analytics, Informed decision making, Digitalisation, Cultural heritage*

1 INTRODUCTION

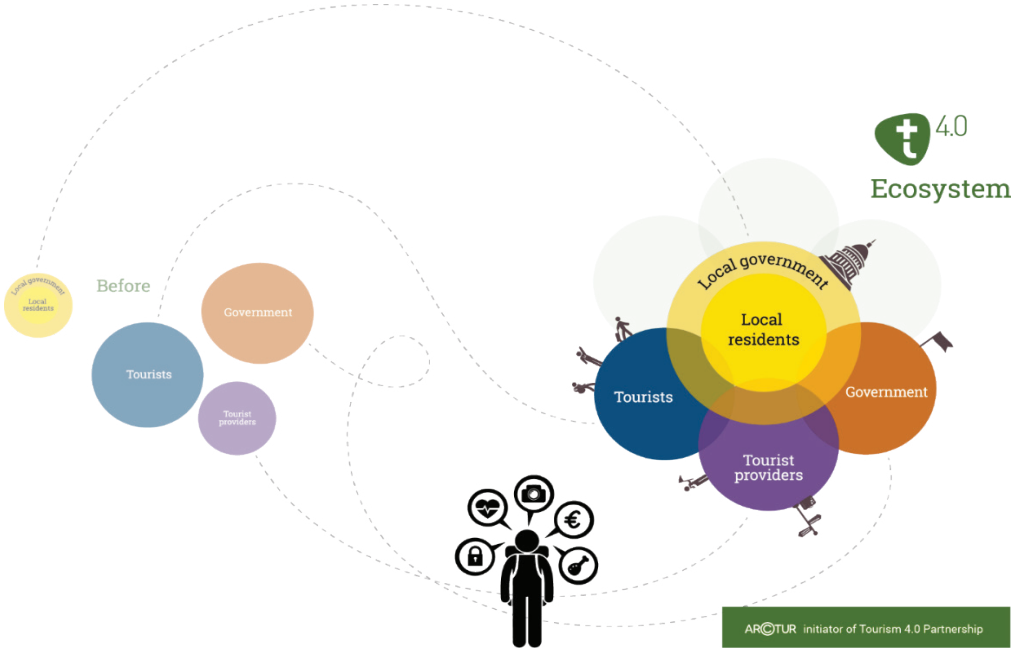
The advent of new technologies and tools has ushered in an era where real data can be harnessed effectively. Furthermore, these advancements empower us to construct a digital replica of tourist destinations, enabling data-driven strategic planning that has the potential to reshape tourism into a force for sustainability.

On one side tourism holds a prominent position as one of the most significant economic activities globally. Prior to the pandemic, Travel & Tourism (including its direct, indirect, and induced impacts) accounted for 10.4 % of global GDP (US$ 10 trillion) in 2019. The World Travel and Tourism Council's (WTTC) latest annual research shows that in 2022, the Travel & Tourism sector contributed 7.6 % to global GDP; an increase of 22 % from 2021 and only 23 % below 2019 levels (World Travel and Tourism Council 2024). Simultaneously, tourism serves as a horizontal layer intertwined with nearly every facet of society. When managed judiciously, it possesses the potential to drive positive societal changes, economic prosperity, and sustainable development, a realization underscored by the United Nations through the pursuit of the 17 Sustainable Development Goals (SDGs) (World Tourism Organization and United Nations Development Programme, 2018). The Tourism 4.0 initiative is at the forefront of this transformation, harnessing technologies from Industry 4.0, including the Internet of Things, Big Data, Artificial Intelligence, Blockchain, Virtual Reality, and more.

In 2018, led by Arctur, a Slovene high-tech company, this initiative evolved into the Tourism 4.0 Partnership, uniting today a consortium of over 230 industrial organizations, universities, leading research institutions in tourism, computer, and information technology, as well as governmental bodies, associations of municipalities, and small-scale tourism service providers. The initial step in this journey involved a fundamental rethinking of tourism, a process that has proven resilient even in the face of challenges posed by the COVID-19 pandemic.

Within the Tourism 4.0 ecosystem, the focus revolves around local inhabitants and their quality of life, with all other stakeholders orbiting around them. Within this framework, a system has been devised, incorporating innovative solutions to measure the impact of tourism, tourist flows, and other disruptive tools aimed at promoting sustainable planning and development. Importantly, this system entails the sharing of at least a portion of the data and profits with the local community.

Figure 1: Tourism 4.0 Ecosystem



(Source: Arctur 2024)

2 THE QUEST FOR LOCAL DATA

At first Tourism Impact Model (TIM) was developed, an award-winning tool using real data to create an objective picture of the impact of tourism in a certain micro-location. It analyses different societal aspects: from environment, economy and culture to collaboration and produces an automatically generated report based on more than 300 indicators. By modelling the impact using different scenarios, it also acts as a digital twin of a tourist destination and allows data-driven strategic planning aligned with the UN Sustainable Development Goals.

TIM has already been validated in 27 destinations in Danube area (Austria, Slovenia...) and 6 destinations in Black Sea Area. The biggest challenge of TIM is to collect the data from various data sources, which takes a lot of human effort. Beyond this issue, very often there are also issues with data availability and data reliability. And in working with destinations, it became clear that the current situation is rather a wild west. We are just at the very beginning of the development of own local data gardens where high quality ingredients for data analytics could grow. This article presents some projects within the framework of Tourism 4.0 fostering this development by the creation of innovative good practices ("Tourism 4.0", 2024).

3 MOUNTAINEERING 4.0

Mountaineering 4.0[1] brings innovative technologies to the Alpine environment. It is based on FLOWS platform, a solution that supports understanding and forecasting visitor patterns at any location (Planinska Zveza Slovenije 2023).

It provides data integration from multiple sources (smart counters, mobile data, points of interest, tourist tax collection, municipal infrastructure such as waste, water and electricity consumption, public WiFi networks), analysis of data in various formats, real-time and historical data, a comprehensive online dashboard with charts and maps of KPIs, in a user-friendly interface. FLOWS also provides advanced forecasting capabilities. It employs advanced data analysis to help professionals prepare for periods of increased visits by adjusting marketing activities, service offerings or resource allocation to meet changes in consumer demand. FLOWS answers key questions such as when peaks occur, the impact of seasonality, the areas of congestion, the influence of traffic flows and how weather, holidays and other events affect visitor patterns.

In the mentioned project, the Slovenian Alpine Association, CIPRA Slovenia and the Tržič Alpine Club, partners of the project have installed a system of smart pedestrian sensors at five of Slovenia's popular hiking destinations - Vršič, Lovrenška jezera, Storžič, Osp and Kum. The sensors collect data in real time on visits and display it on the user-friendly FLOWS dashboard. This supports better understanding of visitor patterns in the Alpine area and the sustainable rerouting of Alpine flows.

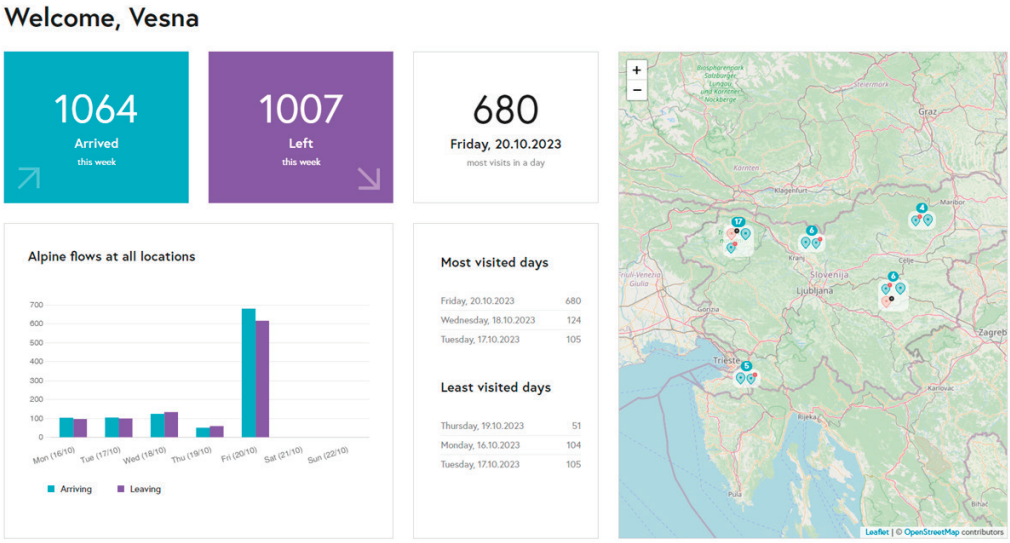
Multitude of data sources data (number of trail visitors, traffic to the area, weather, mountain accidents), when analysed and interpreted, can provide valuable insights for managing and improving the mountain region, enhancing visitor experience, and promoting sustainable tourism practices.

Other data sources that could be used in the project have also been identified however they were not available because of various reasons, legal or technical. For example, number of overnight stays in the mountain huts, occupancy of parking spots etc.

Collecting visitors' data in natural/mountain regions may present challenges such as extreme weather conditions, remote access, lack of infrastructure, and the risk of natural disasters. This project represents a major step forward in the sustainable and data-driven management of mountain tourism.

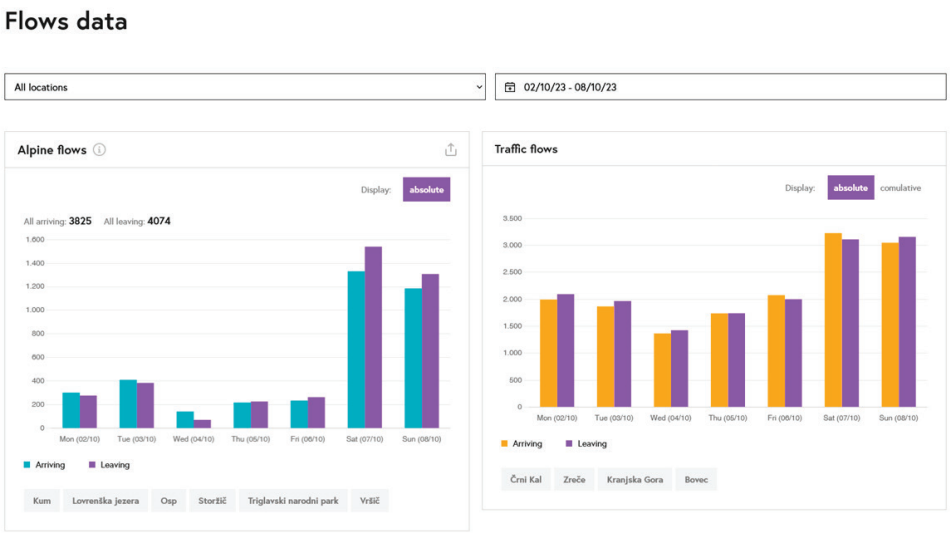
1 Project reference: Planinstvo 4.0, Planinska zveza Slovenije (leading partner), Cipra Slovenija, društvo za varstvo Alp, Planinsko društvo Tržič, 2022-2023, funding Ministry for public administration of Republic of Slovenia.

Figure 2: Flows Dashboard representing summary of trail visits in real time at five locations in Slovenia.



(Source: Arctur, 2024)

Figure 3: Flows dashboard representing data from two different data sources: footfall counters vs traffic counters showing correlation.



(Source: Arctur, 2024)

4 SD4TIM

Space data for TIM (ESA Contract No. 4000138244/22) is the second project from the mentioned framework, funded by European Space Agency, aiming to simplify the TIM user's experience by automatizing the data collecting process, quantifying changes in air pollution - Air Quality Indices, to provide aggregate estimates in Europe using Satellite Earth Observation (EO) data and integrating it into TIM as well as the Land Surface Temperature (LST) data. As a result, TIM assessments can be fin-

ished faster and with higher accuracy. The project started in the middle of TRL2 and finished at TRL3 with the developed Elementary Prototype of the integrated Satellite EO data in TIM.

The first topic researched was air quality which can be measured using local means: stations with various in situ ground sensors, many of which are found in large cities in developed countries and much less frequently elsewhere.

The approach taken in the SD4TIM project makes use of satellite data, which brings many benefits: objective and comparable measurement, replicable anywhere in the world, providing a larger scale view complementary to in-situ data and well adapted to analyse trends at a city, region, or country level. The raw data source integrated used is the CAMS service, offering information based on observation satellite data (Sentinel-5p), in-situ data and scientific modelling.

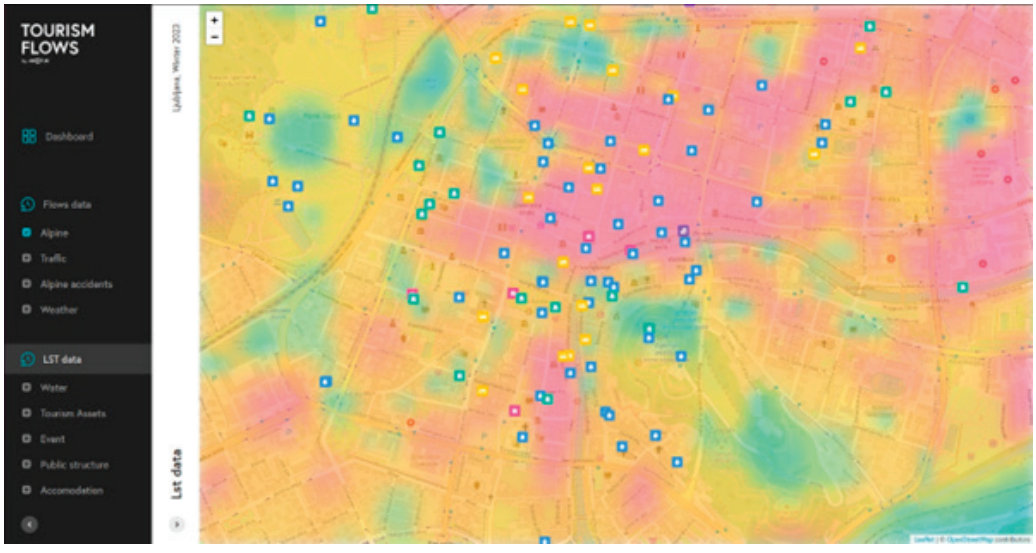
4.1 Air quality

Air quality indicators have great significance for the local strategists and decision makers. In the project it was concluded that satellite data is extremely important since it is generally available and can be of great use to local decision makers. The biggest challenge is to make it easily understandable to them which can be tackled from two directions: (1.) making analysis and interpretation of the data as instinctive as possible and (2.) increasing the knowledge of decision makers on how to use this information.

4.2 Land Surface Temperature (LST)

The second topic researched was Land Surface Temperature (LST), a measure of the temperature of the Earth's surface as perceived by satellite or ground sensors. There are several methods for measuring LST, including thermal satellite sensors, ground-based weather stations, and ground-based sensors. Thermal satellite sensors are most used to measure LST on a large scale, as they allow large geographic areas to be covered and temperature changes to be monitored on a regular basis. LST is influenced by several factors, such as vegetation cover, topography, soil moisture, presence of water and urban density. Data from LST can be used for a variety of applications, including mapping urban areas, monitoring droughts and floods, predicting forest fires, monitoring climate change, assessing air quality, the detection of urban heat islands or even the detection of urban heat loss linked to poorly insulated buildings. However, LST data can be affected by errors and uncertainties, especially in areas with heavy cloud cover and snow coverage. Additionally, LST measurements are not always available at high spatial and temporal resolution, which may limit their usefulness for some applications.

Figure 4: LST data and points of interest for City centre of Ljubljana (summer 2023).



(Source: Arctur 2023)

Figure 5: Coverage of water features in Ljubljana (Summer 2023).

(Source: Arctur 2023)

In the project LST was connected with points of interest provided by the municipalities. Their goal was to understand how they can use the LST data to better design urban planning and check the effectiveness of plans already produced.

Over the years, advanced methods have been developed to improve the measurement and analysis of LST. For example, remote sensing techniques based on high-resolution satellite images have improved the spatial resolution of LST data and tracked temperature changes at the local scale. Surface temperature simulation models have also been developed to improve the accuracy of LST data.

The use of LST data seems to be effective in detecting both the urban heat island effect during summer and the heat loss of buildings during winter. Using the satellite data includes the ability to obtain objective and comparable measurements, the potential for replication across global settings, and the capacity to offer a panoramic perspective that complements localised in-situ data.

5 BEYONDSNOW

Many small medium-altitude snow tourism destinations and communities across the Alpine Space area are facing climate change issues, especially regarding the diminishment of snow coverage. Climatic data indicate that this effect will considerably worsen in the future. The third presented here, BeyondSnow project is led by 13 partners and aims at increasing the socio-ecologic climate resilience of snow tourism destinations and communities and enable them to retain their attractiveness for residents and tourists, by specifically considering eco-system-based approaches. The project is funded by the European territorial cooperation programme "Interreg Alpine Space" (BeyondSnow 2023). New sustainable development paths, transition processes, and implementable solutions will be conjointly devised within specific pilot working areas, which are spatially distributed across six Alpine countries, differing in size, development level and criticalities.

Since the beginning of the project the project partners have been identifying future climate scenarios, vulnerability indicators, and main transition models for snow tourism destinations, developing a theoretical and methodological design of the Resilience Adaptation Model (RAM) that will represent a theoretical model for the innovative and easy to use Resilience Decision-Making Digital Tool (RDMDT). The RDMDT will be made freely available and publicly accessible throughout the Alpine community. The RDMDT will be an automated assessment tool designed to collect quantitative and qualitative data, transforming it into enriched information, allowing local and regional authorities, development agencies and stakeholders to pursue eco-system-based data-driven strategic planning. ("Beyond Snow Project Developments" 2023).

Additionally, pilot actions for RDMDT implementation and resilience enhancement of the pilot working areas are planned. By involving local communities and stakeholders, the project partners aim at field-testing and fine-tuning the RDMDT, as well as co-designing alternative development scenarios, sustainable transition paths and strategies for each pilot working area. Finally, policy recommendations for Alpine Convention, EUSALP & EU are foreseen. The policy recommendations are going to meet the Alpine Convention working group results on climate change strategies, including the Alpine Convention Alpine Climate Board and the Climate Action Plan 2.0. On the EU-level, policy recommendations will be developed in the light of the EU strategy for Sustainable Tourism.

6 DIGITAL INNOVATION OF CULTURAL HERITAGE: WIN, WIN, WIN

Gathering local data makes us understand how drastically change is happening *at home* and not *somewhere else*. Faced with over-tourism or climate change, destinations have a chance to rethink tourist flows, creating both challenges and exciting possibilities for new experiences. This article wants to showcase an example where this was taken as an opportunity to create a story of success - at the crossroads of digital technologies, tourism and cultural heritage.

The Register of Slovene Cultural Heritage, specifically the Registry of Immovable Cultural Heritage, has more than 30,000 entries and the register systematically identifies the protected and most important immovable cultural heritage in Slovenia. From a tourism development point of view, each of the entries presents an opportunity and a potential source of new digitally enriched interpretation and (tourism) experiences. Cultural heritage as a starting point of sustainable tourism development is characterized with deep roots in local culture and the life of local communities, is a reflection of local, regional, national and cross-border identity and symbolic DNA, as well as relatively evenly dispersed across the country, thus "resisting" the agglomeration effects in tourism (leading to over-tourism, iconisation and over-commercialization/Disneyfication). Each registered object of immovable cultural heritage conveys a value and learning that could be interpreted digitally – and thus presented to new audiences in new engaging ways.

It is in this context that local culture and cultural heritage are often seen as 'unpolished diamonds' that can be transformed into assets. This can be done by 'polishing the diamonds', that is, "turning underused or unused resources, situations, facilities or features into socioeconomic assets" (Schwendler 2012) (as the URBACT OP-ACT Thematic Network suggests (Schlappa 2013). Cultural heritage is widely understood as a powerful economic, educational and social resource (Council of Europe 2017), a "development asset" (Loulanski 2006), a "value-adding industry" (Cernea 2001), and "the most significant product of the 21st century" (Ogino 2002). It is clear that heritage and culture in general are especially valued for their contributions to social innovation as well as for their creative and innovative capacity to attract development and act as catalysts for urban transformation - as discussed in several UNESCO publications (UNESCO 2018; UNESCO 2013; UNESCO 2016).

Investments in cultural heritage have already shown both direct and indirect positive impacts. In 2003, Nypan (2006) identified a ratio of 1:27 between direct job creation by heritage institutions and indirect job creation (creative and cultural industries, tourism, etc). For comparison the same ratio of direct to indirect job creation for the automotive industry is 1:6.3. Moreover, a 1998 study found that US$1 million invested in rehabilitation of cultural heritage generates 31.3 jobs, making the impact larger than that for manufacturing (21.3) (Rypkema 1998).

In addition, only 16 % of the jobs that are created from investing in cultural heritage are located at the heritage sites (Greffe 2002), meaning that the positive impacts are largely felt in the vicinity and in neighbouring communities. For example, Nypan attributes only 6-10 % of all heritage tourism spending to the actual objects of cultural heritage, while the largest share of spending happens in the broader community (accommodation, food, related cultural supply, other local businesses, etc.). Although the impact of culture is being increasingly analysed and characterized by (cultural) economists (Doyle 2010; Navrud et al. 2002; Srakar 2010; Seaman 2003), as a part of macroeconomics (UNESCO 2015), cultural heritage within development "lacks a real working formula" (Napolitano 2018) that can be used in the practice of 'polishing diamonds'. Consequently, despite the broad agreement on the need to (socially) innovate at the intersection of heritage and the economy, cultural-heritage actors still struggle.

Despite that the upcoming trends of the virtual experience economy have an immense potential for on-demand enriched experiences in tourism, most notably in the heritage and cultural tourism sector, tourism management organizations are typically not engaged in the creation of new complex tourism products on cultural heritage and are even less incorporating new digital interpretation technologies. The sectors of tourism (tourism providers, tourism destination management organizations) and cultural heritage (GLAM and regional offices of institute for heritage protection) have – despite having many touchpoints and common aims – very seldom cooperated in co-creative processes. Moreover, digital interpretation technologies – such as Virtual Reality, Augmented Reality, holographic projections, video mapping, mobile and web apps – have not been common at leading tourist destinations, especially due to a lack of knowledge, skills and dedicated funding.

Based on the research findings within the largest R&D project focused on tourism in the history of Slovenia Tourism 4.0 TRL 3-6, involving all major universities in the country and Arctur, a hi-tech company which initiated Tourism 4.0 partnership (Tourism 4.0), the Slovene Ministry for Economic Development and Technology took the lead to pave the way and become one of the leading countries in digitally enriched tourist experiences of cultural heritage. The goal of the Ministry was to develop new tourism products that take inspiration in cultural heritage, engage new audiences and stakeholders through digital and hybrid interpretation and thusly contribute to interpretation, awareness-raising, and documentation of (immovable) cultural heritage. Such projects were envisioned to have direct results in tourism development, as well as indirect results in supporting creative and cultural industries, advancing the use of technology in cultural tourism and cultural heritage, contributing to 3D digitization goals and cross-sectorial cooperation at local levels.

Using digital tools and technologies, new tourist products stressed the engagement in Slovenian cultural heritage and conveyed the message and values of protected CH to visitors, craving for unique and local experiences. Cultural heritage and heritage tourism present a unique opportunity for digitising and digitalising cultural heritage for new co-creative and participative processes. The project was based on understanding the needs and co-creation of added value by fostering new local CH tourism experiences with advanced technology. Technology solutions do not only uniquely represent the local identity but also allow for enriched interpretations and timeless preservation.

Projects of digital innovation of CH are thusly intrinsically a combination of product development, storytelling, digital interpretation of CH, advanced technologies (3D digitisation, AR/VR, holographic projections, touchscreens, mobile and web apps, video mapping), user experience design and collaborative co-creative processes.

This project equipped individuals and organizations with the skills and knowledge to digitally transform cultural heritage through a comprehensive approach. It provided workshops, trainings, and a toolkit on cultural hreitage digital innovation, empowering participants before and after application submission. Sharing new approaches, technical guidelines, and standards aimed to inspire applicants, raise expectations, and ensure high-quality, accurate 3D digitization of CH units through established guidelines. The project fostered collaboration between local, regional, national, and EU stakeholders, gathering and disseminating results nationwide to amplify local and regional impact. Active participation in over 50 EU conferences, symposiums, and workshops (2020-2021) served to further disseminate findings on an EU level, while the project's presence at Expo 2020 Dubai leveraged cutting-edge technologies like VR glasses, AR tables, and holograms for impactful presentation. Looking towards sustainability, the project secured participation in new EU projects focused on digitization, immersive tourism products, and education (CINEA, Erasmus+, Horizon Europe), and even established new CH groups, like the national section for underground heritage, dedicated to driving further digital innovation and creating unique tourism experiences. This project empowered individuals, fostered collaboration, and established sustainable practices for CH digital innovation, not only within the project but across Europe.

The project involved 35 tourist destinations in Slovenia and together over 1000 heritage and tourism experts, digitalisation experts and technical staff, local NGOs, companies – tourist and other providers, local residents (storytellers) that were included in the digitalisation process and in the creation of the 5-star tourist experiences. It was well recognised on a national and international level. Moreover, the project was awarded the ECTN award in 2021 - the category Cultural and Creative Industries, 2nd place. Several tourist destinations have also received international awards for their

projects (Top 100 Destination Sustainability Story, BIG SEE Tourism Award...). Moreover, the project has been presented at Expo 2020 in Dubai.

The project was completed in December 2021, with 114 units of digitized cultural heritage and developed 31 5-star (unique, local) tourist experiences. With it, Slovenia has become the pioneer and one of European`s leading countries in the digital innovation of CH.

7 HARNESSING DATA FOR TOURISM: UNVEILING A EUROPEAN STRATEGY

As we've seen, data – both numerical and 3D – is revolutionizing tourist experiences and management. The European Commission (2024) recognizes data as "a key ingredient for innovative products and services," and aims to unlock its value for Europe.

In February 2020, the European strategy for data outlined a plan to create "common European data spaces" in strategic fields like tourism, cultural heritage, and media. These spaces will gradually form a single European data market that upholds EU regulations and values, particularly regarding personal data, consumer protection, and competition. Open to participation, they will offer secure, privacy-preserving infrastructure and fair, transparent, and non-discriminatory access rules.

The vision is to unleash the potential of data-driven innovation, especially by empowering data holders to share their data for free or for compensation. In this way, data spaces share many goals with the Tourism 4.0 initiative. Data from related projects, initiatives, and pilots will be, or will soon be, included in these common data spaces for tourism, heritage, and media.

As a Tourism 4.0 initiator, Arctur plays a crucial role in establishing and implementing data spaces and related activities. Arctur thus bridges the gap between local, bottom-up projects and broader strategic initiatives and trends and present a unique partner in digitalisation pathway for many public and private players.

REFERENCES

1. Arctur. *High Performance Computing, Cloud Computing, Mobile and Web Design, 4PM*. Available at: https://www.arctur.si/ (February 7, 2024).
2. BeyondSnow. 2023. *Enhancing the Resilience of Alpine Space Snow Tourism Destinations and Communities to Climate Change.* Available at: Alpine Space Programme (February 7, 2024).
3. Beyond Snow Project Developments. *Tourism 4.0*. Available at: https://tourism4-0.org/beyond--snow-project-developments (August 29, 2023).
4. Cernea, Michael M. 2001. *Cultural Heritage and Development: A Framework for Action in the Middle East and North Africa*. The World Bank.
5. Council of Europe. 2017. *Recommendation of the Committee of Ministers to Member States on the European Cultural Heritage Strategy for the 21st Century*. Adopted by the Committee of Ministers on 22 February 2017 at the 1278 meeting of the Ministers' Deputies. CM/Rec (2017)1. Council of Europe: Strasbourg.
6. Doyle, Gillian. 2010. Why Culture Attracts and Resists Economic Analysis. *Journal of Cultural Economics* 34(4): 245-259.
7. Greffe, Xavier. 2002. *La Valorisation Économique du Patrimoine, Rapport au Dep et à la Dapa*. Paris: Ministère de la Culture et de la Communication.
8. Loulanski, Tolina. 2006. Cultural Heritage in Socio-Economic Development: Local and Global Perspectives. *Environments: A Journal of Interdisciplinary Studies* 34(2).
9. Napolitano, Pasquale. 2018. *The Socio-economic Impact of the Cultural Heritage on the Communities*. Digicult.
10. Navrud, Ståle, and Richard C. Ready, eds. 2002. *Valuing Cultural Heritage: Applying Environmental Valuation Techniques to Historic Buildings, Monuments and Artifacts*. Edward Elgar Publishing.
11. Nypan, Terje. 2006. *Cultural Heritage Monuments and Historic Buildings as Value Generators in a Post-industrial Economy*. Rev.
12. Ogino, Masahiro. 2002. *The Sociology of Cultural Heritage: From the Louvre to Hiroshima Dome*. Tokyo: Shin-Yo-Sha.
13. Planinska zveza Slovenije. Projekt PLANINSTVO 4.0. Available at: https://www.pzs.si/vsebina.php?pid=281 (February 1, 2024).
14. Rypkema, Donovan. 1998. *Economic Benefits of Historic Preservation*. Forum News 4, no. 5.
15. Schwendler, H. U. 2012. *Polishing Diamonds: Utilising 'Undiscovered' Potentials in Shrinking Cities*. Unpublished working paper of the URBACT Workstream on Shrinking Cities and Demographic Change. Friendly Cities: A Framework for Action.
16. Schlappa, Hans, and J.V. William Neil. 2013. *Cities of Tomorrow – Action Today. URBACT II Capitalisation. From Crisis to Choice: Re-imagining the Future in Shrinking Cities*. Saint-Denis: URBACT.
17. Seaman, Bruce A. 2003. Beyond Economic Impact. In *The Arts in a New Millennium: Research and the Arts Sector.* Praeger.
18. Srakar, Andrej. 2010. *Ekonomsko Vrednotenje Umetniških Dogodkov: Umetnost Med Trgom in Državo*. Fakulteta za Družbene Vede.
19. Tourism 4.0 – Enriched Tourism Experience, Tourism 4.0. Available at: https://tourism4-0.org/ (February 7, 2024).
20. UNESCO. 2013. *The Hangzhou Declaration Placing Culture at the Heart of Sustainable Development Policies*. Adopted in Hangzhou, People's Republic of China, on 17 May 2013. Available at: http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/CLT/images/FinalHangzhouDeclaration20130517.pdf (February 7, 2024).
21. UNESCO. 2015. *Recommendation Concerning the Protection and Promotion of Museums and Collections, Their Diversity and Their Role in Society*. Adopted by the General Conference at its 38th Session, Paris, 17 November 2015. Available at: https://unesdoc.unesco.org/ark:/48223/pf0000246331 (February 7, 2024).
22. UNESCO. 2016. *Culture: Urban Future; Global Report on Culture for Sustainable Urban Development; Summary*. https://unesdoc.unesco.org/ark:/48223/pf0000246291.

23. UNESCO. 2018. *Culture for the 2030 Agenda*. http://www.unesco.org/culture/flipbook/culture-2030/en/Brochure-UNESCO-Culture-SDGs-EN2.pdf.
24. World Travel and Tourism Council. 2024. "*Economic Impact Research.*" Available at: https://wttc.org/research/economic-impact (February 7, 2024).

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1.09 Objavljeni strokovni prispevek na konferenci
Published professional conference contribution

TORRENTIAL FLOODS AND LANDSLIDES – SUSTAINABLE RECOVERY

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ABSTRACT

Storms, floods, and landslides are risks we face. This paper describes torrential floods and landslides and their recovery. The recovery strategy must help people return from disaster to normal life, but the next step must also be sustainable. It involves environmental, social, and economic aspects that can only be achieved by striking an effective balance between the natural environment, human response, and technology.

Due to abundant rainfall and rapid rainwater runoff, torrential and flat waters rise and overflow riverbeds. Floodwaters are associated with erosion, landslides, the carrying away of soil on riverbanks, as well as deposits of materials carried by swollen rivers. Raging waters cause significant damage to rural agriculture. Rapid response and remediation of the damage help reduce the consequences and allow for the continuation of activities. The main goal of sustainable recovery is to develop long-term solutions for natural and human stakeholders.

During heavy rainfall, torrents grow, and landslides are triggered. In such cases, it is important to act quickly and efficiently. The first step is to address activities connected with public safety, health, welfare, security, and the minimization of environmental impact. Torrents and torrential areas must be managed in a natural manner, using a sustainable and interdisciplinary approach to recover from downpours, floods, and landslides.

This paper is prepared by conducting a series of relevant literature reviews in the field of land subsidence and flooding of torrents and by analysing several damage cases in the municipality of Škofja Loka during the heavy rainfall in August 2023. Based on the relevant research, we have found out that there are many possibilities for improving current practices of torrents reconstruction.

***Keywords**: Sustainability, Flood, Landslides, Torrents*

1 INTRODUCTION

Torrential floods and landslides are indeed complex natural phenomena that can be caused by both local conditions and human activities. Factors such as unfavourable geological conditions, diverse morphology, and heavy precipitation during rainfall contribute to the occurrence of these disasters. Additionally, climate change and its impact on the hydrologic system can further exacerbate the frequency and intensity of such events (Haasnoot et al. 2009).

The warming caused by climate change has significant implications for the environment. It can lead to increased temperatures, changes in precipitation patterns, and alterations in the frequency and intensity of natural events. These changes, including heavy rainfall, can trigger torrents and landslides, contributing to the occurrence of flood and landslide disasters.

Heavy rain is generally classified as falling at a rate of greater than or equal to 7.6 mm of water per hour (Coen and Shah 2023). Floods in Slovenia can occur at any time of the year, but most of them, and the heaviest ones occur in spring and autumn (Mikuš et al. 2004). In August 2023, Slovenia was hit by severe weather: downpours (heavy rain), torrential floods and landslides caused destruction. The RS Environment Agency ARSO (2023) issued a red warning for north-eastern, north-western and central Slovenia. This year was the first time that the summer warmth was above average and wet on record. High temperatures, evaporation, accelerated formation of weather fronts, intense precipitation.

In Slovenia, rock falls, landslides, torrential erosion in headwaters, and riverbank erosion are the most hazardous phenomena. These natural hazards pose a risk to the country's infrastructure, settlements, and natural environment. Land sliding and erosion occur in approximately 43 % of the territory (some 8,800 km^2 of labile or potentially unstable slopes), where some 8,000 km of torrential streams drain water from nearly 400 torrential watersheds (Mikuš et al. 2004).

1.1 Torrents

Torrent floods are inevitable; rivers burst their banks and flood, and a series of related chain reactions ensue. Torrents are mountain streams that rise quickly and strongly in case of heavy rainfall, often only for a short time. The danger of torrents lies in the large amounts of torrential debris (ranging from sand and unrounded gravel to larger erosion debris and larger rock blocks) that is eroded and washed away by torrential waters, as well as by debris (wood, trunks, branches, roots) that the torrent uproots in its catchment area or from its bed. Torrents with great erosive power erode banks, shift riverbeds, and carry away dams and bridges.

Landslides and sediments occur, groundwater and water sources are polluted, spills of inadequately protected hazardous substances occur. As a result of polluted silt and other material deposited on the plains, the fertility of cultivated land is decreasing. Sometimes, due to pollution, the land is even unusable without thorough rehabilitation. Sensitive ecosystems are destroyed. Infrastructural and industrial facilities are flooded and damaged (roads, electricity, and water networks). Due to rising waters and sediments, human lives are also threatened (Vidic 2023).

Areas where there is erosion and creeping of soils and landslides pose a specific problem.

1.2 Landslides

Landslides resulting from failures of natural balance in Slovenia have been mostly associated with geological and morphological conditions (Mikuš et al. 2004). Aside from heavy rain, the triggering factors for landslides include the geological structure, terrain's ruggedness, the weather's thickness, vegetation, various interventions (excavations, roads), and additional loads. **Rock weathering is a natural process that gradually weakens the soil.** Due to weathering, the strength of the rock gradually decreases, and at some point, gravity exceeds the shear strengths at the weakest face within the earth mass. Additional factors, such as a greater amount of water during heavy rains, further weaken the unstable rock. The water-soaked ground mass becomes destabilized and begins to move when it is undermined when the slope is overburdened when watercourses erode when there is an earthquake, or due to other external natural or human unfavourable factors. **Stable slopes can transition from apparent stability to untamed dynamics, threatening life and property. Landslides annually inflict damage and disrupt the functionality and structure of various elements, including**

terrain degradation, residential buildings, road networks, sewage systems, telecommunications lines, electricity grids, agricultural crops, and forests.

Slopes where movements are already taking place and may indicate a future landslide can be recognized by the wavy shape of the terrain, the sabre-like curvature of trees, inclined poles, cracks in the ground, etc. If there are several landslides, this is a clear sign that the terrain is prone to creeping. Experts can predict potentially dangerous areas based on the type of bedrock, the thickness of the weather cover, the shape of the terrain, the slope of the slope, and the occurrence of surface and underground water (Ribičič 2014).

Landslides may be triggered by human activities, such as adding excessive weight above the slope, or digging at mid-slope or at the foot of the slope. Often, individual phenomena join to generate instability over time, which often does not allow a reconstruction of the evolution of a particular landslide.

1.3 Restoration process

Reducing the damage is basic. Regulating natural watercourses requires a broader knowledge of natural laws because each watercourse in nature is a world unto itself, and the animals, plants and other organisms that live in it form a complete ecosystem. According to the Water Act (PIS 2023):"Interventions for water regulation must be planned and implemented in such a way that they do not significantly deteriorate the properties of the water regime and do not significantly disrupt the natural balance of water and riparian ecosystems" and "Water management must follow the principle of integrity, which takes into account the natural processes and dynamics of water, as well as the interconnection and interdependence of water and riparian ecosystems in the catchment area".

Hydronomic works and river restoration techniques refer to a large variety of ecological, physical, spatial, and management measures and practices. These are aimed at restoring the natural state and functioning of a natural system in support of biodiversity, recreation, flood safety, and landscape development. Plant communities (biodiversity) change spatially and temporally in response to the input of water and sediment supplied by the stream system. Interventions in the water area should be reduced to the least possible measure by returning at least part of their space to the waters. Many species will be able to survive in such an area, and the water quality will increase with the help of greater biodiversity (Globevnik et al. 2010). Hydronomic works, by nature, constitute significant protection-environmental works.

In recent years, extreme floods, the need for ecological reconstruction of rivers, and the prospect of future global change has raised the awareness that new water management strategies might be needed over the forthcoming years to ensure sustainable water system use. Two systems interact (Haasnoot et al. 2009): society responds to events, and the state of the water system changes in response to management. Planning and managing water resources, sustainable development, and strategies on a river basin level (Bandaragoda and Babel 2010) must integrate the collective efforts of many groups to ensure river basins remain environmentally and economically sustainable over the long term. The appropriate arrangement brings socio-economic benefits (beneficial impact on the quality of the living environment, price acceptability of the arrangement, etc.).

2 PURPOSE AND GOALS

The purpose of this paper is to contribute to the awareness of the complexity and dynamics of the living environment, which is full of uncertainty. Environment is not intended only for humans. After a disaster, the initial activities are oriented towards protecting people's lives and property, economic infrastructure, and return to normal life. On recovery, it is important to set up a strategy to find sustainable solutions, an interdisciplinary approach that takes into account ecosystems, ecosystem services, and human presence. We cannot predict everything. The national strategic goal is as follows: »There will be no torrents and torrential areas in Slovenia that are not managed sustainably, and new damage potential shall not be created in areas of danger and hazard.«

Our research took place from August to December 2023 during intervention activities after a disaster in the municipality of Škofja Loka. The goals of the research were these:

1. field mapping of floods, torrents, and landslides,

2. detecting causes of the torrential and landscape damage,
3. first problem-solving activities.

As the final goal, we discussed a long-term sustainable restoration strategy.

3 METHODS

After studying the relevant professional and scientific articles on heavy rain, torrents, and landslides, we prepared summaries. We were part of the restoration team and went to the field on the first day.

The basis is inventorying and field mapping of torrents and landslides. All data from field work were part of an interventional restoration project. All data were collected, analysed, and interpreted.

The field work took place from August to December 2023 and consisted of inventorying the damage and preparing intervention measures. We used topographical and geological maps, and LIDAR Slovenia online. In the field, we used geological tools.

4 RESULTS

Due to the heavyrain on 4 August, the streams in Idrija, Cerkno, and Škofja Loka hills overflowed. The floods began on 3 August at around 8 p.m. According to ARSO (2023), the worst flooding was in the foothills of the Julian Alps, from Idrija through the Ljubljana basin to Slovenian Carinthia, where 150–200 mm fell; on Loibl, 275 mm fell in 48 hours. A red hydrological warning was also issued for rivers. Due to heavy rain, the National Flood Protection and Rescue Plan was activated. Since the very beginning, the main priority was to help the affected people. In the first weeks after the disaster, we primarily helped by providing temporary accommodation and funds for the basic necessities of life, but going forward, assistance will mainly come in the form of funds to rebuild damaged and replace destroyed homes (Government of the Republic of Slovenia 2023).

Floods and landslides affected 183 of Slovenia's 212 municipalities, with 104 municipalities severely impacted. The total area affected is estimated at 17,203 square kilometres. To date, the Slovenian Government has provided EUR 515.9 million to help people, municipalities and the economy (Government of the Republic of Slovenia 2023).

Goal 1: Field mapping of floods, torrents and landslides

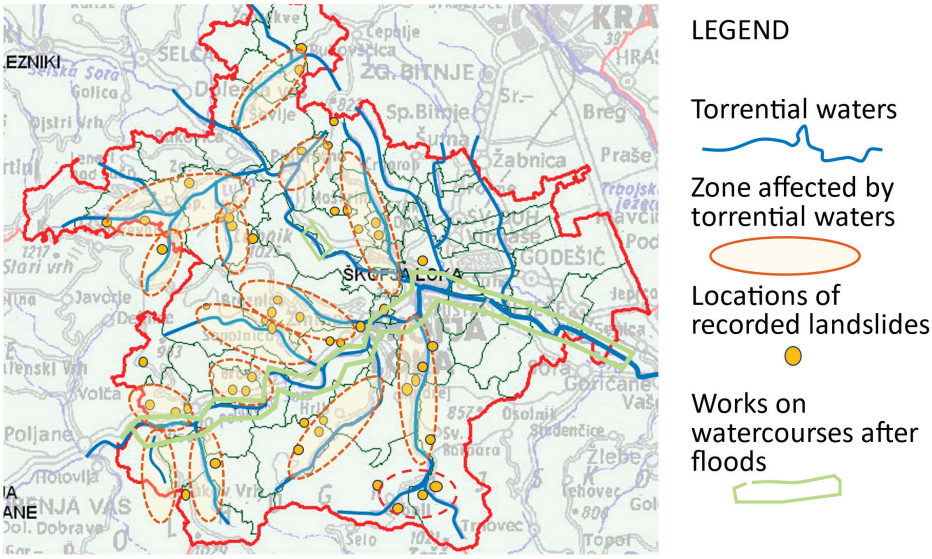
Floods, torrents and landslides mainly occur in lower hilly areas that are typical of the preAlpine regions.

Figure 1: This area has very torrential geomorphological characteristics. Downpours, torrential floods and landslides cause destruction.

(Photo: M. Frlan and F. Vidic, 2023).

Our fieldwork was to inventory: damage caused by rivers and torrents, landslides, roads, and geotechnical infrastructures that were damaged and may be damaged even more severely by torrential rainfall in the future (Figure 2).

Figure 2: Graphical representation of damaged river and torrents; course landslides; roads and geotechnical infrastructures that were damaged and may be even more severely damaged by future torrential rainfall in the municipality of Škofja Loka. Along the Poljanska and the Selška Sora, however, the rivers eroded their banks, overflowed them and deposited large amounts of material.



Depending on the geology and morphology, torrential waters forcefully undermine large amounts of solid material (erosion), transport the washed-out sediments, and deposit them (the Poljanska Sora, the Selška Sora, the Sora). In steep torrents, the transport of washed-out sediments causes the formation of mudflows. The following streams flow into the Selška Sora: Prifarški and Vincarski potok, Srednjiška grapa, Bukovščica, and Luša. Into the Poljanska Sora there flow: Brezniška, Baja Ženkova, Gabrška, Petruzova and Kumrova grapa, and on the other bank: Krniška grapa, Hriboska, Močilska and Bodolska grapa, Sovpat, and Hrastnica. Headwaters in river basins greatly influence the ecological state of the water, the water balance, and the sedimentary regime of the river system.

Goal 2: Detecting causes of the torrential and landscape damage

Damage caused by torrents and triggered landslides depends on the geological structure, terrain's ruggedness, the weather's thickness, vegetation, various interventions (excavations, roads), and additional loads.

The hills in the Škofja Loka municipality are typical of the pre-alpine world; they are built of carbonate and clastic rocks. The damage mostly belongs to the unstable area of younger Paleozoic clastite formation (Carboniferous, Lower and Middle Permian). The dominating rocks are red, green and grey slates, siltstones and sandstones; in some places quartz conglomerates can be found. The rocks are tectonically damaged due to thrusts and faults, and weathered at the surface. Only a small number of landslides belong to weathered soil on Triassic rocks.

Figure 3: Landslides may be triggered by anthropic activities.

(Photo: F. Vidic, 2023)

We registered more than 50 landslides of various sizes and triggers, including geological, morphological, physical, and human. Heavy rain was an external but the basic trigger in this case.

Landslides were the result of natural and anthropogenic factors:

- construction works: excavation for road cuts, backfilling of storage plateaus, construction pits, and similar. Excavations and embankments cause excessive loading of unstable slopes, resulting in landslides of destabilized soil, which are triggered above and below an area in the natural environment;
- landslides on meadows that were the result of soil accumulation in the lower part of former arable land;
- the rising waters of the torrents undermined the banks and consequently caused the triggering of landslides;
- in some places, the torrential rains clogged culverts with their sediment; the water then flowed down the carriageway, eroding and undermining unprotected shoulders;
- inappropriate construction methods and locations of buildings;
- failure to comply with the instructions of experts and their project solutions when remedying past mistakes;
- numerous poorly maintained forest trails vulnerable to torrential activities.

Goal 3: Initial problem-solving activities.

The Government is working intensively on a reconstruction and development act, the main purpose of which is to ensure effective reconstruction, and is also intensifying its work on the financial architecture of the reconstruction (Government of the Republic of Slovenia 2023). One of the first activities after catastrophic torrential floods and landslides is the reconstruction of infrastructure (roads, energy and water supply, telecommunications).

The torrential restoration structures are projects for the protection and stabilization of rivers and riverbeds against any kind of erosion, slides, and general causes that can upset the stability of land, but not only agricultural. Also, they have a strong natural environmental character due to the protection of flora and fauna in torrent areas. The protective principle involves approaches for broader protection. In order to protect the main watercourses (the Poljanska and the Selška Sora, the Sora) from flood and erosion phenomena, torrent restoration works include the following:

- returning rivers to their watercourses,
- cleaning debris from sand, pebbles, rocks, and wood,
- restoration of eroded banks with dry composition (big rocks) or rock and concrete structures, and backfill in the background,
- repair and replacement of bridges.

The following torrent stream facilities prevent the deepening of the riverbed and retain, filter, and interrupt the deposition of ordinary alluvium and alluvium during storms. In addition, transverse structures on torrents stabilize the bottom and prevent deep erosion, and the barriers represent an additional stable heel of the creeping slope. At the first restoration steps, restoration teams employ:

- water course reconstruction,
- restoration of eroded banks with dry composition (big rocks) or rock and concrete structures, and backfill in the background,
- if necessary, use of transverse structures on torrents (on hilly watercourses) to rehabilitate erosion hotspots, protect conditionally stable slopes, etc. (Figure 4),
- restoration of damaged infrastructure.

Figure 4: Different barriers serve to mitigate torrential erosion. "Kašta", a barrier made from wood and rocks, „kašta", a barrier made from concrete lamellae and rocks, a ramp built with stones, and a weir of stone and concrete structure.

(Photo: F. Vidic, 2023)

Landslides. Common occurrence of mass landslides in the mountains leads to serious impacts on the environment, infrastructure and economic activity of man; it is therefore important to reduce their consequences with the following activities:

- protection of the landslide area,
- tree removal,
- removal of low-quality material from the landslide area,
- heel stabilization and foundation preparation,
- stone-concrete layer, if necessary,
- backfilling with water-permeable material,
- grassing the surface.

5 DISCUSSION

This paper shows the first urgent actions that are important to return life after a disaster back to normal. But we must think forward to the next step, of long-term planning to improve protection from torrent floods and landslides and integrate different knowledge into a sustainable strategy. PreAlpine areas are predominantly mountainous, and a large number of torrential phenomena cause serious damage to the mountainous and lowland areas, i.e., they affect people, animals, vegetation, etc. The restoration must improve torrential conditions from the technical, environmental, and socio-economic points of view.

Riverine wetlands in a natural setting are part of a dynamic self-sustaining stream corridor. Restoration works and river restoration techniques refer to a large variety of ecological, physical, spatial, and management practices. Restoring the sustainable, multifunctional use of torrents, rivers, and streams aims to restore the natural state and functioning of a natural condition. It improves the resilience of the river systems and provides the framework system in support of biodiversity, recreation, flood safety, and landscape development (Varras et al. 2015).

Therefore, understanding and addressing the complex interactions between natural factors, human activities, and climate change is crucial for effective mitigation and adaptation measures. By considering these aspects, it is possible to develop strategies and policies that aim to reduce the risks associated with torrential floods and landslides and promote sustainable development in vulnerable areas. Torrents and torrential areas are an important part of the natural environment. By naturally managing these areas, we can help to protect them from damage and ensure their long-term health. We should also avoid placing new developments in areas of danger. This will help to reduce the risk of landslides and other natural disasters.

The sustainable restoration system improves of the torrential conditions and adjusts torrential benefits (environmental, socio-economic, etc.) in a continuously improved torrential environment. In this system, depending on the local conditions of the study area, restoration projects are dominated by horticultural, agrotechnical works or technical concrete structures (Pavlidis 2006).

For sustainable restoration, it is important to have a big picture and act as follows:

- Avoid unnecessary interventions in nature.
- If it is impossible to avoid the exploitation of space, we should understand how nature breathes and consider natural laws. Large and heavy machinery does not mean a long-term victory.
- For major interventions, take into account the opinion of geomechanics, and for smaller ones, experience and, of course, common sense.
- After carrying out construction works, the land should be adequately rehabilitated, grassed, and reforested, watercourses and drainage of water should be provided.
- Each intervention should also be monitored and, if necessary, maintained. This applies both to forest trails intended for harvesting wood as well as to other interventions.

6 CONCLUSION

Damage resulting from natural disasters is increasing. Restoration works, flood control structures, stabilization of the riverbed, retention of moving sediment, and protection are important actions for protecting the human and natural environment (Varras et al. 2015).

The future will be complex. In the context of torrents and landslides, it is important to develop robust, flexible, adaptable, and integrated concepts for mitigation and restoration. These concepts should consider the complex and dynamic nature of these phenomena and should be able to adapt to a wide range of potential future scenarios. Every intervention must be carefully considered and implemented promptly and professionally.

Sustainable management strategies must be holistic and comprehensive, considering current and future challenges. This includes identifying existing vulnerabilities and developing adaptation strategies for various possible futures. By taking a proactive approach, we can reduce the risk of water-related disasters and build a more resilient future for our communities.

We must see the big picture, have a vision of how to deal in different situations with torrent floods and landslide restoration, and improve the conditions of the human and natural environment. Taking a proactive and integrated approach to torrent flood and landslide management, we can build a more resilient future for the economy and community. We can also protect the natural environment and ensure that it will be healthy and productive for future generations.

REFERENCES

1. ARSO. 2023. *Nalivi in obilne padavine od 3. do 6. avgusta 2023*. Available at: https://meteo.arso.gov.si/uploads/probase/www/climate/text/sl/weather_events/padavine_3-6avg2023.pdf (September 20. 2023).
2. Bandaragoda D. J., and Mukand S. Babel. 2010. Institutional Development for IWRM: An International Perspective. *International Journal of River Basin Management* 8(3-4): 215–224.
3. Coen, Eli, and Armaan Shah. 2023. *Torrential Rain*. Available at: https://skydayproject.com/torrential-rain (January 2. 2024).
4. Globevnik, Lidija, Gorazd Urbančič, Monika Petetrlin, and Meta Povž, 2010. Biotska raznovrstnost je življenje. *Slovenski vodar*, 21-22. Ljubljana, Društvo vodarjev.
5. Government of the Republic of Slovenia. 2023. *More than half a billion euro to help people, businesses and municipalities to recover from floods*. Available at: https://www.gov.si/en/news/2023-10-05-more-than-half-a-billion-euro-to-help-people-businesses-and-municipalities-to--recover-from-floods/ (January 2, 2024).
6. Haasnoot, M., Hans Middelkoop, Ermond van Beek and W. P. A. van Deursen. 2009. A Method to Develop Sustainable Water Management Strategies for an Uncertain Future. *Sustainable Development*. Wiley InterScience.
7. Mikuš, Matjaž, Mitja Brilly and Mihael Ribičič. 2004. Floods and Landslides in Slovenia, *Acta hydrotechnica*, 22/37, 113–133, Ljubljana
8. PIS 2023. *Zakon o vodah* (Uradni list RS, št. 67/02, 2/04 – ZZdrI-A, 41/04 – ZVO-1, 57/08, 57/12, 100/13, 40/14, 56/15, 65/20, 35/23 – odl. US in 78/23 – ZUNPEOVE).
9. Ribičič, Mihael. 2014. E-plaz *Zemeljski plazovi in usadi*. Available at: https://www.e-plaz.si/Ribicic/ZemljinskiPlazovi.html. (January 10. 2020).
10. Varras, G., Ia, Tsirogiannis, Cha, Myriounis and V., Pavlidis. 2015. The Effects of Irrigation and Drainage on Rural and Urban Landscapes, Patras, Greece. *Agriculture and Agricultural Science Procedia* 4: 261–270.
11. Vidic, Franc. 2023. Huda ura na Škofjeloškem. *Moje podeželje* 22: 25-28. Strahinj, Biotehniški center Naklo.

1.09 Objavljeni strokovni prispevek na konferenci
Published professional conference contribution

ANALIZA PRISOTNOSTI TEŽKIH KOVIN V INDUSTRIJSKIH ODPADKIH IN NJIHOV UČINEK NA OKOLJE

ANALYSIS OF HEAVY METAL PRESENCE IN INDUSTRIAL WASTE AND THEIR ENVIRONMENTAL IMPACT

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POVZETEK

Sodobno opazovanje narave odpadkov razkriva kompleksen in neizogiben proces preoblikovanja predmetov iz uporabnih stvari v odpadne materiale. Ta naravna dinamika vključuje faze obrabe, razpada in končnega zavržka, kar označuje njihov prehod v nepotrebnost. V kontekstu pospešenega razvoja tehnologije in industrije je prisotna ekspanzija proizvodnje različnih vrst odpadkov, pri čemer se posebej izpostavlja problematika množične proizvodnje nevarnih odpadkov. Ta pojav je neposredno povezan s povečanjem števila potrošnikov, kar dodatno obremenjuje sisteme ravnanja z odpadki. Nevarni odpadki predstavljajo posebno kategorijo odpadkov, ki se najpogosteje generirajo v industrijskih obratih kot stranski produkt različnih proizvodnih procesov. Ta vrsta odpadkov prihaja iz različnih sektorjev, vključno s kemijsko, elektroenergetsko in metalurško industrijo, in je označena z lastnostmi, ki jih naredijo nevarne za zdravje ljudi in okolje. Ključni cilj tega dela je proučevanje in upravljanje nevarnih odpadkov, s posebnim poudarkom na materialih, ki vsebujejo različne vrste in koncentracije težkih kovin. Težke kovine, kot so svinec, živo srebro, kadmij in baker, so prisotne v mnogih industrijskih procesih in se lahko kopičijo v okolju, povzročajo resne ekološke in zdravstvene težave. V delu se podrobno analizira vsako od težkih kovin, vključno z njihovimi viri, kemijskimi lastnostmi ter potencialnimi učinki na zdravje ljudi in ekosisteme. Prav tako se raziskuje koncentracija težkih kovin v različnih vrstah odpadkov, da bi bolje razumeli povezavo med industrijskimi praksami in nastajanjem nevarnih odpadkov. Na koncu, v zaključku dela, je analizirana zastopanost težkih kovin glede na vrsto odpadkov v letu 2018, kar poudarja potrebo po razvoju učinkovitih sistemov za ravnanje in upravljanje nevarnih odpadkov. To delo poudarja pomembnost integracije trajnostnih praks v industrijske procese, da bi zmanjšali proizvodnjo nevarnih odpadkov in minimizirali negativne vplive na okolje in zdravje ljudi.

***Ključne besede**: analiza, odpadki, odlagališče, težke kovine, toksičnost*

ABSTRACT

Modern observation of the nature of waste reveals a complex and inevitable process of transforming objects from useful items into waste materials. This natural dynamic includes phases of wear, decay, and final disposal, marking their transition into obsolescence. In the context of accelerated technological and industrial development, there is an expansion in the production of various types of waste, particularly highlighting the issue of mass production of hazardous waste. This phenomenon is directly linked to the increase in the number of consumers, further burdening waste management systems. Hazardous waste represents a specific category of waste that is most commonly generated in industrial facilities as a byproduct of various production processes. This type of waste originates from different sectors, including chemical, energy, and metallurgy industries, and is characterized by properties that make it dangerous to human health and the environment. The key objective of this paper is the study and management of hazardous waste, with a particular focus on materials containing various types and concentrations of heavy metals. Heavy metals, such as lead, mercury, cadmium, and copper, are present in many industrial processes and can accumulate in the environment, causing serious ecological and health problems. The paper thoroughly analyzes each of these heavy metals, including their sources, chemical properties, and potential effects on human health and ecosystems. It also investigates the concentration of heavy metals in different types of waste to better understand the connection between industrial practices and the generation of hazardous waste. Finally, the conclusion of the paper analyzes the representation of heavy metals according to waste type in 2018, highlighting the need for the development of effective systems for the disposal and management of hazardous waste. This work emphasizes the importance of integrating sustainable practices into industrial processes to reduce the production of hazardous waste and minimize negative impacts on the environment and human health.

Keywords: *Analysis, Waste, Landfill, Heavy metals, Toxicity*

1 UVOD

Proučevanje okolja razkriva, da vse snovi, prej ali slej, postanejo odpadki. Zaradi pospešenega razvoja tehnologije in industrije prihaja do množične proizvodnje odpadkov, kar predstavlja resen globalni problem. Ta pojav povzroča izzive, povezane s hitrostjo predelave, recikliranja in odstranjevanja, ter se šteje za enega ključnih izzivov sodobne civilizacije. Razvoj hitrih in učinkovitih metod recikliranja postaja nujen, da zmanjšamo obremenitev odlagališč odpadkov in ponovno uporabimo materiale (Briški 2016; Harada 1995). Ravnanje z odpadki vključuje zbiranje, skladiščenje, obdelavo, odlaganje, uvoz, izvoz in prevoz odpadkov, zapiranje in saniranje objektov, namenjenih odlaganju odpadkov, ter površin, onesnaženih z odpadki (Srpak 2017; Oladimeji et al. 2024). Namen tega dela je raziskati trajnostne rešitve za zmanjšanje negativnih vplivov na okolje, ohranitev naravnih virov in zagotavljanje trajnostne prihodnosti. Obnovitev virov postaja ključna za podaljšanje življenjske dobe izdelkov in zmanjšanje količine odpadkov. Razvoj učinkovitih metod recikliranja ter izobraževanje javnosti o pomenu zmanjšanja porabe in pravilnega odlaganja odpadkov sta bistvena za reševanje tega problema. Neustrezno odlaganje velikih količin odpadkov na divjih odlagališčih še vedno predstavlja resen izziv (Jungić in Čorić 2013). V tem delu bomo analizirali koncentracije težkih kovin v različnih vrstah odpadkov, vključno s tistimi iz prehrambene, lesne, storitvene, gradbene in kovinske industrije. Globalno povečanje proizvodnje in predelave kovin vodi do njihove koncentracije v okolju, kar predstavlja tveganje za zdravje ljudi. Odpadki pogosto onesnažijo podzemno vodo, kar vpliva na kakovost vode, zraka in tal ter vodi do potencialnih zdravstvenih težav. Zato ljudje, nevedni svoje vloge v tem začaranem krogu, s svojimi dejanji neposredno vplivajo na kakovost vode, zraka in tal, ki jih uporabljajo za svoje potrebe, pogosto nevedni posledic, ki lahko privedejo do različnih bolezni (Sofilić 2015; Oladimeji et al. 2024).

2 NEVARNI ODPADKI IN NJIHOVO GOSPODARJENJE

Nevarni odpadki, ki se večinoma generirajo v industrijskih procesih, so prisotni tudi v gospodinjstvih, kjer se uporabljajo vsakodnevno. Problem nevarnih odpadkov je tesno povezan s stopnjo ozaveščenosti in informiranosti o njihovih tveganjih. Ti odpadki vključujejo snovi z nevarnimi lastnostmi, kot so toksičnost, kancerogenost in vnetljivost, ter so klasificirani v skladu s Katalogom odpadkov (Kiš in Kalambura 2018). Glavni proizvajalci nevarnih odpadkov so industrije, kot sta kovinska proizvodnja in kemična industrija, zlasti v proizvodnji gumijastih in plastičnih materialov. Ta sistem vključuje uporabo metod varnega odlaganja, vključno z reciklažnimi dvorišči, ki so opremljena za pravilno odlaganje nevarnih odpadkov, kot so baterije. Čeprav se nevarni odpadki pogosto štejejo za industrijske, pomemben delež prihaja iz gospodinjstev, kar se označuje kot „problematični odpadki" (Stančić et al. 2015; Vrček 2011). Pri upravljanju teh odpadkov se poudarek daje načelom ponovne uporabe, zmanjševanja in recikliranja (3R), medtem ko odpadki, ki jih ni mogoče reciklirati, podlegajo sežiganju ali odlaganju. Približno 75% nevarnih odpadkov so barve, laki in premazi, starejši izdelki pa pogosto vsebujejo visoke koncentracije škodljivih snovi. Odstranjevanje takšnih premazov lahko povzroči znatne količine nevarnih odpadkov (Vicente in Reis 2008; Kalambura et al. 2018). Če nevarni odpadki končajo v kompostniku, lahko onesnažijo proces kompostiranja. Biološke, kemične in fizikalne metode obdelave nevarnih odpadkov, vključno z nevtralizacijo in dezinfekcijo, se uporabljajo za spreminjanje njihovih lastnosti. Termične metode, kot je sežiganje, zahtevajo visoke temperature in zagotavljajo sterilizacijo odpadkov, vendar se težke kovine, kot sta svinec in kadmij, koncentrirajo v pepelu in zahtevajo nadaljnjo obdelavo (Zsóka et al. 2013). Strupi iz nevarnih odpadkov se lahko kopičijo v organizmu in predstavljajo resno tveganje za zdravje (Srpak et al. 2024). Zato je nujno izvajati ustrezne ukrepe za ravnanje z nevarnimi odpadki, s posebnim poudarkom na prisotnosti težkih kovin, ki lahko povzročijo izrazito toksičnost, če se ne obdelajo ustrezno.

3 METODE V ANALIZI TEŽKIH KOVIN PRI RAVNANJU Z ODPADKI

Težke kovine so skupina kovin, ki vključuje elemente, kot so svinec (Pb), kadmij (Cd), živo srebro (Hg), baker (Cu), cink (Zn), nikelj (Ni), krom (Cr) in druge. Te kovine so znane po visoki gostoti in teži ter imajo v določenih koncentracijah pogosto strupene lastnosti. Elektronski odpadki (e-odpadki) vsebujejo težke kovine, kot so svinec, živo srebro, kadmij in druge. Te kovine lahko najdemo v baterijah, kablih,

tiskanih vezjih in drugih elektronskih delih. Baterije, zlasti tiste, ki vsebujejo svinec, nikelj, kadmij in litij, so vir težkih kovin v odpadkih. Industrijski odpadki pogosto vsebujejo težke kovine, ker se uporabljajo v različnih proizvodnih procesih (odpadne vode, dimni plini in drugi industrijski stranski proizvodi) (Srpak in Zeman 2017). Odpadki, ki nastanejo pri rudarskih dejavnostih, lahko vsebujejo težke kovine, ki so naravno prisotne v kamninah (med izkoriščanjem rudnin lahko te kovine pridejo v okolje). Težke kovine imajo lahko resne negativne učinke na okolje in zdravje ljudi. Zato je pomembno ustrezno ravnanje z odpadki in ukrepi za zmanjševanje izpustov težkih kovin v okolje, recikliranje materialov, ki jih vsebujejo ter izvajanje ustreznih postopkov odstranjevanja in čiščenja. Nacionalni in mednarodni predpisi pogosto predpisujejo standarde in smernice za ravnanje s težkimi kovinami v odpadkih, da se zmanjša njihov vpliv na okolje (Zsóka et al. 2013; Vukšić in Šperanda 2016). Težke kovine, kot so baker, cink, železo in mangan, so nujne za pravilno delovanje človeškega telesa, druge, kot so svinec, kadmij, živo srebro, arzen, kositer, paladij, platina in kobalt, pa so za telo strupene. Vnos težkih kovin v telo ima lahko dvojni značaj, saj lahko delujejo kot strup in zdravilo hkrati. Glede na nenehno rast proizvodnje in uporabe kovin se povečuje tudi koncentracija težkih kovin v tleh, vodi in zraku, ki vplivajo na rastline, živali in človeško telo. Pomanjkanje esencialnih težkih kovin (Zn, Cu, Mn, Fe, Se) lahko povzroči resne motnje v telesu, medtem ko so neesencialne težke kovine (Pb, Cd, As, Hg) prisotne v zemeljski biosferi in krožijo v naravi. različne oblike (Tabela 1).

Tabela 1: Koncentracije težkih kovin v različnih vrstah odpadkov iz leta 2018

IZVOR OTPADKOV	ZNAK VZORCA	Pb (mg/kg)	Cd (mg/kg)	Ni (mg/kg)	Cr (mg/kg)	V (mg/kg)	Hg (mg/kg)
Prehranska tehnologija	0/3/18	4.67	0	3.62	0.21	1.3	0.005
Lesna industrija	0/4/18	3.77	0	3.66	14.76	2.67	0.017
Storitvena dejavnost (avto salon, servis)	0/6/18 0/29/18	28.8 20.22	0 0	2.94 6.14	0.91 4.46	0 0	0.006 0.009
Gradbena ind.	0/7/18 0/8/18 0/9/18	117,755.69 94,435.91 648.38	16.53 1.04 0	95.75 79.15 391.87	290.76 586.87 237.31	170.18 154.97 645.63	0.037 0.022 0.107
Kovinska ind.	0/19/18 0/20/18 0/72/18	28.24 24.27 72.13	13.14 0 0	8.48 2.53 77.73	7.45 0.56 205.27	1.21 0 0	0.047 0.004 0,013
Odlagališče	0/70/18	28.78	1.8	6.79	18.64	3.39	0.02

(Vir: Analiza koncentracije težkih kovin v različnih vrstah odpadkov za leto 2018, 2018.)

Nenehna rast proizvodnje kovin vodi do povečanja njihovih koncentracij v tleh, vodi in zraku, kar lahko negativno vpliva na rastline, živali in ljudi. Pomembno je razumeti razliko med esencialnimi in neesencialnimi težkimi kovinami, saj lahko pomanjkanje esencialnih kovin povzroči resne zdravstvene težave, medtem ko neesencialne kovine predstavljajo tveganje za zdravje in okolje (Tabela 2).

Tabela 2: Težke kovine in njihov vpliv na zdravje

Težka kovina	EU- mg/l	SZO mg/l	US EPA mg/l	Kronični in akutni učinki na zdravje
Bakar (Cu)	0,3-3	2	1	Draženje grla, ust, nosu in oči; glavobol, poškodbe ledvic, smrt
Cink (Zn)	0,1-5	1	5	Poškodbe imunskega sistema, bolečine v trebuhu
Kadmij (Cd)	0,005	0,003	0,005	Driska, bruhanje, izguba teže, smrt
Olovo (Pb)	0,05	0,01	0,015	Anemija, neplodnost, izguba apetita, poškodbe ledvic in živčnega sistema
Živa (Hg)	0,001	0,001	0,002	Poškodbe pljuč, ledvic, draženje nosu in oči, vpliv na razvoj ploda
Nikal (Ni)	0,2	1	0,07	Vpliv na jetra, imunski in živčni sistem
Arsen (As)	0,01	0,01	0,05	Vpliv na prebavni in živčni sistem, spremembe na koži in nohtih

(Vir: Analiza koncentracije težkih kovin v različnih vrstah odpadkov za leto 2018, 2018.)

4 REZULTATI IN RAZPRAVA

Analiza koncentracij težkih kovin v odpadkih iz različnih industrij razkriva pomembne razlike, ki so rezultat specifičnih proizvodnih procesov in materialov, uporabljenih v teh sektorjih (Briffa et al. 2020). V prehrambeni tehnologiji je bilo zaznanih 4,67 mg/kg svinca in 3,62 mg/kg niklja. Povečana koncentracija svinca v prehrambenih odpadkih je lahko povezana z uporabo svinčenih goriv, ki prispevajo k širjenju svinca v okolju. Svinac je znan kot eden najbolj razširjenih težkih kovin, njegova prisotnost v odpadkih pa predstavlja tveganje za zdravje ljudi, saj se lahko akumulira v biokemijskih procesih. V lesni industriji koncentracija kroma znaša 14,76 mg/kg, kar kaže na uporabo kromiranih materialov v proizvodnji lesenih izdelkov. V storitvenih dejavnostih, zlasti v avtoservisih, je bila odkrita najvišja koncentracija svinca 28,8 mg/kg. To je lahko posledica uporabe svinčenih materialov v akumulatorjih ter v različnih orodjih in opremi. Nikelj, ki se uporablja zaradi svojih polirnih lastnosti, je prav tako prisoten v teh sektorjih, njegova koncentracija pa lahko nakazuje na vse večjo uporabo v industriji. V gradbeni industriji je pričakovana prisotnost svinca rezultat zgodovinske uporabe svinčenih cevi in svinčenih spojin v barvah in glazurah. Čeprav se svinčene cevi danes redko uporabljajo, se svinec še vedno lahko nahaja v starejših gradbenih materialih, kar predstavlja potencialni vir kontaminacije med obnovami ali demontažami. V kovinski industriji obdelava kovin povzroči sproščanje delcev težkih kovin, vključno z nikljem, kromom in svincem. Povišane koncentracije teh kovin v odpadkih so lahko povezane s postopki rezanja, brušenja in drobljenja, ki sproščajo toksične delce v okolje. To poudarja potrebo po strogih regulacijah in nadzoru odpadkov iz teh industrij, da bi zmanjšali tveganje kontaminacije tal in podzemnih voda (Olaniran 2023). Poleg prisotnosti svinca, niklja in kadmija je pomembno omeniti tudi pojav vanadija v koncentraciji 3,39 mg/kg v vzorcih z odlagališč. Vanadij se pogosto nahaja v naravi v bližini drugih kovin, kot sta svinec in železo, in lahko škoduje zdravju ljudi. Neustrezno razvrščanje in odlaganje odpadkov, zlasti gradbenih in kovinskih, dodatno povečujeta tveganje prodiranja težkih kovin v tla, kar lahko povzroči kontaminacijo okolja in negativne učinke na zdravje ljudi. Zaključno, nepravilno odlaganje in neustrezno upravljanje odpadkov, zlasti v industrijskih sektorjih, predstavlja resen izziv za varstvo okolja. Glede na vse večje koncentracije težkih kovin v odpadkih je nujno razviti strategije za zmanjšanje njihove proizvodnje in zagotoviti učinkovit sistem ravnanja z odpadki, vključno z recikliranjem in predelavo materialov (Zhang et al. 2021). Prav tako je ključnega pomena izobraževanje javnosti o pravilnem odlaganju odpadkov in nevarnostih, povezanih s težkimi kovinami, da bi zmanjšali tveganja za zdravje in okolje.

5 ZAKLJUČEK

Analiza koncentracij težkih kovin v odpadkih iz različnih industrij omogoča identifikacijo virov in distribucijo teh kovin, kar je ključno za ravnanje z odpadki in varstvo okolja. Glede na toksičnost kovin, kot so svinec, kadmij in živo srebro, je nujno nenehno ozaveščati delavce o tveganjih, povezanih z materiali, ki jih obdelujejo. Za globinsko razumevanje obnašanja težkih kovin v okolju je pomembno preučiti njihove kemijske lastnosti, vključno z bioakumulacijo. Odpadki iz gradbene, kovinske in lesne industrije vsebujejo visoke koncentracije kovin, kot so Hg, Cd, Pb, Cr, Ni in V, kar predstavlja resno grožnjo tlem, če niso ustrezno zaščitena. Ta situacija zahteva preventivne ukrepe in izobraževanje javnosti o resnosti problema. Avtorji v delu poudarjajo, da je zelo pomembno ozaveščanje o nevarnostih težkih kovin, pa tudi izobraževanje o pravilnem odlaganju odpadkov iz industrij z visokimi koncentracijami kovin, kar je ključno za preprečevanje onesnaženja. V kontekstu trajnostnega delovanja se poudarja recikliranje in ponovna uporaba virov. Integracija ekološkega kmetijstva, ki izključuje uporabo mineralnih gnojil, herbicidov in pesticidov, dodatno prispeva k zaščiti tal, vode in hrane pred onesnaženjem s težkimi kovinami. Ta pristop omogoča ohranjanje zdravja ljudi in okolja, zmanjšuje tveganje za kopičenje težkih kovin v organizmih in morebitne zdravstvene težave. Poleg tega je nujno razviti celovite strategije za ravnanje z odpadki, ki vključujejo inovativne metode recikliranja, učinkovite sisteme predelave in stroge regulative za nadzor nad odlaganjem odpadkov. Javnost mora biti nenehno izobraževana o pomenu zmanjševanja odpadkov, pravilnega ločevanja in potencialnih nevarnostih nepravilnega odlaganja. Le s celovitim pristopom, ki združuje znanstveno razumevanje, tehnološke inovacije in izobraževanje, bomo lahko učinkovito zmanjšali negativne vplive težkih kovin na okolje in zdravje ter zagotovili trajnostno prihodnost za naslednje generacije.

LITERATURA

1. Briški, Felicita. 2016. *Zaštita okoliša.* Zagreb: Fakultet kemijskog inženjerstva i tehnologije Sveučilišta u Zagrebu i Element.
2. Briffa, Jessica, Emmanuel Sinagra in Renald Blundell. 2020. Heavy metal pollution in the environment and their toxicological effects and removal methods. *Heliyon* 6(9), e04691. https://doi.org/10.1016/j.heliyon.2020.e04691.
3. Harada, Masazumi. 1995. Minamata disease: Methylmercury poisoning in Japan caused by environmental pollution. *Critical Reviews in Toxicology* 25(1): 1–24. https://doi.org/10.3109/10408449509089885.
4. Jakop, Erika. 2018. *Analiza koncentracije teških metala u različitim vrstama otpada za 2018. godinu.* Čakovec: Međimursko veleučilište u Čakovcu.
5. Jungić, Dragan in Robert Čorić. 2013. Teški metali u antropogenom tlu i procjednoj vodi u voćnjaku jabuka na području Donjeg Međimurja. *Agronomski glasnik: Glasilo Hrvatskog agronomskog društva* 75(4): 201–210.
6. Kalambura, Sanja, Domagoj Kiš in Siniša Guberac. 2018. *Gospodarenje otpadom II.* Osijek: Poljoprivredni fakultet u Osijeku, Sveučilište J. J. Strossmayera.
7. Kiš, Domagoj in Sanja Kalambura. 2018. *Gospodarenje otpadom I.* Osijek: Poljoprivredni fakultet u Osijeku, Sveučilište J. J. Strossmayera.
8. Oladimeji, T. E., Ali, H. M., Abbas, Q., & Raza, A. 2024. Review on heavy metals from industrial activities and their removal from wastewater. *Heliyon* 10(6). https://doi.org/10.1016/j.heliyon.2020.e04691.
9. Olaniran, Olusegun O. 2023. Analysis of heavy metals and toxicity level in the tannery effluent and the environs. *Environmental Monitoring and Assessment, 195*(8), https://doi.org/10.1007/s10661-023-11154-4.
10. Sofilić, Tahir. 2015. *Zdravlje i okoliš.* Sisak: Sveučilište u Zagrebu, Metalurški fakultet.
11. Srpak, Melita. 2017. *Ekološka održivost.* Čakovec: Međimursko veleučilište u Čakovcu. https://www.mev.hr/wp-content/uploads/2018/02/Ekoloska-odrzivost.pdf.
12. Srpak, Melita in Silvija Zeman. 2017. Zbrinjavanje azbestnog otpada. *Zbornik radova Međimurskog veleučilišta u Čakovcu* 8(2): 95–106.
13. Srpak, Melita, Silvija Zeman, Vladimir Križaić in Darko Pavlović. 2024. Spatial-planning aspect of waste management in Varaždin County. V *Eighth International Scientific Conference June 5th – World Environment Day: The Book of Abstracts*, 104–105. Bihać: University of Bihać, Biotechnical Faculty.
14. Stančić, Zrinka, Davor Vujević, Damir Dogančić, Saša Zavrtnik, Ivica Dobrotić, Zlatko Bajsić, Ivana Dukši in Dragutin Vincek. 2015. Sposobnost akumulacije teških metala kod različitih samoniklih biljnih vrsta. *Environmental Engineering – Inženjerstvo okoliša* 2(1): 7–18.
15. Vicente, Paula in Elizabeth Reis. 2008. Factors influencing households' participation in recycling. *Waste Management & Research* 26(2): 140–146. https://doi.org/10.1177/0734242X07076477.
16. Vrček, Valerije. 2011. *Druga strana potrošačkog raja: U klopci između bolesti i zdravlja.* Zagreb: Školska knjiga.
17. Vukšić, Neška, in Marcela Šperanda. 2016. Raspodjela teških metala (Cd, Pb, Hg, As) i esencijalnih elemenata (Fe, Se) u šumskom tlu i biljnim zajednicama državnog otvorenog lovišta Krndija II XIV/23. *Šumarski list* 140(3–4): 147–153. https://doi.org/10.31298/sl.140.3-4.5.
18. Zhang, Xu, Huanhuan Yang, Ruirui Sun, Meihua Cui, Ning Sun in Shouwen Zhang. 2021. Evaluation and analysis of heavy metals in iron and steel industrial area. *Environment, Development and Sustainability* 23(5): 2997–3010. https://doi.org/10.1007/s10668-021-01893-0.
19. Zsóka, Ágnes, Zsófia M. Szerényi, Anna Széchy in Tamás Kocsis. 2013. Greening due to environmental education? Environmental knowledge, attitudes, consumer behavior and everyday pro-environmental activities of Hungarian high school and university students. *Journal of Cleaner Production* 48: 126–138. https://doi.org/10.1016/j.jclepro.2012.09.029.

2025

1.08 Objavljeni znanstveni prispevek na konferenci
Published scientific conference contribution

DIGITALIZATION AND SUSTAINABILITY AWARENESS IN MICRO AND SMALL ENTERPRISES IN CROATIA: BUILDING RESILIENCE WITHOUT MANDATORY REPORTING

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ABSTRACT

Despite the growing global demand for sustainable practices, this research explores how micro and small enterprises (MSEs) in Croatia approach sustainability, despite the lack of mandatory reporting requirements. As communities face environmental and demographic challenges, understanding how MSEs integrate sustainability practices is crucial for fostering resilience and supporting their development. This study uses a mixed-methods approach, combining quantitative surveys and qualitative interviews, to assess the barriers and opportunities MSEs face in implementing sustainable practices. The findings provide valuable insights for policymakers and support organizations seeking to encourage sustainability in the small and medium business sector, illustrating how this facilitates transparency and operational resilience. Ultimately, this research contributes to a broader understanding of sustainable development by demonstrating how voluntary reporting can enable MSEs to play a more active role in building more resilient communities and environmental responsibility.

Keywords: *Sustainability Reporting, Micro and Small Enterprises (MSEs), Digitalization, Resilience, Sustainable Development*

1 INTRODUCTION

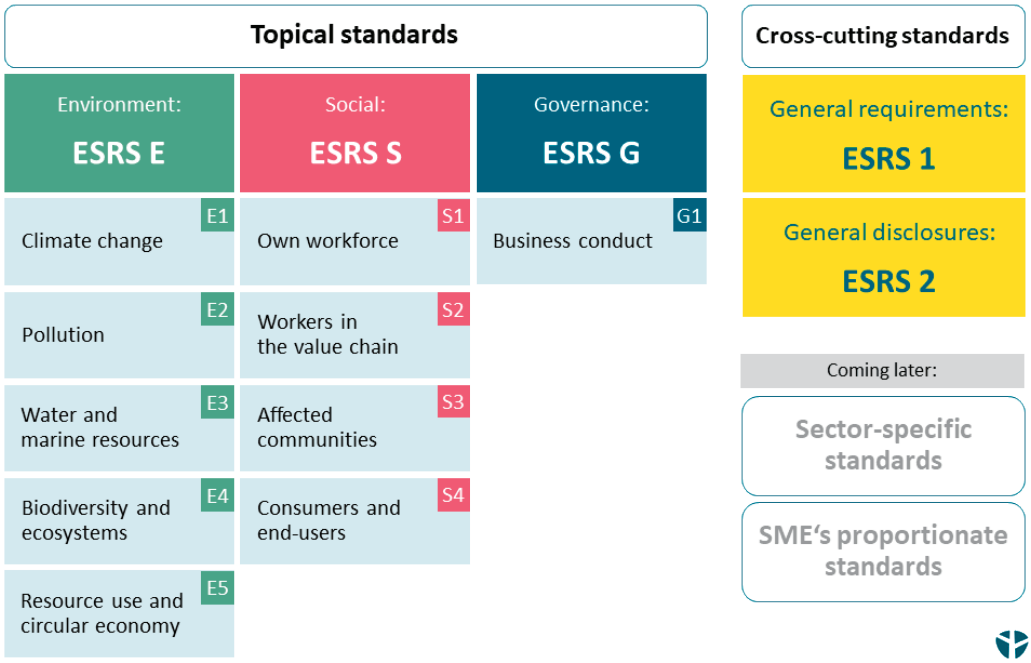
1.1 Context of the Republic of Croatia: The Importance of Including Micro and Small Enterprises in Sustainable Practices

Micro and small enterprises are the backbone of the Croatian economy, accounting for 88.3% (137,950) of micro and 10.1% (15,748) of small enterprises out of a total of 156,145 entrepreneurs, according to data from 2023. Their inclusion in sustainable practices is crucial for achieving sustainable development goals at both the national and European levels.

Sustainable practices are based on the principles of sustainable development outlined in the Brundtland Report (The Federal Council 1987) and involve business strategies that integrate economic, ecological, and social aspects of business. Implementing these principles in micro and small enterprises not only reduces their ecological footprint but also fosters innovation, enhances market competitiveness, and facilitates access to financial resources, while also creating favourable conditions for attracting investors.

The importance of adopting sustainable practices in the context of the Republic of Croatia stems from the need to align with European standards, including the adoption of the Corporate Sustainability Reporting Directive – CSRD (Official Journal of the European Union, L 322/15, 2022) and other EU policies that promote transparency and responsible business practices. Reports are prescribed by the European Sustainability Reporting Standards - ESRS (European Commission 2023a), under the leadership of the European Financial Reporting Advisory Group – EFRAG (European Financial Reporting Advisory Group ESRS Q&A Platform 2024) given the share of micro and small enterprises in the economy, their inclusion in sustainable practices is crucial for achieving the national sustainable development goals and economic resilience of the Republic of Croatia.

Figure 1: European Sustainability Reporting Standards (ESRS)



(Source: Ernst & Young Global Limited 2025)

EFRAG's mission is to serve the European public interest in both financial and sustainability reporting by developing and promoting European views on corporate reporting. EFRAG provides technical advice to the European Commission in the form of draft European Sustainability Reporting Standards (ESRS), developed in accordance with strict directives, and supports the effective implementation of ESRS.

1.2 Relevance for EU Policies and Link to the International Context

The European Union, through documents such as the European Green Deal and Digital Decade 2030 (European Commission 2024) has placed sustainability at the heart of its development policies, defining sustainability as a key prerequisite for economic growth, social responsibility, and ecological balance in the single European market.

The European Green Deal aims to achieve climate neutrality by 2050, while the Digital Decade*2030* encourages digital transformation to strengthen business resilience. Croatia has fully aligned its strategies through the Croatian Digital Strategy for the period up to *2032 (National Newspaper, 123/27, 2024)* and the National Development Strategy until *2030.* At the global level, sustainability is a key factor for competitiveness, as confirmed by initiatives such as the Paris Climate Agreement and the United Nations Sustainable Development Goals (SDGs). These standards define guidelines for ecological responsibility and reducing the negative impact of business operations on the environment. The European Union, through the CSRD directive, *the EU Taxonomy for Sustainable Activities* and the Sustainable Finance Disclosure Regulation – SFRD (European Commission, Questions and Answers 2023b), implements these global goals at the European market level.

1.3 Challenges in Implementing Sustainable Practices (With and Without Mandatory Reporting)

Despite the benefits of sustainable business practices, micro and small enterprises in Croatia face numerous challenges in implementing sustainable practices, including limited material and intangible resources, lack of technical knowledge, and the perception of high initial costs. These challenges are categorized into three main areas. The first are financial and technical challenges. Micro and small enterprises often have limited financial resources to invest in sustainable technologies and are frequently lacking financial resources altogether. Additionally, the lack of technical knowledge and expertise complicates the application of sustainable business models. According to resource dependence theory (Pfeffer & Salancik 1978a), it is stated that organizations depend on the availability of key resources, and the lack of these resources can limit their ability to adapt to regulatory requirements. The second area involves administrative burdens and regulatory challenges. According to the Corporate Sustainability Reporting Directive (CSRD) the reporting obligations have been extended to medium-sized enterprises (up to 250 employees, up to 43 million euros in assets, and up to 50 million euros in revenue), while micro and small enterprises are currently exempt from mandatory reporting, it is anticipated that in the future, this will apply to all actively operating legal entities. The third area involves the lack of awareness and education, including insufficient information available to micro and small enterprises about the long-term benefits of sustainability, such as reducing operational costs, increasing market competitiveness, and accessing various funds. The Diffusion of Innovations Theory specifically addresses this issue (Rogers 1962) explains how the lack of information, including the aforementioned lack of awareness and education, can slow down the adoption of new business practices.

1.4 Research Objectives and Main Research Questions

The aim of this research is to analyse the impact of implementing sustainable practices on the resilience and competitiveness of micro and small enterprises in Croatia, with an emphasis on the role of digitalization as a tool for promoting sustainable business.

The main research questions include:

1. How does the implementation of sustainable practices impact the resilience and competitiveness of micro and small enterprises?

According to the Dynamic Capabilities Theory (Teece, Pisano & Shuen 1997), enterprises that implement sustainable practices develop greater long-term resilience to market changes and regulatory requirements, strengthening their competitiveness.

2. What are the key challenges and incentives for micro and small enterprises in adopting sustainable practices?

According to the Resource Dependence Theory (Pfeffer & Salancik 1978a) and the Institutional Barriers Theory (DiMaggio & Powell 1983), certain limitations, such as a lack of financial resourc-

es, knowledge, or administrative barriers, affect the ability of micro and small enterprises to adopt sustainable practices.

3. How can digitalization enhance the implementation of sustainable practices?

The Diffusion of Innovations Theory (Rogers 1962) emphasizes how digital tools can increase transparency and simplify reporting on sustainable practices, consequently making it easier to implement sustainability in enterprises of all sizes.

The introduction of sustainable practices in micro and small enterprises in Croatia is of strategic importance for the country's economic development and a necessary prerequisite for aligning with European sustainability policies. Despite numerous challenges, efforts to include micro and small enterprises in the implementation of sustainable practices are stronger than ever, driven by numerous incentives.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Sustainable Business and Its Application in Micro and Small Enterprises

Sustainable business is defined as a business model that integrates economic, ecological, and social aspects of business to achieve long-term stability and resilience. This concept is based on the Brundtland Report (The federal Council, The Brundtland Report 1987) in the context of micro and small enterprises, it manifests through resource optimization, waste reduction, increased energy efficiency, and the use of local suppliers and sustainable materials.

The theoretical framework of sustainable business is further developed through the Triple Bottom Line theory (Elkington 1997), which emphasizes the importance of alignment across three dimensions: economic success, social responsibility, and environmental sustainability. According to this model, business success is not measured solely by financial results but also by its impact on the community and the environment. Elkington's theory provides a strong foundation for the analysis of sustainable business, particularly highlighting micro and small enterprises, which require more flexible business models and patterns.

The application of sustainable models can help micro and small enterprises build resilience against market changes, including numerous regulatory requirements, as confirmed by empirical research. Specifically, according to the research by Schaltegger and Wagner, (2011) such enterprises experience increased operational efficiency, cost reduction, and an improvement in reputation and trust among key stakeholders.

Theoretical Framework of Resource Dependence (Pfeffer & Salancik 1978b) explains how the lack of resources (both material and intangible) can limit the ability of micro and small enterprises to adopt sustainable business models. At the same time, the Diffusion of Innovations theory suggests that (Rogers 1962) highlights that these enterprises adopt sustainable practices more slowly because they have limited access to information and expertise.

Despite the challenges, it is assumed that sustainable business offers significant advantages for micro and small enterprises: resource optimization and increased energy efficiency reduce operational costs, while socially responsible business practices are perceived as a competitive advantage in the market. This is particularly emphasized through the regulatory requirements of the European Union and the aforementioned Corporate Sustainability Reporting Directive (CSRD). The necessity of digitalization as a prerequisite for the integration of sustainable practices is highlighted in the Technology Diffusion Theory (Rogers 1962) which emphasizes how digital tools enable easier monitoring of sustainability indicators, such as energy consumption or waste management.

2.2 The Role of Sustainability in Strengthening the Resilience and Competitiveness of Enterprises

The implementation of sustainable practices plays a key role in strengthening the resilience and competitiveness of enterprises, allowing micro and small businesses to better manage risks, adapt timely to changing market conditions, and achieve long-term reduction in operational costs. The theoretical framework for this assertion is provided by the Dynamic Capabilities Theory (Teece, Pisano & Shuen 1997) which highlights the importance of a company's ability to adapt to changes in the environment through innovation, learning, and strategic adjustment.

Resilience refers to a company's ability to cope with crises and unpredictable situations, and it is reflected in increased financial stability, reputational advantages, and cost reduction. It also enables competitiveness in the markets where the company operates, as highlighted in the Creating Shared Value theory (Porter & Kramer 2011), stating that enterprises that implement sustainable practices not only reduce negative environmental impacts but also create additional economic value through innovation, increased productivity, and attracting ethically-oriented consumers and investors.

Strengthening resilience and competitiveness through sustainable practices for micro and small enterprises offers additional benefits, including access to financial resources and available EU funds: The European Regional Development Fund (ERDF) and the Competitiveness of Enterprises and Small and Medium-sized Enterprises Program (COSME). For enterprises oriented towards internationalization, aligning with sustainable standards enhances access to international markets, as sustainability has become one of the key criteria in supply chains.

2.3 Overview of Current and Future Sustainability Regulations in Croatia and the EU

Sustainability regulation in the Republic of Croatia and the European Union has undergone significant changes in the past decade, with an emphasis on increasing transparency, accountability, and environmental sustainability in the real sector.

At the national level, Croatia has adopted several key strategic documents that provide guidance for sustainable business practices and digitalization. Notably, the National Development Strategy until 2030 (National Development Strategy of the Republic of Croatia until 2030, 2022) establishes sustainable development as a fundamental priority of national policies, with a focus on environmental responsibility, reducing greenhouse gas emissions, and the digital transformation of business. In parallel, the Digital Croatia Strategy until *2032* (Official Journal of the European Union, L 322/15, 2022) aims to accelerate the digitalization of businesses, including micro and small enterprises, with the goal of facilitating the implementation of sustainable practices through the use of digital tools for monitoring and reporting sustainability. With this approach, the Republic of Croatia has created an institutional framework for sustainable economic growth.

At the European Union level, the most important regulatory framework in the field of sustainability is the Corporate Sustainability Reporting Directive (Corporate Sustainability Reporting Directive – CSRD) adopted in 2021, and which came into effect in the Republic of Croatia on January 1, 2024. The goal of this directive is to increase business transparency concerning environmental, social, and governance (ESG) factors, which enables companies to better manage risks and adapt to environmental standards. Additionally, the directive extends the obligation of non-financial reporting to all large and medium-sized enterprises, and, as we suggest in the paper, it is expected to eventually include micro and small enterprises.

Alongside the CSRD directive, key EU regulations include the EU Taxonomy for Sustainable Activities which is a classification system for economic activities aligned with sustainability goals, and the Sustainable Finance Disclosure Regulation (SFRD), which defines disclosures to end investors regarding sustainability risk, harmful impacts on sustainability, sustainable investment goals, or the promotion of environmental, social, and governance characteristics in investment decision-making and advisory processes. The EU Taxonomy defines which activities are considered environmentally sustainable, helping investors and businesses make informed decisions regarding investments in sustainable projects. This further supports the implementation of the European Green Deal, through which the European Union has set a climate neutrality goal by 2050. This plan includes reducing greenhouse gas emissions, transitioning to renewable energy sources, increasing energy efficiency, preserving biodiversity, and promoting a sustainable economy and circular models of production and consumption.

In the future, it is expected that new regulatory requirements will continue to be introduced in line with the goals of the European Green Deal and the UN's Sustainable Development Goals (SDGs). Stricter reporting and compliance standards are anticipated, with an emphasis on the introduction of digital tools for automatic sustainability monitoring.

2.4 The role of digitalization in promoting sustainable practices and transparency in micro and small enterprises

Digitalization plays a crucial role in promoting sustainable practices and increasing business transparency in micro and small enterprises, enabling more efficient resource management, reducing ecological footprints, and ensuring compliance with regulatory requirements. According to the theory of technological diffusion (Rogers 1962) the adoption of new technologies depends on perceived benefits and the complexity of their application, which, in the context of sustainable practices, includes access to tools that allow monitoring ecological indicators and improving business processes.

Digital tools enable more precise tracking of sustainability indicators such as energy consumption, greenhouse gas emissions, and waste management. This practice aligns with the Corporate Sustainability Reporting Directive (CSRD) which emphasizes the need for transparent reporting on environmental, social, and governance (ESG) factors in business operations.

On the other hand, digitalization enhances transparency both internally and externally with stakeholders. By implementing digital sustainability reporting systems, businesses can document sustainable practices, increasing investor and customer trust. This aspect is theoretically based on legitimacy theory (Suchman 1995), which posits that organizations that transparently report their operations are more likely to gain market and regulatory trust.

Furthermore, digitalization supports education and ensures businesses are informed about sustainable practices. Thus, the challenges posed by digitalization potentially become opportunities, offering micro and small enterprises the possibility of acquiring the necessary knowledge to comply with existing national and European regulatory frameworks through various online educational platforms, digital guides, and virtual consultants.

3 RESEARCH METHODOLOGY

3.1 Objective and Research Design

The aim of the research is to analyse the attitudes and practices of micro and small enterprises in the Republic of Croatia regarding sustainable practices, identify key challenges and obstacles in implementing sustainable solutions, and explore the potential role of digitalization in enhancing sustainability. The results will serve as a foundation for recommendations on the development of policies and incentive measures to support sustainability in micro and small enterprises without a legal obligation to report on sustainability.

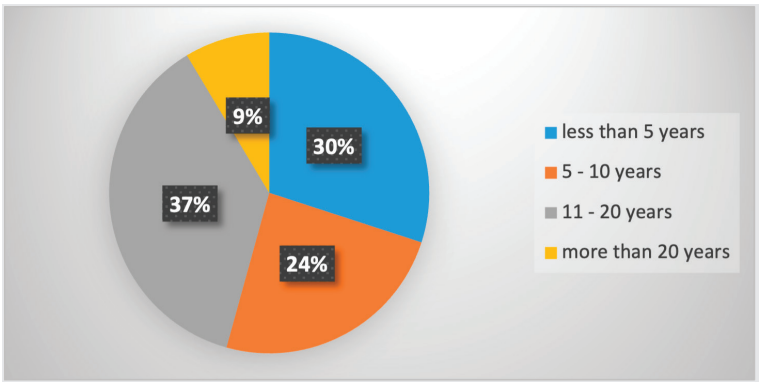
The research was conducted through a survey questionnaire (Appendix 1) targeted at micro and small enterprises. The survey included a combination of closed and open-ended questions to quantitatively and qualitatively analyse respondents' attitudes toward sustainability, digitalization, and regulatory aspects, within the time period from January 10, 2025, to January 31, 2025. The collected data were processed using descriptive statistical methods to identify key trends and patterns in the responses. The questionnaire covered demographic data about the enterprises, their level of awareness regarding sustainability, the implementation of sustainable practices, and their perception of the impact on business resilience. Data from 70 enterprises were analysed.

4 RESULTS

4.1 General Characteristics of the Surveyed Enterprises

The majority of the surveyed enterprises belong to the category of micro enterprises (64.3%) with fewer than 10 employees and operate in the services sector (58.6%) and retail sector (17.1%). Most of the enterprises have been in operation for over 10 years (37.1%), indicating business stability despite market challenges.

Figure 2: Graphical Representation of the Structure of Enterprises by number of employees



(Source: Authors' Compilation)

Of the surveyed enterprises, the majority are from the Slavonia and Baranja region (52.9%) and the Zagreb area (25.7%). Most of the enterprises have up to 10 employees (50% have one to five employees, 25.7% have six to ten employees).

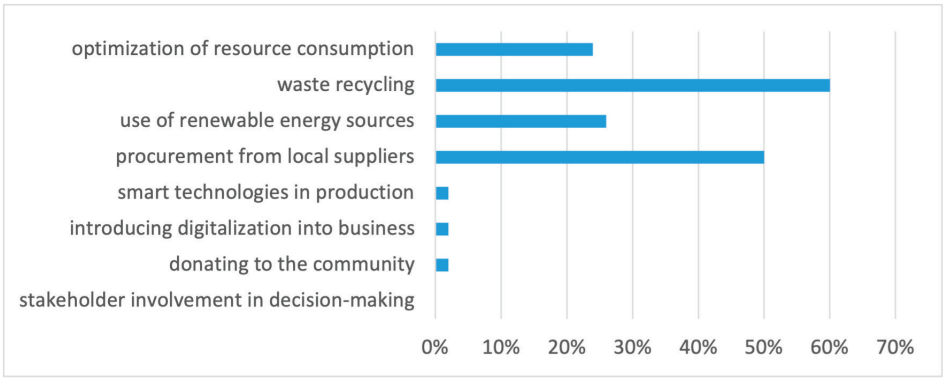
4.2 Level of Awareness about Sustainability

The results show that 74.3% of respondents are familiar with the concept of sustainability, but their perception of the importance of sustainable practices varies. Only 45.7% of respondents believe sustainability is very important for business operations, while 11.4% believe sustainability is not important at all for business operations. As key aspects of business sustainability, the following are cited: reducing business costs through energy-efficient processes (61.4%), ecological responsibility and waste reduction (52.9%), and social responsibility (54.3%).

The research results show that **50% of the surveyed enterprises already implement certain sustainable practices,** while the rest do not (25.7% of enterprises do not apply sustainability in their operations, 14.3% plan to introduce sustainable measures within one year, and 10% are considering implementation in the next three years). These data suggest that a significant proportion of micro and small enterprises are already engaging in sustainable activities, while the rest either plan to make changes in the future or do not see an immediate need to do so.

Among the enterprises that confirmed they are implementing sustainable practices, the most common measures include waste recycling (60%), sourcing from local suppliers (50%), and optimizing resource consumption (48%). The use of renewable energy sources is present in 26% of enterprises, indicating relatively low interest in this type of investment.

Figure 3: Sustainable Practices Implemented by Enterprises

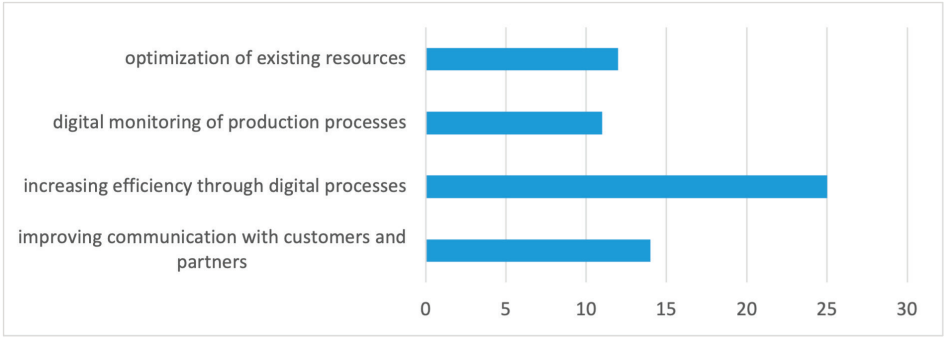


(Source: Authors' Compilation)

Among the surveyed enterprises that do not implement sustainability in their operations (50%), 30% cite the main reason as a lack of information and education on sustainable practices. Scepticisms towards sustainability is also prevalent – some respondents believe that sustainability in business often boils down to "greenwashing," a marketing strategy with no real ecological impact. Others highlight that sustainability is an additional administrative burden that does not bring direct business benefits.

The majority of enterprises, 68%, do not use digital tools to implement or monitor sustainable practices, while 32.9% have implemented digital tools in their businesses. Among the respondents who implement digital tools, 75.8% do so by increasing efficiency through digital processes (e.g., electronic documents instead of paper), 36.4% by optimizing existing resources (energy or material consumption), 33.3% through digital monitoring of production processes (and waste reduction), and 42.4% by improving communication with customers and partners.

Figure 4: The Contribution of Digital Technologies in the Enterprise



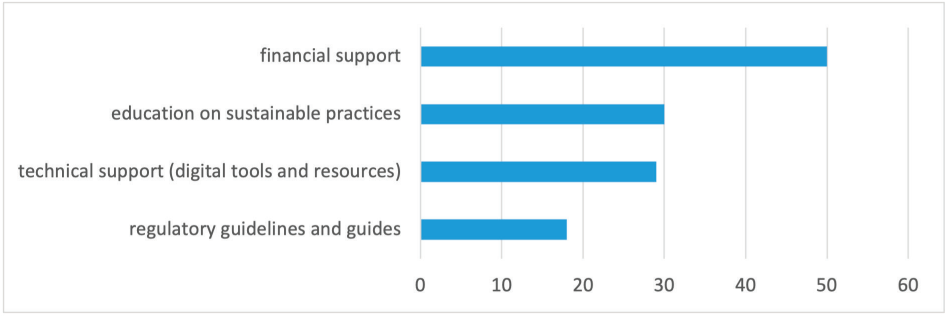
(Source: Authors' Compilation)

Digitalization is recognized as a useful tool for sustainability, but many respondents still do not use digital tools, with 80% citing the cost of implementation and a lack of knowledge about available tools as the main barriers to digitalization.

4.3 Sustainability Reporting

A part of the respondents believes that mandatory sustainability reporting would help micro and small enterprises in structuring sustainable practices – 54.3% of them, and the most useful form of support in implementing sustainable practices includes financial support (71.4%), education on sustainable practices (42.9%), technical support through digital tools and resources (41.4%), and regulatory guidelines and manuals (25.7%).

Figure 5: Support in Implementing Sustainable Practices



(Source: Authors' Compilation)

5 CONCLUSION

The research has shown that micro and small enterprises in the Republic of Croatia recognize the importance of sustainability and its positive impact on competitiveness and resilience, but they face various challenges in implementing sustainable practices.

Despite the recognized benefits, such as reducing operational costs and increasing market competitiveness, there are key challenges that include financial costs, administrative burdens, and limited access to information and tools, which slow down their implementation. It is important to highlight that digitalization is seen as a potential solution for enhancing sustainable practices through transparency, resource optimization, and monitoring environmental indicators. However, its application is still not widespread, and enterprises have not fully utilized digital tools, primarily due to initial costs and a lack of knowledge.

Measures that could contribute to the development of sustainable practices in micro and small enterprises that are not subject to reporting requirements include:

- Ensuring financial support, including easier access to sustainability funds (enabling the reduction of initial implementation costs)
- Education and access to information on sustainable business practices and digital tools that can be applied, implemented, and facilitate their execution,
- Simplification of administrative procedures and reduction of bureaucratic barriers to ease compliance in case of regulatory requirements,
- Encouraging the development of digital solutions tailored to micro and small enterprises, enabling more efficient monitoring and implementation of sustainable business models within their operations.

The results of this research can serve as a foundation for future initiatives aimed at enhancing sustainability in micro and small enterprises and for shaping policies that will support their long-term competitiveness and sustainable practices. Additionally, the research offers guidance for policies that will enable their long-term development in line with European and global sustainability goals.

REFERENCES

1. Brundtland, Gro Harlem. 1987. *Our common future.* Oxford University Press.
2. Croatian Chamber of Commerce. 2022. *Why sustainable business is more important than ever.* Available at: https://www.hgk.hr/komentar-hgk-zasto-je-odrzivo-poslovanje-danas-potrebnije-no-ikada (March 8, 2025)
3. DiMaggio, Paul Joseph and Walter Powell. 2015. *The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields.* Available at: https://www.academia.edu/41967521/The_Iron_Cage_Revisited_Institutional_isomorphism_and_Collective_Rationality_in_Organizational_fields (February 16, 2025)
4. Educational Technology. 2023. *Diffusion of Innovations Theory.* Available at: https://educational-technology.net/diffusion-of-innovations-theory/ (February 5, 2025)
5. European Financial Reporting Advisory Group. 2024. *Compilation of Explanations for 2024 ESRS.* Available at: https://www.efrag.org/sites/default/files/media/document/2024-07/Compilation%20Explanations%20January%20-%20July%202024.pdf (January 25, 2025)
6. Elkington, John. 1997. *Cannibals with forks: The triple bottom line of 21st-century business.* Capstone Publishing.
7. Elkington, John. 2004. *Triple Bottom Line.* Available at: https://johnelkington.com/archive/TBL-elkington-chapter.pdf (February 8, 2025)
8. EU Taxonomy for Sustainable Activities. 2021. *EU Taxonomy for Sustainable Activities.* Available at: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en (March 1, 2025)
9. EUR-Lex. 2022. *Directive 2022/2464/EU - Corporate sustainability reporting.* Available at: https://eur-lex.europa.eu/legal-content/HR/TXT/PDF/?uri=CELEX:32022L2464 (February 8, 2025)
10. European Commission. 2021. *Sustainable Finance and EU Taxonomy.* Available at: https://eur-lex.europa.eu/legal-content/HR/TXT/HTML/?from=EN&uri=PI_COM%3AC%282021%294987 (January 24, 2025)
11. European Commission. 2023a. *European sustainability reporting standards.* Available at: https://finance.ec.europa.eu/news/commission-adopts-european-sustainability-reporting-standards-2023-07-31_en (April 9, 2025)
12. European Commission. 2023b. *EU Green Deal – Key Policies for Sustainability.* Available at: https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_4043 (January 25, 2025)
13. European Commission. 2024. *The European Green Deal.* Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_hr (January 24, 2025)
14. European Commission. 2025a. *EU Green Deal and Sustainability.* Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_hr (February 24, 2025)
15. European Commission. 2025b. *Sustainable Development Goals.* Available at: https://commission.europa.eu/strategy-and-policy/sustainable-development-goals_en?prefLang=hr (March 2, 2025)
16. European Commission. 2025c. *Sustainable Finance and EU Taxonomy.* Available at: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en (February 8, 2025)
17. European Commission. 2025d. *Europe's Digital Decade – Digital Targets 2030.* Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_hr (January 23, 2025)
18. European Council. 2024. *Paris Agreement on Climate.* Available at: https://www.consilium.europa.eu/hr/policies/paris-agreement-climate/ (February 10, 2025)
19. Ernst & Young Global Limited - EY. 2025. *European Sustainability Reporting Standards (ESRS) in a nutshell.* Available at: https://denkstatt.at/en/esrs-standards-explained/ (August 31, 2025)
20. Financijska agencija. 2023. *Business performance of entrepreneurs in 2023, categorized by size.* Available at: https://www.fina.hr/novosti/rezultati-poslovanja-poduzetnika-u-2023.-godini-razvrstani-po-velicini (January 15, 2025)
21. Forvis Mazars. 2022. *First draft of ESRS: Aligning financial and sustainability reporting.* Available at: https://www.forvismazars.com/hr/hr/nase-usluge/odrzivost-esg/prvi-set-nacrta-esrs-a (May 10, 2025)

22. FourWeekMBA. 2024. *Rogers Diffusion of Innovations.* Available at: https://fourweekmba.com/rogers-diffusion-of-innovations/ (February 8, 2025)
23. Hillman, Amy. 2009. *Resource Dependence Theory: A Review.* Available at: https://www.academia.edu/69365981/Resource_Dependence_Theory_A_Review (February 11, 2025)
24. IUS-INFO. 2024. *Regulatory Foundations of Sustainability in the Financial Market.* Available at: https://www.iusinfo.hr/aktualno/u-sredistu/regulatorni-temelji-odrzivosti-na-financijskom-trzistu-pregled-postojece-regulative-s-naglaskom-na-sfdr-uredbu-58160 (January 28, 2025)
25. Ministry of Tourism and Sports of the Republic of Croatia. 2024. n.d. *The first European sustainability reporting standards under consultation.* Available at: https://mint.gov.hr/odrzivi-turizam-22984/na-savjetovanju-prvi-europski-standardi-izvjestavanja-o-odrzivosti/23519 (May 10, 2025)
26. National Newspaper. 2023. *Sustainable business law.* Available at: https://narodne-novine.nn.hr/clanci/sluzbeni/2023_01_2_17.html (January 23, 2025)
27. National Development Strategy of Croatia. 2021. *National Development Strategy of Croatia until 2030.* Available at: https://hrvatska2030.hr/wp-content/uploads/2021/02/Nacionalna-razvojna-strategija-RH-do-2030.-godine.pdf (February 2, 2025)
28. Pfeffer, Jeffrey and Gerald R. Salancik. 1978a. *The external control of organizations: A resource dependence perspective.* Harper & Row.
29. Pfeffer, Jeffrey and Gerald R. Salancik. 1978b. *Resource Dependence Theory.* Available at: http://kendlevidian.pbworks.com/w/file/fetch/100099305/Pfeffer%20and%20Salancik%201978%20Notes.pdf (April 8, 2025)
30. Porter, Michael and Mark Kramer. 2011. *Creating shared value. Harvard Business Review* 89(1–2): 62–77.
31. Rogers, Everett Mitchell. 2003. *Diffusion of Innovations.* Available at: https://archive.org/details/diffusionofinnov00roge (March 15, 2025)
32. Schaltegger, Stefan, and Marcus Wagner. 2011. *Sustainable entrepreneurship and sustainable business models: An overview of current research. Journal of Business Economics* 55(1): 1–31.
33. Schrack Training Center. 2023. *European standards for sustainability reporting.* Available at: https://schracktrainingcenter.com/kb/europski-standardi-za-izvjestavanje-o-odrzivosti (February 8, 2025)
34. Suchman, Mark. 1995. *Managing legitimacy: Strategic and institutional approaches. Academy of Management Review* 20(3): 571–610.
35. Teece, David, Gary Pisano and Amy Shuen. 1997. *Dynamic capabilities and strategic management. Strategic Management Journal* 18(7): 509–533.
36. United Nations. 2024. *Sustainable Development Goals.* Available at: https://sdgs.un.org/goals (February 8, 2025)
37. Uplift – platforma za rast i razvoj malih poduzetnika. 2022. *It's not just for the big: How small businesses can contribute to achieving global sustainability goals.* Available at: https://uplift.hr/nije-samo-za-velike-kako-mala-poduzeca-mogu-dati-doprinos-ostvarenju-globalnih-ciljeva-odrzivosti (January 8, 2025)
38. Uzor Hrvatske. 2022. *European standards for sustainability reporting.* Available at: https://www.uzorhrvatske.hr/info/priopcenja/350-europski-standardi-za-izvjestavanje-o-odrzivosti (February 10, 2025)
39. World Commission on Environment and Development. 1987. *Sustainable development.* Available at: https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html (February 18, 2025)

APPENDIX 1

Basic Information About the Organization

1. Size of Your Enterprise

a) Micro
b) Small

2. In which region of Croatia does your enterprise operate?

a) Central Croatia
b) Istria and Primorje
c) Slavonia
d) Dalmatia
e) Zagreb and surroundings

3. How long has your enterprise been operating?

a) Less than 5 years
b) 5-10 years
c) 11-20 years
d) More than 20 years

4. How many employees does your enterprise currently have?

a) 1-5 employees
b) 6-10 employees
c) 11-20 employees
d) More than 20 employees

5. Main activity of your enterprise

a) Production
b) Service
c) Trade
d) Other (please specify):

Business Sustainability

6. Are you familiar with the concept of sustainable business?

a) Yes
b) No

7. Do you consider sustainability important for your enterprise's business?

a) Not important
b) Somewhat important
c) Very important

8. Which aspects of sustainability do you consider most important for your enterprise? (You can select multiple answers)

a) Reducing business costs through more energy-efficient processes
b) Environmental responsibility and waste reduction
c) Social responsibility (towards the community, employees)
d) Better company image
e) Adapting to regulatory changes
f) Other (please specify):

9. Do you currently implement any sustainable practices in your enterprise?

a) Yes
b) No
c) Plan to implement in the next year
d) Plan to implement in the next 3 years
e) Plan to implement in the next 5 years

10. If yes, which sustainable practices do you implement? (You can select multiple answers)

a) Recycling waste
b) Optimizing resource consumption (water, energy)
c) Using renewable energy sources (e.g., solar panels)
d) Sourcing from local suppliers (supporting the community)
e) Other (please specify):

Enterprise Resilience

11. Do you believe that sustainable practices can increase your enterprise's resilience to the challenges it faces today?

a) No
b) Partially
c) Yes

12. What are the biggest challenges to introducing sustainable practices in your enterprise?

a) Insufficient financial resources
b) Lack of knowledge and information
c) Unclear legal regulations
d) Lack of interest from the owners
e) Lack of employee motivation
f) Other (please specify):

13. How would you like to improve sustainability in your enterprise?

a) Education on sustainability and available tools
b) Financial support or grants
c) Cooperation with other enterprises or the community
d) Other (please specify):

Digitalization and Sustainability

14. Do you use digital tools to implement or monitor sustainable practices in your enterprise?

a) Yes
b) No
c) No, but we plan to in the future

15. If the previous answer is yes, how do digital technologies contribute to sustainability in your enterprise? (You can select multiple answers)

a) Optimizing existing resources (e.g., energy or material consumption)
b) Digital monitoring of production processes (and waste reduction)
c) Increasing efficiency through digital processes (e.g., e-documents instead of paper)
d) Improving communication with customers and partners
e) Other (please specify):

16. Do you believe that digitalization facilitates the introduction of sustainable practices in micro and small enterprises?

a) Does not facilitate
b) Partially facilitates
c) Facilitates
d) Cannot assess

17. Which digital tools do you use to promote sustainability? (Multiple answers possible)

a) Energy consumption tracking software
b) Waste management tools
c) Digital platforms for ESG reporting
d) Software for supply chain optimization
e) None
f) Other (please specify):

Closing Questions

18. Do you believe that mandatory sustainability reporting would help micro and small enterprises?

a) Yes

b) No

19. Which form of support would be most useful for your enterprise in implementing sustainable practices? (Multiple answers possible)

a) Financial support

b) Education on sustainable practices

c) Technical support (digital tools and resources)

d) Regulatory guidelines and manuals

20. What are the three key benefits you see in adopting sustainable practices?

a) Reducing costs

b) Improving reputation

c) Access to financial support

d) Increasing market competitiveness

e) Environmental preservation

21. What sources of information about sustainable practices do you most often use?

a) Professional associations

b) Online guides and webinars

c) Consulting companies

d) EU and national institutions

22. Do you have any additional comments or suggestions about the topic of sustainable practices in micro and small enterprises?

(Open-ended response)

1.08 Objavljeni znanstveni prispevek na konferenci
Published scientific conference contribution

URBAN MOBILITY MEASURES FOR HEALTHIER FUTURE: ADAPTING MADRID'S LOW EMISSION ZONES MODEL FOR SOFIA

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ABSTRACT

This study explores the intersection of sustainable mobility, development, and public health in the urban environment through the implementation of low-emission zones (LEZs). Focusing on Madrid's experience since 2018, it examines the contribution of LEZs to fostering the transition to greener transport modes, the expansion of public transport networks and improving public health. The research aimed to map out the steps for transferring these benefits to the city of Sofia in order to help transform it into a more resilient and sustainable city. A case-study approach was employed, analysing the urban, social and economic elements that influence the success of the implementation of LEZs in Madrid. Data on urban mobility patterns, socio-economic factors, air quality, noise pollution and land use were examined using time-series analysis, Geographic information systems (GIS) for spatial and network analysis, alongside measurable indicators. Finally, the research adapts the findings to Sofia, considering the specific local urban, regulatory, social and economic challenges by developing a model with guidelines for implementation. The introduction of LEZs in Sofia has the potential to significantly improve public health and create more resilient urban communities by enhancing the use of cleaner transportation alternatives and promoting sustainability and adaptability to climate change.

***Keywords**: Urban mobility, Sustainability, Low-emission zones, Public health, Resilience*

1 INTRODUCTION

Mitigating climate change effects on the urban environment and improving public health are urgent goals to achieve as part of nations and cities race to net zero. Among the first most important adopted documents in this regard is the 2015 Paris Agreement, an international treaty on climate change, adopted by 196 countries at the UN Conference (COP21) with the main goal of striving to "limit the temperature increase to 1.5°C above pre-industrial levels". According to the agreement, to limit global warming to 1.5°C, greenhouse gas (GHG) emissions must peak no later than 2025 and decrease by 43% by 2030 (United Nations 2015).

The other important binding document is the 2030 Agenda for Sustainable Development, with goal number 13 "Climate Action" from the Sustainable Development Goals adopted in it in 2015 (UN Department of Economic and Social Affairs 2015) and included in the plan for the localization of measures, New Urban Agenda, Habitat III (Habitat III Secretariat 2017).

The GHG emissions, including from transport (11-12%), are a major contributor to the cities' air quality and other climate issues, although overall they are already slowly but steadily decreasing for both Spain and Bulgaria (H. Ritchie et al. 2020). Modes of transport in the city, that use petrol and especially diesel fuel, have an undeniable negative impact on health and wellbeing causing air and noise pollution (Kozina, Radica, and Nižetić 2020) and in some cases severe traffic accidents, as older cars and motorcycles do not have the modern safety systems and can often produce dangerous malfunctions.

One of the tools and measures that emerged to tackle the mentioned urban challenges and to reduce dependence on the traditional fuel cars and motorcycles are the Low emission zones, which constitute well defined zones with variety of restrictions for polluting vehicles (Institute for Transportation and Development Policy 2023) from priced to not priced entrance, from severe restrictions for all to milder ones for residents and passing through traffic. These zones differ in size and restrictions throughout more than 300 cites in Europe but their success in directly and immediately reducing air pollution in the form of particulate matter (PM), especially with diameter less than or equal to 2.5 μm ($PM_{2,5)}$ and nitrogen oxides (NO_x) and in promoting and prioritizing more active and clean modes of transport, particularly walking and cycling, is undeniable (Transport & Environment 2019).

1.1 Madrid case study

Madrid's first LEZ model was initially introduced as part of a systematic approach included along with other sustainability initiatives in the "Plan A: Air Quality and Climate Change Plan" (Ayuntamiento de Madrid 2017), included a total of 30 measures, adopted in September 2017 by the Madrid City Council. A large part of the measures (21 out of 30) of this plan are aimed at sustainable urban mobility and promotion of public transport, walking and the shared bike service called BiciMAD (EMT Madrid and Ayuntamiento de Madrid 2025), operated by the Municipal Transport Company ("Empresa Municipal de Transportes", EMT).

In late 2019 the LEZ model became part of an entirely new Sustainable Development Strategy called Madrid 360 (Ayuntamiento de Madrid 2024a), an increase from one to three (3) zones in total: two of which are LEZ with Special Protection "Centro" (corresponding to the previous LEZ limits) and "Plaza Elíptica", the third constitutes the entire city, declared as a LEZ as well. The interventions in the urban environment part of the Madrid 360 strategy are a combination of sustainable urban mobility measures combined with other sustainability initiatives with significant positive results in lowering air and acoustic pollution (localized effects) and promoting alternative modes of transport to the private car, namely walking, biking and using public transport. The main goal of the strategy is to reduce emissions (compared to the levels of 1990) in the city of Madrid by 65% by 2030 and to achieve climate neutrality by 2050 (Ayuntamiento de Madrid 2022). The strategy fully adheres to the Strategic Development goals (UN Department of Economic and Social Affairs 2015).

Some of the results of the strategy's implementation are already reality with 3 consecutive years (as of 2024) with all 24 air quality stations show the lowest NO_2 levels since the start of application of the community regulations (Ayuntamiento de Madrid 2024a).

1.2 Sofia case study

Among the current environmental conditions in the Bulgarian capital are elevated air pollution in certain locations especially during the colder months, elevated noise pollution, especially around the main transport roads, urban transport with low frequency and with insufficient coverage and increased urban heat islands effect. The implemented sustainability strategies (Sofia Municipality and Infraproekt Konsult Ltd. 2019) over the last 10 years, for example the Integrated plan for Sustainable Development and Regeneration (Architecture and Urban planning Department Sofia 2013) are only semi-successful including a first attempt to partially introduce a LEZ in the city center only for the winter months between December and February that is active since December 2022. The insufficient results from these initiatives is mainly due to the lack of proper control (for example the current LEZ in Sofia is not controlled by fines and the restrictions are not enforced strictly), the unstable political situation in the country for the past 5 years and in many poor or lack thereof actual execution of the plans, despite the detailed and comprehensive research and target projects included in for example the Vision for Sofia 2030.

Majorly improving Sofia' sustainability and resilience to climate changes requires stricter implementation, administration, monitoring and continuous adaptation of modern approaches that are tailored to the specific socio-demographic, administrative and legislative conditions in the country and in the city where around a quarter of the country's population is concentrated (I. National Statistical Institute Bulgaria 2024).

1.3 Purpose and Goals

1.3.1 Purpose

The study's purpose is to create a model encompassing a detailed phased approach with guidelines necessary to firstly choose suitable possible locations and secondly successfully implement LEZs and their related sustainable urban mobility interventions in Sofia city.

1.3.2 Goals

The first goal of this research is to identify the best practices established in the LEZs implementation in combination with the rest of Madrid' strategic interventions in the urban infrastructure, mobility patterns, administration, and legislation, using appropriate analysis techniques, depending on official available data.

The second goal is to properly assess the success in the application of the interventions according to the indicators and compare these results with Sofia's current situation to find the pain points where more strict measures are needed and where Sofia might have good practices already in place.

The third and final goal is to create a model for implementation with guidelines for LEZs.

2 METHODS

A case-study approach was employed, analysing the urban, social, and economic elements relevant to the implementation of LEZs in Madrid. Socio-economic data, including population growth, density and distribution, were examined using time-series analysis to capture urban trends over time. SQL-based data manipulation was applied to clean, aggregate and normalise tabular data for land use, air and noise pollution.

Geospatial vector, raster and tabular data was processed in a GIS software (QGIS) using spatial joins, geoenrichment with demographic information, data enrichment through overlay analyses, spatial and network analysis (for land use, population distribution, urban mobility patterns, public transport (PT), and PT accessibility), and spatial interpolation (Inverse Distance Weighting (IDW) method) for air quality and noise pollution data. Measurable indicators were derived from the analysis to synthesize and quantify targets.

3 RESULTS

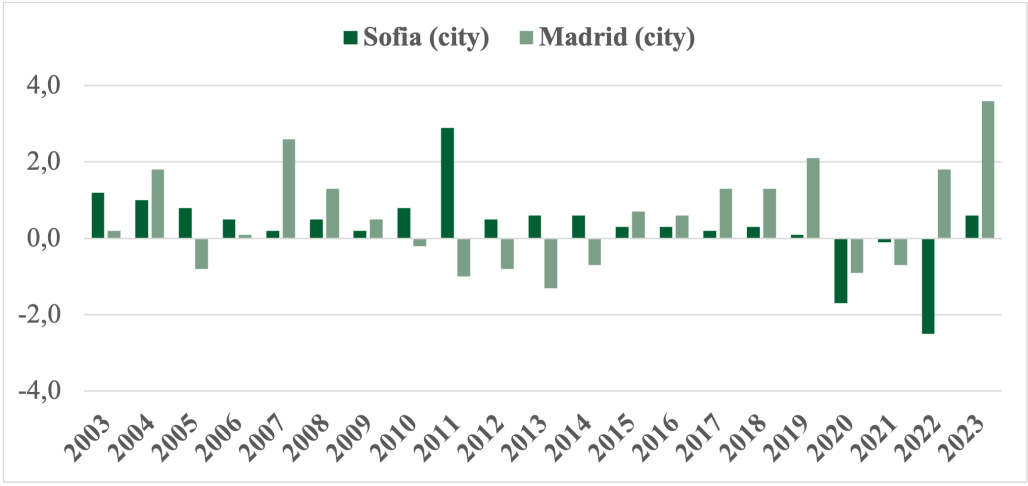
3.1 Analysis results

The urban profiles of Madrid and Sofia were compared on key factors that influence urban developments, improvements and growth. Starting with the socio-demographic and economic ones the year over year growth (YoY Growth) of Madrid and Sofia's populations represented in Fig.1 was calculated using the below stated formula.

$$YoYGrowth = \frac{Population\ this\ year - Population\ previous\ year}{Population\ previous\ year} \times 100$$

Both cities' populations currently have a growing trend for the past 20 years from 1,11M (2002) to 1,19M (2023) for Sofia and from 3,09M (2002) to 3,46M (2023) for Madrid. There was a continuous growth after 2010 in Sofia and a 5 year decrease in the same period for Madrid and finally a short decline, coinciding with the Covid19 Pandemic years between 2020 and 2022 for both capitals (Figure 1.). The population growth is considered when comparing, calculating or normalizing other urban metrics further in the analysis.

Figure 1: Population variation (YoY growth) from 2003 to 2023: Sofia and Madrid



(Source: Compiled by the author based on data from official sources) (Ayuntamiento de Madrid 2024b; Instituto Nacional de Estadística de España 2024c; National Statistical Institute Bulgaria 2024)

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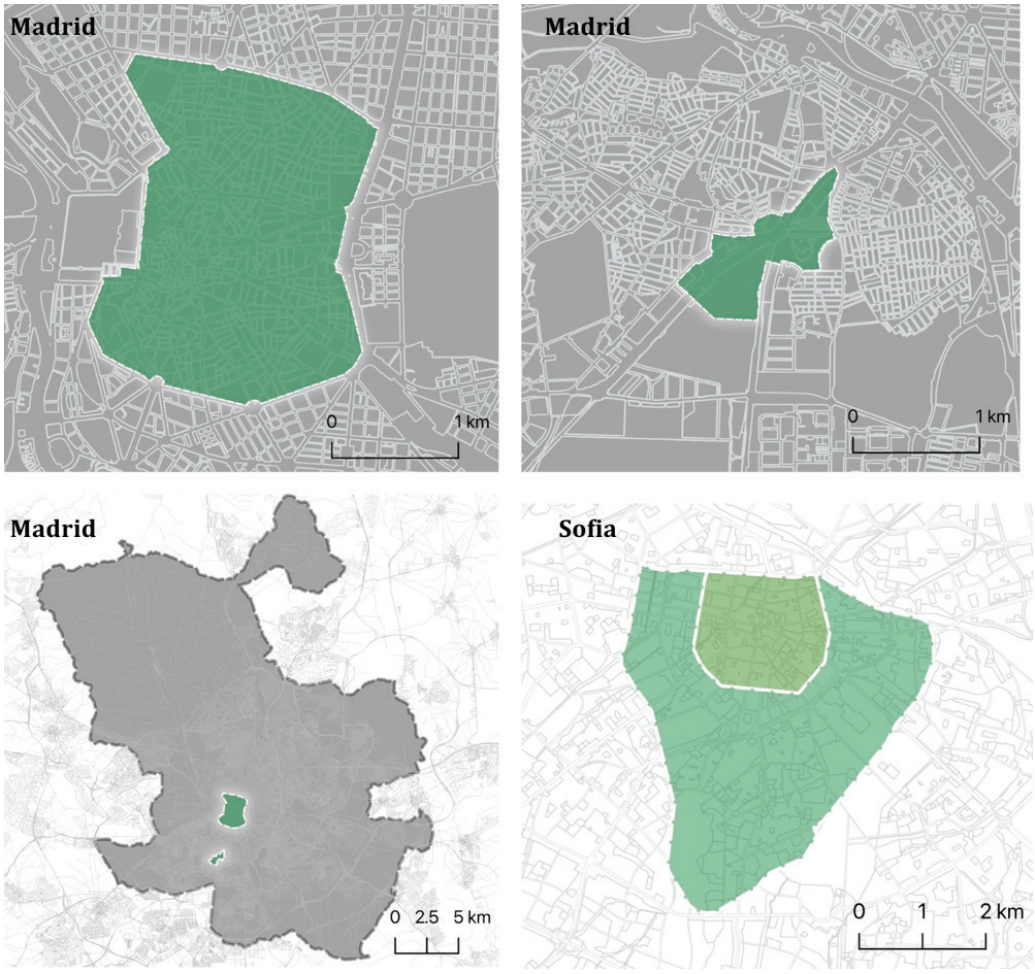
The LEZs' current scopes for Madrid and Sofia are shown in Figure 2. It becomes apparent the scope and size of the LEZ currently implementing for the winter months in Sofia is not the problematic element of why it is until today not successful.

Figure 2: Location of LEZs in Madrid (top row, bottom left) and new LEZ in Sofia (bottom right)



(Source: Compiled by the author based on data from official sources) (Geoportal del Ayuntamiento de Madrid 2021b) (Sofia Municipality 2024)

3.2 Indicators

Madrid's LEZ model's impact on reducing GHG emissions and Particulate matter (PM) 2.5, improving air quality, acoustic pollution, and road safety was then assessed by focusing on key indicators from an urban, environmental and transport planning perspective.

The indicators are represented in two separate tables, based on indicator categories. The specific indicators are chosen with the goal of encompassing most aspects of LEZ's implementation and effects on the urban environment and public health. The tracked values are based on two main types of data:

- readily available open access tabular data (CSV, XLSX file formats) from official sources, collected and then further validated, cleaned and enriched, when necessary, inside Spreadsheets or using SQL, and then taken as a measurement
- results from the analysis (using open access data) when concerning the need to use geospatial data (Shapefiles, GeoJSON, Geopackage file formats) for spatial and network analysis inside the free open-source GIS software QGIS.

The values are organized in 3 groups: "Initial" with values for Madrid before the introduction of LEZs and Sofia's latest current state values, "End", which are the latest found or most up-to-date for Madrid and "Target" values for Sofia set by the author based on either the End values from Madrid or on the analysis conducted so far.

Table 1: Indicators for measuring the impact of LEZs on the urban systems, environment, and public health: initial, end, and target values for Urban and environment related categories: Air and Noise Pollution, and Urban planning (values compiled by the author based on data from official sources).

Cat.	Indicators	Methods for measuring the indicators	Unit of measure	Initial values city level		End values	Target values
				Madrid 2018	Sofia latest	Madrid latest	Sofia 2025+
Air and noise pollution	$PM_{2,5}$ concentration	Air quality measurement stations. (annual mean) **	µg/m³	9.2	2018: 19.8 [b]	10	<5
	PM_{10} concentration		µg/m³	40	2018: 34.6 [b]	40	<15
	NO_2 concentration levels		µg/m³	40	2022: >50 [j]	2020: 11.7	<10
	GHG emissions from road transport (as part of all GHG emissions)	Air quality measurement stations	%	36.6 [c]	2015: 17.3 [d]	2022: 32.6 [c]	<10
	Level of acoustic pollution daily average	Noise measurement stations	dB	62,6 [e]	2022: 64.1 [f]	2023: 62,3 [e]	<53**
	All-cause premature mortality rate linked to urban environmental factors like air pollution	Hospital records, public health databases	%	n.a.	n.a.	2021: 3.4 [g]	0
Urban planning	Green areas (only publicly accessible)	Open data, Land use plan	%	6.3 [h]	56.8 [b]	6.7 [h]	56.8 [b]
	Public spaces (including green areas)	Land use plan, Data analysis using SQL	%	13.7 [i]	56.8 [b]	13.7 [i]	56.8 [b]
	Public spaces (including local/pedestrian streets and green areas)	Land use plan, Data analysis using SQL	%	20.7 [i]	n.a	20.7 [i]	56.8

* For target values for air quality indicators are used the annual mean recommended levels established by the World Health Organization (World Health Organization (WHO) 2021).
**Target value for acoustic pollution is set according to the WHO Environmental noise guidelines for the European Region for road traffic noise (World Health Organization (WHO) 2018)
d (Denkstatt 2017); i (Geoportal del Ayuntamiento de Madrid 2021a); g (Iungman et al. 2021);
b (Sofiaplan 2021); f (National statistical institute 2022); k (Statista 2023); c (Directorate General for Sustainability and Environmental Control Sub-directorate of Energy and Climate Change 2024, 5);
j (Environmental Association "Za Zemiata" 2024) ; e (Portal de datos abiertos del Ayuntamiento de Madrid 2024a); h (Portal de datos abiertos del Ayuntamiento de Madrid 2024b);

Table 2: Indicators for measuring the impact of LEZs on the urban systems, environment, and public health: initial, end, and predicted values for Mobility related categories: Modal Split and traffic, PT and Accessibility (values compiled by the author based on data from official sources).

Cat.	Indicators	Methods for measuring the indicators	Unit of measure	Initial values city level		End values	Target values
				Madrid 2018	Sofia latest	Madrid latest	2035
Modal split and traffic	Modal split: PT	Traffic monitoring and counting points, GPS tracking, app-based mobility data, travel surveys	%	34.4 a	2017: 37 b	n.a.	>40
	Modal split: walking		%	38.2 a	2017: 29,7 b	n.a.	>35
	Modal split: cycling		%	0.6 a	2017: 1,8 b	n.a.	>5
	Modal split: cars and motorcycles		%	24.1 a	2017: 30,4 b	n.a.	<20
	Motorization rate	Vehicle registration databases, population census	Cars/ 1000 inh.*	420 c	2020: 663	2021: 540	<500
	Road safety	Road accidents databases, hospital databases	deaths/ 1M inh.	11.5 d	2023: 35 e	2023: 7.5d	<5
PT and accessibility	Optimal metro load capacity	Passengers passing through metro entrance barriers	Annual trips/ inh.	201.2f	2023: 103.7l	2023: 191.4f	>150
	Optimal surface PT load capacity	Transport documents sold, video monitoring	Annual trips/ inh.	2018: 128.7 j	2014: 242m	2023: 131.4g	250
	Metro stations	PT databases	Stations/ km2	0.5K	2023: 0.23 l	2023: 0.5 k	0.5
	Surface PT stops		Stops/ km2	17.4 j	2021: 9.2 m	2023: 18.3 j	>15
	Bike sharing services use	Bicycles rented annually	Annual trips/inh.	2018: 1.1i	n.a.	2023: 2.2g	>1
	Walking accessibility (<15min metro station, <5min surface PT stop)	Network Analysis	%	85	2021: 73.1	2023: 90	100
	PT stops and stations with accessibility for people with reduced mobility	Ordinance conditions comparison analysis	%	100 e	n.a.	100 e	100

*inh.=inhabitants
b (Sofia Municipality and Infraproekt Konsult Ltd. 2019); m (Sofiaplan 2021);
c (Area de Gobierno de Medio Ambiente 2022); i (Portal de datos abiertos del Ayuntamiento de Madrid 2022); d (Dirección General de la Policía Municipal de Madrid 2024); j (EMT Madrid 2024a); g (EMT Madrid 2024b); f (Metro de Madrid 2024a); k (Metro de Madrid 2024b); l (Metropolitan Sofia 2024); a (Monzón et al. 2024); e (National Statistical Institute and Ministry of Interior of Bulgaria 2024); h (International Association of Public Transport 2025)

3.3 Adoption model, guidelines next steps

The research results will be used in a multicriterial analysis to finally adapt the findings to Sofia, considering the specific local urban, regulatory, social and economic challenges by developing a model with guidelines for implementation.

A multi-criteria decision analysis (MCDA) is chosen to help streamline finding the most suitable LEZ locations based on the results of the indicators which are further evaluated and given scores. As selection criterions in this next step will be used pollution distribution (air and noise), PT accessibility, both walking and cycling and traffic information. These criterions in the form of raster or vector layers will be used I the MCDA model with assigned weights. Results of the MCDA will be used in the rest of the PhD Research.

The guidelines for choosing LEZ locations, synthesized after this study are the following:

- Data first: A data-driven approach must be employed when choosing potential LEZ locations to ensure best results in terms of environmental benefits.
- Phased implementation, with each phase ending in evaluation of the execution:
  - Phase 1: Immediate measures (low-cost interventions like for example "slow zones" (with restrictions for driving speed of 30km/h), awareness campaigns).
  - Phase 2: Public transport and cycling infrastructure improvements.
  - Phase 3: Gradual enforcement through warnings and then fines.
  - Phase 4: Expansion of LEZs.
- Public acceptance and stakeholder involvement: the importance of involving various stakeholders in the planning and implementation process, a clear definition of roles of citizens, businesses, and government agencies, timeline of their involvement. Strategies for public engagement and behavioral change.
- Financial incentives for Zero-emission alternatives: making subsidies and tax incentives part of the process for enforcing the LEZs, especially for citizens who reside inside the limits of the zones with restrictions. Financial support is beneficial to promoting electric mobility and non-motorized transport.
- Monitoring: the control and actual enforcement of the LEZs is just as important as their overall implementation from the rest of the guidelines.

4 DISCUSSION

The proper introduction of LEZs in Sofia has the potential to significantly improve public health and create more resilient urban communities by enhancing the use of cleaner transportation alternatives and promoting sustainability and adaptability to climate change. In its current incomplete form, the limited to a few months in year LEZ in the Bulgarian capital, introduced after this research started, could not possibly achieve the same results as the larger-scale LEZs as an integral part of the comprehensive sustainable mobility approach of Madrid. Sofia is already behind with some of the goals set in the extensive "Vision for Sofia" Strategy and the city's administration needs to take on a firmer approach to mitigating its ongoing pollution issues, to addressing its road safety concerns and accessibility challenges as well as to promote and actually support further the sustainable modes of transport like for example bike-sharing and electric urban transport vehicles.

The current study as a part of the author's PhD research, which has not yet concluded at the time of writing this article, means that that the analysis of some of the data is yet to be expanded, including a more detailed spatial analysis approach to the air and noise pollution data series. Some data was also not readily available or found in the publicly accessible documents and official open data webpages related to all urban data for some time periods which means some indicator measurements might be slightly outdated or incomplete.

Nevertheless, implementing the multiple LEZs approach in combination with all other sustainable mobility measures simultaneously in the rest of the big Bulgarian cities, not only in the capital, could be explored in connection to this study and to the overall net-zero goals of the country.

5 CONCLUSION

This paper presents a structured approach to implementing LEZs as a successful sustainable urban transport measure that can significantly contribute to improving public health and citizen's quality of life by reducing air and noise pollution through the introduction of traffic limitations, by improving traffic safety through new speed limits and larger pedestrian zones, by improving city walkability and promoting healthier mobility alternatives to the private car.

The ongoing urgent need to mitigate climate change and improve public health could be achieved through thoughtfully planned measures with a phased implementation, like the low and zero-emission zones, that are well-accepted by the local communities given the use of a comprehensive public inclusion campaigns, forums and workshops and following of the guidelines for fund-

ing and other incentives for the citizens. Other measures that could be researched in the same way could be the Barcelona Superblocks which have also already found an implementation in Madrid.

These measures gradually transform people's quality of life within city limits, create places out of public spaces and promote a healthier urban living, using the planning for the people approach and shifting away from the last century's car-centric urban developments.

REFERENCES

1. Architecture and Urban planning Department Sofia. 2013. *Integrated Plan for Sustainable Development and Regeneration.* Available at: https://nag.sofia.bg/Pages/Render/765 (February 1, 2025).
2. Area de Gobierno de Medio Ambiente. 2022. *Plan de Movilidad Sostenible Madrid 360*.
3. Ayuntamiento de Madrid. 2017. *Plan A: Air Quality and Climate Change Plan for the City of Madrid*.
4. ———. 2022. *Roadmap to Climate Neutrality by 2050. Madrid 360 Update*.
5. ———. 2024a. *Madrid 360 Official Webpage.* Available at: https://www.madrid360.es/ (January 31, 2025).
6. ———. 2024b. *Población Por Distrito y Barrio Madrid. Portal de Datos Abiertos Del Ayuntamiento de Madrid.* Available at: https://datos.madrid.es/portal/site/egob (January 29, 2025).
7. Denkstatt. 2017. *Inventory of the Greenhouse Gas Emission of Sofia Municipality*. Available at: www.denkstatt.bg (February 1, 2025).
8. Dirección General de la Policía Municipal de Madrid. 2024. *Siniestralidad Vial 2023*.
9. Directorate General for Sustainability and Environmental Control Sub-directorate of Energy and Climate Change. 2024. *Inventory of Madrid City Greenhouse Gas Emissions 2022*. Madrid.
10. EMT Madrid. 2024a. *Cuentas Anuales e Informes de Gestión.* Available at: https://www.emtmadrid.es/Elementos-Cabecera/Enlaces-Pie-vertical/EMPRESA/Somos/Informes-anuales.aspx (February 1, 2025).
11. ———. 2024b. *EMT Madrid Viajeros Transportados 2023.* Available at: https://www.emtmadrid.es/Noticias/EMT-Madrid-bate-records-en-2023,-superando-los-454.aspx (February 1, 2025).
12. EMT Madrid, and Ayuntamiento de Madrid. 2025. *BiciMAD.* Available at: https://www.bicimad.com/estadisticas (January 31, 2025).
13. Environmental Association "Za Zemiata." 2024. *Nitrogen Dioxide Air Pollution from Transport before, during and after the Low-Emission Zone in Sofia*.
14. Geoportal del Ayuntamiento de Madrid. 2021a. *Urbanismo. Destino Urbanístico Del Suelo.* Available at: https://geoportal.madrid.es (February 1, 2025).
15. ———. 2021b. *Zona de Bajas Emisiones de Especial Protección (ZBEDEP) Distrito Centro, Regulada En La Ordenanza de Movilidad Sostenible.* Available at: https://geoportal.madrid.es (February 1, 2025).
16. Habitat III Secretariat. 2017. New Urban Agenda 2030. *United Nations Conference on Housing and Sustainable Urban Development (Habitat III)*, 2017, i–54.
17. Institute for Transportation and Development Policy. 2023. *What Is A Low Emission Zone?* Available at: https://itdp.org/2023/02/22/what-is-a-low-emission-zone/ (January 31, 2025).
18. Instituto Nacional de Estadística de Espaňa. 2024a. *Estadística de Migraciones y Cambios de Residencia.* Available at: https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736177098&menu=ultiDatos&idp=1254735573002 (January 31, 2025).
19. ———. 2024b. *Nacimientos Por Lugar de Residencia de La Madre y Sexo.* Available at: https://www.ine.es/jaxiT3/Tabla.htm?t=6506 (January 31, 2025).
20. ———. 2024c. *Population by municipalities. Madrid.* Available at: https://www.ine.es/jaxiT3/Datos.htm?t=33847 (January 29, 2025).
21. International Association of Public Transport. 2025. *Madrid • CityTransit Data.* Available at: https://citytransit.uitp.org/madrid (January 30, 2025).
22. Iungman, Tamara, Sasha Khomenko, Mark Nieuwenhuijsen, Evelise Pereira Barboza, Albert Ambròs, Cindy M. Padilla, and Natalie Mueller. 2021. The Impact of Urban and Transport Planning on Health: Assessment of the Attributable Mortality Burden in Madrid and Barcelona and Its Distribution by Socioeconomic Status. *Environmental Research* 196 (May). Available at: https://doi.org/10.1016/J.ENVRES.2021.110988 (February 1, 2025).
23. Kozina, Ante, Gojmir Radica, and Sandro Nižetić. 2020. Analysis of Methods towards Reduction of Harmful Pollutants from Diesel Engines. *Journal of Cleaner Production* 262 (July): 121105. Available at: https://doi.org/10.1016/J.JCLEPRO.2020.121105 (February 1, 2025).

24. Metro de Madrid. 2024a. *Accesibilidad Universal de Las Estaciones de Metro Para Personas Con Movilidad Reducida.* Available at: https://www.metromadrid.es/es/accesibilidad#panel1 (January 28, 2025).
25. ———. 2024b. *Metro de Madrid En Cifras.* Available at: https://www.metromadrid.es/es/quienes-somos/metro-de-madrid-en-cifras (February 1, 2025).
26. Metropolitan Sofia. 2024. *Operating Metro Sofia.* Available at: https://www.metropolitan.bg/en/scheme/operating-metro (February 1, 2025).
27. Monzón, Andrés, Cristina López, Ramón Del Cuvillo, Allison Fernández, Marta Fernández, and Silvia Hernández. 2024. *Informe Observatorio de la Movilidad Metropolitana 2022 - Avance 2023*. Madrid. Available at: https://publicaciones.transportes.gob.es (January 29, 2025).
28. National statistical institute. 2022. *Registered Noise Levels by District and Town.* Available at: https://www.nsi.bg/en/content/2574/registered-noise-levels-district-and-town (January 30, 2025).
29. National Statistical Institute Bulgaria. 2024a. *Births by Place of Residence, Statistical Regions, Districts and Sex. Available* at: https://www.nsi.bg/en/content/2956/births-place-residence-statistical-regions-districts-and-sex (January 30, 2025).
30. ———. 2024b. *Migration of the Population by Districts, Municipalities and Sex.* Available at: https://www.nsi.bg/en/content/3060/migration-population-districts-municipalities-and-sex (January 30, 2025).
31. National Statistical Institute Bulgaria, Infostat. 2024. *Population by cities in Bulgaria.* Available at: https://infostat.nsi.bg/infostat/pages/reports/result.jsf?x_2=1089 (January 9, 2025).
32. National Statistical Institute, and Ministry of Interior of Bulgaria. 2024. *Road Traffic Accidents in Bulgaria 2023*. Available at: https://www.nsi.bg/en/publications/road-traffic-accidents-in-the-republic-of-bulgaria-2023-2254 (January 30, 2025).
33. Portal de datos abiertos del Ayuntamiento de Madrid. 2022. *BiciMAD. Alta de Usuarios y Usos Por Día Del Servicio Público de Bicicleta Eléctrica.* Available at: https://datos.madrid.es/portal/site/egob (February 1, 2025).
34. ———. 2024a. *Contaminación Acústica. Datos Históricos Mensuales.* Available at: https://datos.madrid.es/portal/site/egob (February 1, 2025).
35. ———. 2024b. *Superficie de Parques y Zonas Verdes de Madrid.* Available at: https://datos.madrid.es/portal/site/egob (February 1, 2025).
36. Ritchie, Hannah, Pablo Rosado, and Max Roser. 2020. *Greenhouse Gas Emissions.* Available at: https://ourworldindata.org/greenhouse-gas-emissions (January 29, 2025).
37. Sofia Municipality. 2024. *Low Emission Zones.* Available at: https://www.sofia.bg/low-emission-zones (January 26, 2025).
38. Sofia Municipality, and Infraproekt Konsult Ltd. 2019. *Sustainable Urban Mobility Plan for the City of Sofia 2035*.
39. Sofiaplan. 2021. *Open Data Portal Sofiaplan.* Available at: https://sofiaplan.bg/api/ (January 26, 2025).
40. Statista. 2023. *Europe: NO_2 Concentrations in Select Cities 2023 | Statista.* Available at: https://www.statista.com/statistics/1185973/no2-concentrations-in-select-cities-in-europe-covid-19/ (February 2, 2025).
41. Transport & Environment. 2019. *Low-Emission Zones Are a Success - but They Must Now Move to Zero-Emission Mobility*. Available at: https://www.transportenvironment.org/sites/te/files/publications/2019_09_Briefing_LEZ-ZEZ_final.pdf (January 9, 2025).
42. UN Department of Economic and Social Affairs. 2015. *2030 Agenda for Sustainable Development | SDGs.* Available at: https://sdgs.un.org/2030agenda (January 31, 2025).
43. United Nations. 2015. *The Paris Agreement | UNFCCC.* December. Available at: https://unfccc.int/process-and-meetings/the-paris-agreement (January 31, 2025).
44. World Health Organization (WHO). 2018. *Noise Guidelines for the European Region*. Available at: http://www.euro.who.int/pubrequest (January 30, 2025).
45. ———. 2021. *Air_qulity_Guidelines_WHO. 2021*. Available at: https://www.who.int/publications/i/item/9789240034228 (January 30, 2025).

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1.08 Objavljeni znanstveni prispevek na konferenci
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CHALLENGES AND OPPORTUNITIES IN DEVELOPING ESG STRATEGIES: A PATH TO CARBON NEUTRALITY ALIGNED WITH EU GUIDELINES

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ABSTRACT

ESG (Environmental, Social, and Governance) strategies have emerged as a cornerstone for corporate sustainability, driven by the urgency of achieving carbon neutrality by 2050 in line with European and global directives. This paper explores the multifaceted challenges organisations face when designing and implementing ESG strategies, emphasizing their alignment with EU regulations such as the Corporate Sustainability Reporting Directive (CSRD) and the EU taxonomy. These frameworks aim to standardise sustainability reporting and ensure the integration of ESG principles into core business practices. This study highlights key obstacles, including the complexity of collecting, analysing, and reporting reliable environmental and social data, as well as ensuring transparency and regulatory compliance. Additionally, it addresses the difficulties in establishing measurable environmental indicators and integrating them into decision-making processes. The lack of standardisation in ESG metrics across industries further complicates efforts to meet stakeholders' expectations. The article presents examples of best practices from organisations that have successfully navigated these challenges, offering insights into strategies for fostering collaboration among stakeholders, including management, employees, and supply chain partners. The findings underscore the importance of a holistic approach that balances environmental goals with social and governance considerations, ensuring long-term business resilience. This paper provides actionable recommendations and practical insights for organisations (universities, large companies, small and medium-sized enterprises (SMEs) striving to transition towards sustainable business models. It serves as a valuable resource for companies seeking to not only comply with regulatory demands but also to create meaningful impact through their ESG strategies, contributing to global sustainability goals. The paper addresses a research gap by transferring some of the extensive experience of large European companies that have set ambitious sustainability goals to the Slovene context. Best practices to achieve carbon neutrality by 2050 within the framework of the adopted European Green Deal are presented both for large enterprises and SMEs.

***Keywords**: ESG strategy, sustainability, carbon neutrality, EU directives, CSRD, transparency, taxonomy, best practices*

1 INTRODUCTION

Environmental, Social, and Governance (ESG) strategies have become pivotal for corporate sustainability in the 21st century. With the European Union (EU) aiming for carbon neutrality by 2050, ESG frameworks have been integrated into corporate agendas to meet both regulatory requirements and societal expectations. This paper examines the critical challenges and opportunities organisations face in developing ESG strategies, focusing on alignment with EU guidelines such as the Corporate Sustainability Reporting Directive (CSRD) (EU 2022) and the EU taxonomy (EU 2020). By analysing these frameworks, the paper underscores their role in standardising sustainability practices and driving progress toward global sustainability goals.

2 PURPOSE AND GOALS

This study aims to:

1. Identify the key challenges organisations face in developing and implementing ESG strategies.
2. Explore opportunities for improving ESG frameworks through alignment with EU directives.
3. Provide actionable recommendations for achieving carbon neutrality while ensuring regulatory compliance and stakeholder engagement.

The ultimate goal is to offer a comprehensive resource for diverse organisations—universities, large corporations, and micro, small and medium enterprises (SMEs)—to transition towards sustainable business models effectively.

3 METHODS

The research employs a mixed-methods approach, combining qualitative and quantitative analyses:

- Literature Review: Analysis of EU regulations, including the CSRD and EU taxonomy, to understand their impact on corporate sustainability practices.
- Case Studies: Examination of organisations (particularly the primary aluminium production) that have successfully implemented ESG strategies, highlighting best practices and lessons learned. Six sustainability reports from major aluminium producers within the EFTA region (Rio Tinto, Alcan, Hydro, Slovalco, Aluminium Dunkerque, Novelis) were reviewed, along with four sustainability reports from Slovenian companies (Petrol, Acroni, Impol, Cinkarna). Based on these experiences, a sustainability report, together with a taxonomy, was prepared for the aluminium producer in Kidričevo for the years 2022 and 2023.
- Interviews: Insights from industry experts, policymakers, and sustainability officers to identify real-world challenges and solutions. Between 2023 and 2024, several in-person interviews were conducted at four European Aluminium meetings, an association comprising more than 600 large companies engaged in aluminium production and processing. In addition, interviews were carried out with the largest companies in Slovenia through the Chamber of Commerce and Industry of Slovenia, covering the steel, paper, and glass industries. An interview with a representative of the Municipality of Kidričevo, where aluminium production takes place, was conducted as part of the process of obtaining the Aluminium Stewardship Initiative (ASI) standard, focusing on sustainability challenges in the social domain. Regarding sustainability investment, meetings were held with representatives of banks in Slovenia.
- Data Analysis: Evaluation of sustainability reports to assess the effectiveness of current ESG metrics and their alignment with regulatory requirements.

4 RESULTS

4.1 Challenges in Developing ESG Strategies

4.1.1 Data Collection and Reporting

Organisations face significant obstacles in gathering reliable environmental and social data with the goal of one-click data availability. Reporting requires information from different departments

in the company, locations or subsidiaries. The lack of standardised metrics and frameworks exacerbates the complexity, leading to inconsistencies in reporting. There has been a very significant increase in demand for corporate sustainability information in recent years, especially on the part of the investment community. That increase in demand is driven by the changing nature of risks to undertakings and growing investor awareness of the financial implications of those risks. That is especially the case for climate-related financial risks. There is also a growing awareness of the risks and opportunities for undertakings and for investments resulting from other environmental issues, such as biodiversity loss, and from health and social issues, including child labour and forced labour. The increase in demand for sustainability information is also driven by the growth in investment products that explicitly seek to meet certain sustainability standards or achieve certain sustainability objectives and to ensure coherence with the ambition of the Paris Agreement under the United Nations Framework Convention on Climate Change adopted on 12 December 2015 (the 'Paris Agreement'), the UN Convention on Biological Diversity and Union policies.

4.1.2 Regulatory Compliance

Ensuring alignment with evolving EU directives poses a challenge, particularly for SMEs with limited resources. Compliance with the CSRD requires extensive internal restructuring and investment in new technologies. Through the CSRD reporting obligation, the growing demand for transparent and reliable information about companies' performance in environmental, social, and governance (ESG) areas will be addressed. It replaces the Non-Financial Reporting Directive (NFRD) (EU 2014) in effect since 2014.

4.1.3 Stakeholder Engagement

Balancing the expectations of diverse stakeholders—including investors, employees, and supply chain partners—remains a significant hurdle. Misalignment among stakeholders can hinder effective ESG implementation.

4.1.4 Integration into Decision-Making

Establishing measurable environmental indicators and embedding them into strategic decision-making processes is another challenge. Many organizations struggle to quantify their environmental and social impacts in actionable terms. The company has to maximise the value of the data and track the targets over the years, monitor goals, measure key performance indicators (KPIs) and meet CSRD reporting obligations in the most optimal way. The IT departments in the companies are very much involved in that extensive and complex process and help with competitive advantages that increase the long-term profitability.

4.2 Reporting Obligations for Large Companies and SMEs

The companies have to evaluate financial risks and opportunities, as well as positive and negative impacts, from an inside-out and outside-in perspective. The first necessary step to the CSRD reporting obligation is the so-called Double Materiality Assessment, which involves plotting a graph to ensure that the company lays the foundation for a strategy and a report that will stand up to scrutiny. Currently, all large companies which have >500 employees and are publicly listed were already required to comply with NFRD. Starting in January 2025, large companies that meet two of the following three criteria will be affected: >250 employees, annual turnover of >€20 million or/and net revenue of >€40 million. The scope of this directive will be gradually extended over the coming years. Ultimately, this expansion will result in a reporting obligation for approximately 50,000 companies across the EU, including around 15,000 in Germany. Starting in January 2026, all publicly listed SMEs will be required to report if they exceeded two of the following three criteria: more than 10 employees, balance sheet total of more than €450,000 or a turnover of more than €900,000. Non-European companies are required to report by 2028 with the following conditions: a net turnover of more than €150 million € in the EU and at least one subsidiary or branch located within it.

4.2.1 EU Taxonomy and Relevant Regulations

The EU Taxonomy (Directive 2022/2464 (EU 2022), Regulation EU 2021/2178 (EC 2021), Regulation EU 2021/2139 (EC 2021), and Regulation EU 2020/852 (EU 2020)) provides a classification system for environmentally sustainable activities. It aims to:

- Ensure clarity and transparency in sustainability reporting.
- Establish criteria for determining whether an economic activity contributes substantially to environmental objectives, such as climate change mitigation and adaptation.
- Promote sustainable investments by providing investors with reliable information on environmentally friendly activities.

The EU Taxonomy establishes a common understanding of green economic activities that make a substantial contribution to EU environmental goals, by providing consistent, objective criteria. Together with the Corporate Sustainability Reporting Directive (CSRD) these two instruments will ensure that companies falling under the scope of the CSRD disclose the environmental performance information of the company as well as information about a company's Taxonomy-aligned economic activities. For financial products and financial entities, the Sustainable Finance Disclosure Regulation (SFDR) has been applied from the 10th of March 2021. Compliance with sustainability-related disclosures is expected to have considerable behavioural effects on financial firms, and indirectly on the business models of companies that are being invested in. The green economic activities are defined according to six EU environmental objectives: climate change mitigation, climate change adaptation, sustainable use and protection of water and marine resources, transition to circular economy, pollution prevention and control, and protection and restoration of biodiversity and ecosystems. It also sets out four conditions that an economic activity has to meet to be recognised as Taxonomy-aligned: making a substantial contribution to at least one environmental objective, doing no significant harm to any other environmental objective, complying with minimum social safeguards and complying with the technical screening criteria. According to Delegated regulation (EU) 2021/2178 (EC 2021), the companies should prepare the data and calculate the proportion of turnover, capital expenditure (*CapEx*) and operational expenditure (*OpEx*) from products or services associated with taxonomy-aligned economic activities for a certain year (templates for the KPIs of non-financial undertakings in Annex II).

4.2.2 Obligations for Large Companies

Large companies are required to disclose detailed information on their environmental performance and social impact under the Corporate Sustainability Reporting Directive (CSRD). This includes:

- Adherence to the EU taxonomy's criteria for sustainable activities.
- Comprehensive reporting on environmental, social, and governance metrics using eleven (11) European Sustainability Reporting Standards (ESRS) outlined in Regulation EU 2023/2772 (EC 2023).
- Alignment with global sustainability goals, including the *United Nations Sustainable Development Goals (SDGs)* (UN 2015a).
- Reporting on their carbon footprint (ESRS E1), which includes measuring, managing, and reducing greenhouse gas (GHG) emissions across Scope 1, Scope 2, and Scope 3 categories.

Two ESRS standards are related to general requirements and disclosures (ESRS 1&2), five standards (ESRS E1 to E5) to environmental issues (climate change, pollution, water & marine resources, biodiversity and ecosystems, and resource use and circular economy), four standards (ESRS S1 to S4) to social demand (own workforce, workers in the value chain, affected communities, consumers and end-users) and one standard (ESRS G1) to business conduct. EFRAG develops with industry experts sector-specific standards (agriculture, livestock, fisheries, mining, energy and utilities, food, transportation, etc.) and will be released later.

Articles 19a and 29a of Directive 2013/34/EU (EU 2013) apply to large undertakings that are public-interest entities with an average number of employees in excess of 500, and to public-interest entities that are parent undertakings of a large group with an average number of employees in excess of 500 on a consolidated basis, respectively. The obligation for large companies according to CSRD directive will start by the 30th of September 2025.

4.2.3 Obligations for SMEs

While SMEs face less stringent requirements, they are encouraged to adopt simplified reporting practices that align with the EU taxonomy. Key obligations include:

- Providing concise disclosures on their contributions to environmental objectives.
- Demonstrating alignment with selected ESRS standards.
- Participating in capacity-building initiatives to improve their reporting capabilities and meet stakeholder expectations.
- Reporting on value chain emissions (upstream and downstream) to provide a complete picture of their environmental impact.

The sustainability reporting standards for small and medium-sized undertakings will constitute a reference for undertakings that are within the scope of the requirements introduced by the amending Directive EU 2022/2464 regarding the level of sustainability information that they could reasonably request from small and medium-sized undertakings that are suppliers or clients in the value chains of such undertakings. Small and medium-sized undertakings whose securities are admitted to trading on a regulated market in the Union should, in addition, be given sufficient time to prepare for the application of the provisions requiring sustainability reporting, due to their smaller size and more limited resources, and taking account of the difficult economic circumstances created by the Covid-19 pandemic. Therefore, the provisions on corporate sustainability reporting with regards to small and medium-sized undertakings, except micro undertakings, whose securities are admitted to trading on a regulated market in the Union should apply for financial years starting on or after the **1st of January 2026**. Following that date, for a transitional period of **two years**, small and medium-sized undertakings whose securities are admitted to trading on a regulated market in the Union should have the possibility of opting-out from the sustainability reporting requirements laid down in this amending Directive, provided they briefly state in their management report why the sustainability information has not been provided. Member States should consider introducing measures to support small and medium-sized undertakings in applying the sustainability reporting standards.

4.3 Reporting Requirements for Carbon Footprint (ESRS E1)

Under ESRS E1, companies have to:

- Measure and report their greenhouse gas (GHG) emissions, categorized into:
  - Scope 1: Direct emissions from owned or controlled sources.
  - Scope 2: Indirect emissions from the generation of purchased electricity, steam, heating, and cooling.
  - Scope 3: All other indirect emissions occurring in the value chain, including upstream and downstream activities (logistic).
- Set science-based targets for emissions reduction and outline the strategies for achieving these targets.
- Provide detailed disclosures on climate-related risks and opportunities, in alignment with the Task Force on Climate-related Financial Disclosures (TCFD).

Financial markets need clear, comprehensive, high-quality information on the impacts of climate change. This includes the risks and opportunities presented by rising temperatures, climate-related policy, and emerging technologies in our changing world. The Financial Stability Board (FSB) created the Task Force on Climate-related Financial Disclosures (TCFD) in 2015 to improve and increase reporting of climate-related financial information (Financial Stability Board 2015). TCFD are structured around four thematic pillars that represent core elements of how organizations operate: governance, strategy, risk management, and metrics and targets.

If the company imports certain products as part of European emissions trading, they have to fulfil the requirements of the CO_2 Carbon Border Adjustment Mechanism (CBAM) as well. The EU CBAM (EU 2023) is a carbon tariff on carbon intensive products in six sectors, such as aluminium, cement, electricity, fertilisers, hydrogen, and iron and steel. The period from 1st October 2023 to the end of December of 2025 will constitute a transitional phase, in which the importers of products into EU

will need to report their emissions. During that phase, the regulators will check if other products can be added to the list – e.g. some downstream products. From the beginning of 2026, importers of products included in these 6 sectors will begin to pay a border carbon tax for their products based on the price of allowances in the EU Emissions Trading System (ETS) (EU 2003). By 2023 all sectors covered by the EU ETS will be covered by CBAM. By 2034, free allowances in the relevant sectors in the EU will be phased out as the fully implemented CBAM ensures a level playing field for European companies in comparison to importers.

4.4 Reporting on Value Chain (Upstream and Downstream) Impacts

To ensure comprehensive sustainability reporting, organizations are required to:

- Analyse and disclose emissions and other environmental impacts across the value chain.
- Upstream Activities: Include emissions from suppliers, production, and logistics.
- Downstream Activities: Cover emissions from product use, end-of-life treatment, and distribution.
- Collaborate with stakeholders across the value chain to collect accurate data and implement measures for reducing the overall carbon footprint.

4.5 Alignment with United Nations Goals and Principles

The integration of ESG strategies must align with the United Nations' 17 Sustainable Development Goals (SDGs) (UN 2015b), focusing on:

- Climate Action (Goal 13)
- Responsible Consumption and Production (Goal 12)
- Decent Work and Economic Growth (Goal 8)

Additionally, organizations should adhere to the *UN Global Compact's Ten Principles (UN 2000)*, which emphasize:

1. Human rights.
2. Labour standards.
3. Environmental protection.
4. Anti-corruption measures.

4.6 Opportunities in ESG Implementation

4.6.1 Technological Advancements

Innovations in data analytics, blockchain, and artificial intelligence offer opportunities to enhance transparency and accuracy in ESG reporting.

4.6.2 Stakeholder Collaboration

Collaborative initiatives among governments, NGOs, and private sectors can facilitate knowledge sharing and resource optimization, addressing common challenges.

4.6.3 Financial Incentives

Access to green financing and subsidies provided by EU frameworks encourages investment in sustainable practices.

4.6.4 Long-Term Business Resilience

Adopting a holistic ESG approach ensures resilience against market disruptions, fostering trust among stakeholders and enhancing corporate reputation.

5 DISCUSSION

The findings highlight the intricate interplay between regulatory compliance and organisational capabilities. The lack of standardised metrics across industries underscores the need for harmo-

nised frameworks to ensure consistency and comparability. Furthermore, the role of leadership in driving ESG integration emerges as a critical factor. Effective communication and collaboration among stakeholders are essential for overcoming resistance and fostering a shared commitment to sustainability goals. The aluminium industry in the EU and Slovenia exemplifies these challenges, particularly in the context of the green transition. High energy consumption and reliance on non-renewable energy sources make decarbonisation efforts particularly challenging. Companies must invest significantly in green technologies, including renewable energy sources and energy-efficient production processes, to meet ESG requirements. However, these investments also present opportunities for leadership in sustainability and long-term cost savings. A noteworthy example is the publication of sustainability reports combined with green investments presented with turnover, CapEx and OpEx for 2023 (Talum d. d. 2024). for products and services of a primary aluminium company, showcasing transparency and commitment to sustainable practices which has already made huge steps from primary to secondary aluminium production.

These reports highlight how targeted investments in renewable energy and circular economy practices can drive meaningful progress. The analysis also reveals that while larger corporations have the resources to adapt to regulatory demands, SMEs require tailored support mechanisms to bridge gaps in expertise and funding. The importance of leveraging technological tools and fostering a culture of innovation cannot be overstated, as these elements drive efficiency and effectiveness in ESG implementation.

6 CONCLUSION

This paper underscores the urgency of developing robust ESG strategies aligned with EU guidelines to achieve carbon neutrality by 2050. By addressing challenges such as data collection, regulatory compliance, and stakeholder engagement, organizations can unlock opportunities for sustainable growth and resilience. The actionable recommendations provided serve as a roadmap for entities across various sectors to transition toward sustainable business models, contributing to global sustainability goals.

6.1 Recommendations

A) Enhance Data Standardisation: Develop industry-specific guidelines for ESG metrics to improve reporting consistency.
B) Leverage Technology: Invest in digital tools for real-time data analysis and reporting.
C) Foster Stakeholder Collaboration: Establish platforms for dialogue among stakeholders to align goals and expectations.
D) Tailor Support for SMEs: Provide targeted funding and training programs to assist smaller organizations in meeting regulatory requirements.
E) Promote Leadership Commitment: Encourage leadership to champion ESG initiatives, fostering a culture of sustainability.

REFERENCES

1. European Commission (EC). 2021. *Commission Delegated Regulation (EU) 2021/2178*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2178 (August 18, 2025)
2. European Commission (EC). 2021. *Commission Delegated Regulation (EU) 2021/2139*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R2139 (August 18, 2025)
3. European Commission (EC). 2023. *Commission Delegated Regulation (EU) 2023/2772 (ESRS)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302772 (August 18, 2025)
4. European Union (EU). 2003. *Directive 2003/87/EC of the EU Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas (GHG) emission allowance trading within the EU and amending Council Directive 96/61/EC (ETS)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02003L0087-20240301 (August 18, 2025)
5. European Union (EU). 2013. *Directive 2013/34/EU*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013L0034 (August 18, 2025)
6. European Union (EU). 2014. *Directive 2014/95/EU of the EU Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups (NFRD)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0095 (August 18, 2025)
7. European Union (EU). 2019. *Regulation (EU) 2019/2088 of the EU Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (SFDR)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R2088 (August 18, 2025)
8. European Union (EU). 2020. *Regulation (EU) 2020/852 of the EU Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0852 (August 18, 2025)
9. European Union (EU). 2022. *Directive 2022/2464 on Corporate Sustainability Reporting (CSRD)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022L2464 (August 18, 2025)
10. European Union (EU). 2023. *Regulation (EU) 2023/956 of the EU Parliament and the Council of 10 May 2023 establishing a carbon border adjustment mechanism (CBAM)*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R0956 (August 18, 2025)
11. Financial Stability Board (FSB). 2015. *Task Force on Climate related Financial Disclosures (TCFD)*. Available at: https://www.fsb-tcfd.org/ (August 18, 2025)
12. United Nations (UN). 2000. *United Nations Global Compact's Ten Principles*. Available at: https://unglobalcompact.org/what-is-gc/mission/principles (August 18, 2025)
13. United Nations (UN). 2015a. *Sustainable Development Goals (SDGs)*. Available at: https://sdgs.un.org (August 18, 2025)
14. United Nations (UN). 2015b. *United Nations' 17 Sustainable Development Goals (DSGs)*. Available at: https://sdgs.un.org/goals (August 18, 2025)
15. Talum d. d. 2024. *Sustainable development report of Group Talum for 2023*. Available at: https://www.talum.si/pdf/trajnost/PORO%C4%8CILO%20O%20TRAJNOSTNEM%20RAZVOJU%202023%20slo%20z%20linki_WEB.pdf (August 18, 2025)

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1.09 Objavljeni strokovni prispevek na konferenci
Published professional conference contribution

THE IMPACT OF EU REGULATIONS ON STAKEHOLDER ROLES IN BALTIC FOOD SYSTEMS

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ABSTRACT

The food systems of Estonia, Latvia, and Lithuania are increasingly influenced by European Union (EU) regulations, which set frameworks for food safety, sustainability, and fair market practices. While these regulations aim to promote uniformity and sustainability across member states, their impact on stakeholders in the Baltic food systems remains under-explored. This study investigates the integration of stakeholders in the implementation of EU sustainability policies within Baltic food systems, emphasising the Common Agricultural Policy (CAP) 2023–27. Through the analysis of EU and national strategic documents and stakeholder representation data, the research highlights the roles of diverse actors, including policymakers, farmers, organisations, and consumers. Results reveal variations in stakeholder engagement across Lithuania, Latvia, and Estonia, emphasising challenges and opportunities in achieving sustainability goals. By identifying gaps in multi-level governance, the study offers recommendations for effective stakeholder collaboration and outlines directions for future research.

***Keywords**: Baltic food systems, Common Agricultural Policy, food policy, sustainability labelling, agricultural policies, rural development, policy implementation*

1 INTRODUCTION

The Baltic region comprising Estonia, Latvia, and Lithuania presents a distinct and evolving landscape for food systems management. As part of the European Union, the Baltic states operate within frameworks such as the CAP, the European Green Deal, and the Farm to Fork Strategy. Their agricultural sectors, characterised by smallholder farming and regional specialisation, play a critical role in both local economies and cross-border supply chains.

There are several approaches to understanding the implementation of European regulations in the food systems: Stakeholder Theory, Institutional Theory, and Regulatory Compliance Frameworks (Fernando and Lawrence 2014, 152; Prager and Freese 2009).

Stakeholder Theory emphasises the importance of involving all stakeholders in decision-making processes to ensure inclusive and sustainable policy implementation, particularly in complex multi-level governance systems like those in the Baltic region. Institutional Theory examines the influence of formal and informal rules, norms, and practices on stakeholders' behaviour. In the context of EU food policy, it helps to understand how local institutions in Estonia, Latvia, and Lithuania align with or adapt to EU regulations. Regulatory Compliance Frameworks refers to the systems and processes that organisations use to ensure they meet legal, environmental, and policy standards.

1.1 Strategic Policies

A significant development shaping the region's food systems is the adoption of the new CAP 2023–27, which came into force on January 1, 2023. This framework is a cornerstone of EU agricultural reform, aiming to align food systems with the European Green Deal, the Farm to Fork Strategy, and the Biodiversity Strategy. On September 6, 2022, the European Commission implemented Regulation (EU) 2022/1475, introducing a unified system for monitoring and evaluating CAP Strategic Plans. This regulatory effort ensures harmonised data collection across the EU.

Each Baltic state has developed a unique CAP Strategic Plan tailored to its specific agricultural and rural development needs. Lithuania's plan emphasises the expansion of organic farming, with a goal to increase organic agricultural land to 20% by 2030, while integrating renewable energy initiatives across the farming sector. Latvia focuses on strengthening its small and medium-sized farms by providing targeted subsidies and fostering innovation in agricultural practices. Estonia prioritises digitalisation and sustainability, leveraging advanced technologies to improve productivity and supply chain transparency while reducing environmental impacts.

The Baltic states as a region have demonstrated collaborative governance approaches to EU food policy implementation, especially through multi-stakeholder engagement platforms. The Baltic countries are making progress in harmonising food sustainability goals with EU policies. Baltic countries share common food system challenges such as sustainable production, food security, and rural development and are increasingly working together to address these issues (Liva and Zvirbule 2024). However, the authors caution that while regional cooperation has proven effective, the challenge remains in maintaining this cooperation long-term and ensuring the representation of all relevant stakeholders (OECD 2003, 156).

1.2 Gaps and Limitations

The gaps in understanding the long-term impacts of these policies and the challenges of maintaining multi-stakeholder collaboration include the limited exploration of the role of large agribusinesses in shaping food system policies, and insufficient research on the engagement of small-scale farmers, particularly in rural areas, in policy implementation (El Benni et al. 2023). There is a lack of studies examining the long-term impacts of EU food policies on stakeholder dynamics and sustainability outcomes. Cross-border cooperation between the Baltic States, while acknowledged, has not been fully explored in terms of the barriers to effective collaboration, such as differing national priorities and economic disparities.

The research focus on how these stakeholders, including farmers, local authorities, and environmental groups, collaborate to meet EU sustainability objectives.

It also assess the effectiveness of multi-stakeholder governance frameworks, identify gaps in engagement, and provide recommendations for improving the implementation of EU food policies in the region.

This study has several limitations. The reliance on secondary data limits the ability to capture real-time stakeholder perspectives and on-the-ground challenges. Variations in data availability across Estonia, Latvia, and Lithuania may have influenced the depth of analysis for certain indicators. The study primarily focuses on established CAP strategies and may not fully account for evolving policy dynamics or innovations introduced after 2023.

2 METHODOLOGY

This research adopts a qualitative research paradigm to explore the roles of stakeholders in the implementation of EU agricultural policies, specifically the Common Agricultural Policy (CAP), within the food systems of the Baltic States (Estonia, Latvia, and Lithuania). The study relies on secondary data analysis of key policy documents, national strategic plans, and relevant case studies to examine stakeholder involvement and the impact of EU regulations. Data was gathered through document analysis. The study relies on an in-depth analysis of key policy documents, including EU regulations, CAP Strategic Plans for each Baltic state, and national agricultural policies. The analysis focuses on identifying the roles and responsibilities assigned to stakeholders in policy. Stakeholder Mapping involves identifying and categorising key actors within the food systems of each Baltic state (Atkočiūnienė et al. 2022). Comparative Analysis examines similarities and differences in stakeholder engagement, financing and policy implementation across Estonia, Latvia, and Lithuania. By comparing these national approaches, the research aims to identify patterns of effective governance, shared obstacles, and opportunities for cross-border collaboration. The research adheres to ethical standards by exclusively using publicly available data and ensuring proper attribution to all sources. No confidential or sensitive data will be used, and the analysis respects the intellectual property rights of cited materials.

3 RESULTS

The CAP 2023-2027 has been instrumental in shaping the agricultural and sustainability efforts within the Baltic States. Its implementation reflects both the shared goals and the unique priorities of Estonia, Latvia, and Lithuania.

3.1 Financial Allocations Across the Baltic States

Latvia has been allocated €2.5 billion, with a significant portion directed toward direct payments and rural development The funding distribution includes €1.7 billion for direct payments, €791 million for rural development measures, and €10 million for market support measure (European Commission 2022). Lithuania's CAP Strategic Plan has a total budget of €4.2 billion for the same period. Approximately €3 billion is allocated for income support, with a focus on fair incomes for farmers. Additionally, more than 4,600 young farmers will be supported to set up and receive additional aid, Estonia's CAP Strategic Plan has a budget of €1.6 billion for 2023–2027. Of this, €456 million is dedicated to achieving environmental and climate goals, and €340 million is allocated for rural development. This table provides a clear overview of each country's CAP allocation and funding distribution during the 2023-2027 period.

Table 1: Comparative Distribution of Common Agricultural Policy (CAP) 2023–2027 Funds in Estonia, Latvia, and Lithuania

Category	Estonia	Latvia	Lithuania
Total CAP Budget (2023–2027)	€1.4 billion	€2.5 billion	€3.9 billion
Direct Payments	€1 billion (71.4%)	€1.7 billion (68%)	€2.2 billion (56%)
Eco-Scheme Budget	€279.4 million (27.7% of direct payments)	€438.1 million (25.6% of direct payments)	€753.1 million (25% of direct payments)
Rural Development	€0.6 billion (42.8%)	€0.8 billion (32%)	€1.7 billion (44%)
Focus on Young Farmers	€15 million for young farmer installation and rural business startups	€41.9 million allocated for young farmer support (5.6% of rural development budget)	€72.8 million dedicated to generational renewal (7.8% of rural development budget)
Biodiversity Commitments	23.27% of UAA under organic farming	34.82% of UAA under reduced pesticide use commitments	12.84% of UAA under organic farming
Climate Change Mitigation	79.2% of UAA committed to carbon storage	38.48% of UAA committed to carbon storage	28.21% of UAA committed to carbon storage
Modernization and Digitalization	6.17% of farms modernized	16.36% of farms modernized	1.27% of farms modernized
LEADER Coverage (Local Development)	95.95% of rural population	100% of rural population	100% of rural population
Rural Job Creation	1,249 new rural jobs supported by CAP projects	1,739 new rural jobs supported	4,680 new rural jobs supported
Environmental Investment	€170.8 million for environmental and climate-related investments	€213.7 million for sustainable investments (33% of rural development)	€362.5 million for environmental investments (39% of rural development)

(Source: Author's compilation based on European Commission (2023))

In recent years, a mandatory component of every strategic plan has been a strong focus on digitalisation, aimed at simplifying and accelerating processes of change and development. Digital innovations, such as precision farming tools, IoT systems, and drones, are now transforming agriculture in the Baltic States (Critelli et al. 2023). Latvia has 16.36% of farms expected to adopt digital farming technologies by 2025. Lithuania excels in integrating smart-village strategies into its rural development plans, which aim to enhance connectivity, support IoT-based farming solutions, and create sustainable rural economies. Estonia leverages its robust digital infrastructure to advance precision farming and improve supply chain transparency.

The number of organisations specialising in this field is steadily growing. A prime example of policy implementation can be seen in Estonian companies like Paul-Tech, which specialise in precision farming technologies (Invest in Estonia 2023). While their primary focus is on soil monitoring, the integration of drone technology complements these precision tools by providing aerial insights into crop health and field conditions, enhancing productivity and sustainability.

3.2 Stakeholders Engagement

Each stakeholder group contributes uniquely to implementing policy objectives, fostering sustainable development, and addressing specific regional challenges. Mutual stakeholders in the Baltic region include government institutions, farmer organisations, environmental NGOs, academic and research institutions, civil society organisations, private sector entities, EU institutions, and consumers.

Government institutions, such as Ministries of Agriculture in each Baltic state lead CAP implementation by drafting national strategic plans, monitoring progress, and allocating funding. For example, in 2023, Latvia allocated €1.3 billion for CAP projects, with 40% dedicated to eco-schemes and environmental sustainability programs. Local municipalities also play a critical role, distributing rural development funds to small and medium-sized farmers while addressing region-specific needs.

Farmer organisations and cooperatives, such as the Latvian Farmers' Federation and the Estonian Chamber of Agriculture and Commerce, represent agricultural stakeholders' interests and provide critical support in navigating CAP funding mechanisms. These bodies have organised over 150 workshops in 2023, helping farmers understand eco-schemes, renewable energy initiatives, and direct payment procedures. Funding support varies, but the Lithuanian Agricultural Advisory Service reportedly secured €25 million for capacity-building programs.

Environmental NGOs, like the Estonian Fund for Nature and the Lithuanian Green Policy Institute ensure that CAP projects align with biodiversity and sustainability goals. These organisations actively monitor the environmental outcomes of CAP projects. For example, Latvian environmental groups collaborated on a €5 million project to restore wetlands in 2023, contributing to climate change mitigation efforts.

Academic and research institutions in the Baltic region contribute through data-driven analysis and stakeholder capacity building. The Estonian University of Life Sciences, for instance, led a €2 million EU-funded project in 2023 to assess digital agriculture's role in achieving CAP objectives, which has already influenced policy adjustments. The Lithuanian Research Centre for Agriculture and Forestry (LAMMC) focuses on developing innovative, research-based products and technologies to enhance agricultural practices.

Civil Society Organisations (CSOs) in the Baltic States play a pivotal role in promoting social inclusion, advocating for marginalised groups, and identifying systemic barriers within the agricultural sector. In Estonia, CSOs have access to various foreign funding opportunities, including the European Commission's Citizens, Equality, Rights and Values program, and the Active Citizens Fund, supported by the European Economic Area and Norway. the Estonian Organic Farming Foundation (EOFF) has been instrumental in promoting sustainable agricultural practices among smallholder farmers. In Latvia, it is the Latvian Rural Forum that focuses on empowering rural communities by facilitating access to CAP funds.

Agribusinesses and supply chain actors contribute to CAP objectives by investing in advanced technologies and promoting sustainable practices. For example, a Latvian agribusiness firm invested €10 million in digital supply chain technologies in 2023, aligning with the CAP priority of improving transparency and efficiency. Initiatives like the Agrifood Forum 2024 aim to expand digital infrastructure in rural areas, build capacity, and encourage micro-entrepreneurship within the agrifood value chain.

The European Commission that approved the CAP Strategic Plans of Estonia and Latvia, European Committee of the Regions that consist of local and regional representatives, including Estonia, Latvia, and Lithuania, who ensures that the interests of their regions are represented in EU decision-making processes.

4 DISCUSSION

EU food policies, particularly the CAP, have long-term implications for stakeholder dynamics and sustainability. The emphasis on large-scale production has led to increased consolidation of farms, potentially sidelining smallholders. This trend raises concerns about the sustainability of rural communities and environmental health (Röder et al. 2024). Recent policy shifts aim to address these issues by promoting eco-schemes and sustainable practices. The CAP includes measures aimed at supporting small farms, but the effectiveness of these measures varies. Critics argue that the CAP's subsidy structure tends to favour larger farms, as payments are often linked to the amount of land owned, leading to a concentration of benefits among large agribusinesses. Their substantial resources and influence enable them to lobby effectively for favourable terms, often resulting in policy frameworks that disproportionately benefit large-scale operations. In this context, it is necessary to clarify the terms of adopted plans in each country, which are permitted in response to the unpredictability of weather conditions and economic uncertainty. For example, Latvia approved amendments to simplify farmer registration, revise conditions of good agricultural and environmental standards, and expand opportunities to receive eco-scheme support, among other changes.

Challenges remain in effectively integrating consumer perspectives into CAP processes. Limited direct participation mechanisms and varying levels of consumer awareness about CAP's impact can hinder meaningful engagement. Studies have shown that consumer preferences in the Baltic States are shifting towards sustainably produced and locally sourced food products (Rocchi et al. 2022). Additionally, consumer advocacy groups in the region have been active in raising awareness about food quality and safety standards, influencing policy discussions related to CAP. Their engagement ensures that consumer interests are considered in the formulation and implementation of agricultural policies.

The European Court of Auditors (ECA) has raised concerns about the alignment of the European Union's Common Agricultural Policy (CAP) with the environmental and climate objectives outlined in the EU Green Deal. In their special report, the ECA concluded that while the CAP Strategic Plans for 2023-2027 are greener than in previous periods, they do not fully match the EU's ambitions for climate and environmental sustainability (European Court of Auditors 2024). The ECA recommends that the European Commission promote exchanges of good practices in eco-schemes, estimate the CAP's contribution to the Green Deal's environmental and climate targets, and strengthen the future CAP monitoring framework for climate and environmental outcomes.

5 CONCLUSION

The study confirms that CAP 2023–2027 has a transformative impact on the Baltic States, fostering sustainable agricultural practices and enhancing stakeholder collaboration. The alignment of national strategies with EU sustainability objectives, such as the European Green Deal and the Farm to Fork Strategy, demonstrates the region's commitment to addressing environmental challenges, promoting rural development, and ensuring food security. Despite these advancements, challenges persist, including regional disparities in resource allocation, uneven adoption of digital technologies, and gaps in stakeholder engagement, particularly for small-scale farmers and marginalised groups.

To fully realise the potential of CAP, a multifaceted approach is required. Integrating advanced digital technologies such as IoT, drones, and artificial intelligence can accelerate innovation and increase productivity across the agricultural sector. Promoting inclusivity by tailoring support mechanisms to the needs of smallholders and rural communities will ensure that benefits are equitably distributed. Strengthening governance frameworks, including better monitoring and evaluation mechanisms for Green Deal targets, will enhance transparency and accountability in CAP implementation.

Collaborative initiatives, such as knowledge-sharing platforms and joint investments in sustainable infrastructure, can help overcome shared challenges while reinforcing the region's resilience in the face of global economic and environmental uncertainties.

Future research should prioritise examining the long-term impacts of CAP on stakeholder dynamics and sustainability outcomes. Additionally, exploring innovative policy tools and emerging trends, such as the integration of artificial intelligence and precision farming techniques, can provide insights to further optimise agricultural practices. By addressing these areas, the Baltic States can strengthen their leadership in sustainable agriculture, setting an example for other EU member states and contributing to a more sustainable and equitable global food system.

REFERENCES

1. Atkočiūnienė, Vilma, Gintarė Vaznonienė, and Ilona Kiaušienė. 2022. The Role and Functions of Stakeholders in the Development of Local Food Systems: Case of Lithuania. *European Countryside* 14 (3): 511–539. https://doi.org/10.2478/euco-2022-0026.
2. Critelli, Lt. Col. Jamie A., Maj. Gustavo F. Ferreira, Bill Erysian, and Lynn Williams. 2023. NATO's Most Vulnerable Flank, but Not for the Reasons We Think. *Military Review*. https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/July-August-2024/NATOs-Flank/
3. El Benni, Nadja, Christian Grovermann, and Robert Finger. 2023. Towards More Evidence-Based Agricultural and Food Policies. *Q Open* 3 (3): qoad003. https://doi.org/10.1093/qopen/qoad003.
4. European Commission. 2022. *Regulation (EU) 2022/1475 of 6 September 2022 on Monitoring and Evaluating CAP Strategic Plans. Official Journal of the European Union*, L 234: 1-15.
5. European Commission. 2023. C*ommon Agricultural Policy* 2023-27 Strategic Plans. Accessed January 15, 2025. https://ec.europa.eu/agriculture/cap-my-country.
6. European Court of Auditors. 2024. *Special Report on the CAP and Green Deal Alignment*. Luxembourg: Publications Office of the European Union. Accessed January 11, 2025. https://www.eca.europa.eu/en/publications/SR-2024-20.
7. Fernando, Susith, and Stewart Lawrence. 2014. A Theoretical Framework for CSR Practices: Integrating Legitimacy Theory, Stakeholder Theory, and Institutional Theory. *Journal of Theoretical Accounting Research* 10(1): 149-178.
8. Invest in Estonia. 2023. Estonian Precision Agriculture Startup Paul-Tech Raises €1.4M. Last modified September 14, 2023. Accessed January 10, 2025. https://paul-tech.com/estonian-precision-agriculture-startup-paul-tech-raises-e1-4m-to-equip-farmers-with-real-time-soil-insights/.
9. Liva, Diana, and Andra Zvirbule. 2024. Transitioning towards sustainable agriculture in the Baltic countries – Strategic and regulatory framework assessment. *Proceedings of the 2024 International Conference "Economic Science for Rural Development"* 58: 20–31. https://doi.org/10.22616/ESRD.2024.58.002.
10. OECD. 2003. Agricultural and Rural Development Policies in the Baltic Countries: Lithuania, Latvia, Estonia. *OECD Publishing*. https://doi.org/10.1787/9789264104297-en.
11. Prager, Katrin, and Jan Freese. 2009. Stakeholder involvement in agri-environmental policy making – Learning from a local- and a state-level approach in Germany. J*ournal of Environmental Management* 90(2): 1154–1167. https://doi.org/10.1016/j.jenvman.2008.05.005.
12. Rocchi, Lucia, Anastasija Novikova, and Bernardas Vaznonis. 2022. Assessing Consumer Preferences and Willingness to Pay for Agricultural Landscape Attributes in Lithuania. *Land* 11(10): 1620. https://doi.org/10.3390/land11101620.
13. Röder, Norbert, Christine Krämer, Regina Grajewski, Sebastian Lakner, and Alan Matthews. 2024. What is the environmental potential of the post-2022 common agricultural policy? *Land Use Policy* 144(C): 107219. https://doi.org/10.1016/j.landusepol.2024.107219.

1.08 Objavljeni znanstveni prispevek na konferenci
Published scientific conference contribution

HEMP AS A SUSTAINABLE BUILDING MATERIAL: REDUCING CARBON FOOTPRINT AND ENHANCING CARBON SEQUESTRATION

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ABSTRACT

The construction industry remains one of the leading contributors to global carbon emissions and largest generator of solid waste worldwide, with traditional materials such as concrete and steel imposing significant environmental costs. In the pursuit of sustainable alternatives, industrial hemp has emerged as a promising bio-based building material. This review synthesizes current research on hemp-based construction products, particularly hempcrete, and evaluates their potential to reduce the carbon footprint. Hemp's rapid growth, low-input cultivation, and ability to sequester atmospheric CO_2 during its life cycle position it as both a renewable resource and a passive carbon sink. Furthermore, materials such as hempcrete not only store carbon within building envelopes but also offer advantageous thermal, hygroscopic, and fire-resistant properties, contributing to long-term energy efficiency. Life cycle assessments consistently demonstrate that hemp-based materials can achieve net carbon negativity, especially when integrated with lime binders that carbonate over time. Despite these benefits, barriers such as regulatory limitations, scalability issues, and cost competitiveness remain challenges to widespread adoption. This paper critically reviews existing literature, and material performance data to assess the viability of hemp in sustainable construction and outlines pathways for its integration into mainstream building practices. The findings underscore hemp's potential role in advancing low-carbon, regenerative architecture.

Keywords: *carbon footprint, hempcrete, carbon sequestration, sustainable building*

1 INTRODUCTION

The building and construction sector is a significant contributor to global climate change and environmental degradation. According to the European Commission, construction activities are responsible for approximately 40 percent of total energy consumption and generate more than 50 percent of total waste within the European Union (European Commission, 2025). Furthermore, the sector accounts for nearly 40 percent of global carbon dioxide (CO_2) emissions, primarily due to the high embodied carbon in traditional materials such as concrete, steel, and brick (United nations environmental programme, 2022). As the urgency to decarbonize the built environment grows, there is increasing interest in bio-based and regenerative materials that can reduce both operational and embodied emissions.

Among the emerging materials, industrial hemp (*Cannabis sativa* L.) has garnered significant attention for its potential to contribute to low-carbon construction. Hemp is a fast-growing, high-biomass crop that requires minimal pesticides, enriches soil health, and sequesters substantial quantities of CO_2 during its cultivation (Wei and Memari, 2025). When processed into construction-grade products such as hempcrete, fiber insulation, and hemp-lime composites, it offers a unique opportunity to store carbon within the built environment, while improving thermal performance and reducing resource dependency.

The European Industrial Hemp Association (EIHA) has strongly advocated for the recognition of hemp as a strategic resource in the transition toward climate-neutral construction. In its 2023 position paper, EIHA estimates that industrial hemp can sequester between 9 and 15 tonnes of CO_2 per hectare within a 4-5 month growing season (EIHA, 2023). When used in construction, the carbon storage is extended beyond the plant's lifecycle through incorporation in walls and insulation, particularly in hempcrete, which continues to absorb CO_2 as the lime binder carbonates over time (Pretot et al., 2014). This closed-loop carbon capture process positions hemp-based materials as one of the few viable options for carbon-negative building systems.

Numerous life cycle assessment (LCA) studies support these claims. Arrigoni et al. demonstrated that hemp-lime mixtures can store between –1.6 and –79 kg CO_2 equivalent per square meter, depending on binder ratios and wall thickness (Arrigoni et al., 2017). Similarly, a recent review by Steyn et al. consolidates two decades of data, confirming that properly designed hempcrete systems outperform traditional insulation in both thermal performance and environmental impact (Steyn et al., 2025). In addition to carbon benefits, hemp-based materials contribute to indoor air quality, regulate humidity, and offer fire resistance—traits that enhance their appeal for sustainable construction (Ip & Miller, 2012).

Despite its environmental and performance advantages, the adoption of hemp-based building systems remains limited due to regulatory barriers, inconsistent standards, and a lack of familiarity among architects and builders. The inclusion of hempcrete in the 2024 International Residential Code (IRC) represents a significant milestone toward wider acceptance, but further integration into national codes and mainstream supply chains is needed (Arrigoni et al, 2017).

This review aims to provide a comprehensive synthesis of the current state of knowledge on hemp as a sustainable building material. It evaluates the environmental, thermal, and structural performance of hemp-based products; reviews the carbon sequestration potential and life-cycle impacts; and explores challenges to market adoption. In doing so, it seeks to establish hemp's role in reshaping the material ecology of the built environment.

2 PURPOSE AND GOALS

The purpose of this review is to critically evaluate the potential of industrial hemp as a sustainable and carbon-negative building material, with particular emphasis on its carbon sequestration capacity, life cycle performance, and role in reducing the environmental impact of the construction industry. In light of increasing regulatory pressure to decarbonize the built environment and reduce construction waste, the review seeks to consolidate the existing body of knowledge on hemp-based building materials and assess their technical, environmental, and practical viability.

3 METHODS

This paper adopts a qualitative systematic review methodology grounded in an interpretivist paradigm, aiming to synthesize and interpret existing knowledge on hemp as a sustainable building material. The review included peer-reviewed academic articles, policy papers, technical reports, and industry white papers published between 2010 and 2025. Data was collected through a systematic search of academic databases including Scopus, Web of Science, ScienceDirect, and Google Scholar. Industry documents were retrieved from the official websites of EIHA, the European Commission, and relevant environmental and engineering bodies. The search used combinations of keywords such as "hempcrete", "industrial hemp in construction", "carbon sequestration building materials", "bio-based insulation", and "life cycle assessment of hemp". Themes were then synthesized across documents to identify consensus, divergence, and gaps in knowledge. No software was used for automated text analysis to preserve interpretive depth.

4 RESULTS

This review incorporates findings from 15 peer-reviewed academic sources, including original research and reviews (Table 1), and 5 policy and technical documents (Table 2) published by leading institutions such as the European Commission, UNCTAD, and the European Industrial Hemp Association (EIHA). Together, these sources provide a multidimensional understanding of hempcrete as a viable material for sustainable construction, with a focus on carbon reduction, material performance, and strategic implementation.

Table 1: List of peer-reviewed academic sources included in this review

Author(s)	Year	Title	Source Type	Journal	Focus Area
Lupu et al.	*2022*	*Hempcrete—Modern solutions for green buildings*	*Original Research*	*IOP Conf. Ser. Mater. Sci. Eng.*	*Green building solutions with hempcrete*
Zuabi & Memari	*2021*	*Review of Hempcrete as a Sustainable Building Material*	*Review*	*Int. J. Archit. Eng. Constr.*	*General review on hempcrete sustainability*
Jami, Karade & Singh	2019	A review of the properties of hemp concrete for green building applications	Review	J. Clean. Prod.	Mechanical and environmental properties
Asghari & Memari	2024	State of the art review of attributes and mechanical properties of hempcrete	Review	Biomass	Mechanical performance and standards
Yadav & Saini	2022	Opportunities & challenges of hempcrete as a building material	Review	Mater. Today Proc.	Adoption barriers and benefits
Heidari et al.	2019	Regionalised life cycle assessment of bio-based materials in construction	Original Research	Materials	LCA of hemp shiv with coatings
Sáez-Pérez et al.	2022	Improving the Behaviour of Green Concrete Geopolymers Using Hemp	Original Research	Minerals	Experimental use of hemp in green concrete
Ip & Miller	2012	Life cycle greenhouse gas emissions of hemp-lime wall constructions in the UK	Original Research	Resour. Conserv. Recycl.	LCA of hemp-lime systems
Seng, Magniont & Lorente	2019	Characterization of a precast hemp concrete. Part I: Physical and thermal properties	Original Research	J. Build. Eng.	Thermal and physical performance
Walker, Pavia & Mitchell	2014	Mechanical properties and durability of hemp-lime concretes	Original Research	Constr. Build. Mater.	Durability testing of hempcrete
Arosio et al.	2022	Life Cycle Assessment of a Wall Made of Prefabricated Hempcrete Blocks	Original Research	Bio-Based Building Materials	Prefabricated hempcrete LCA
Arrigoni et al.	2017	Life cycle assessment of natural building materials	Original Research	J. Clean. Prod.	Carbonation and environmental impact
Pretot, Collet & Garnier	2014	Life cycle assessment of a hemp concrete wall	Original Research	Build. Environ.	Thickness and coating impact on LCA
Sinka et al.	2018	Comparative life cycle assessment of magnesium binders for hemp concrete	Original Research	Resour. Conserv. Recycl.	Binder alternatives in hempcrete
Mahmood, Kavgic & Noel	2024	Hygrothermal and mechanical characterization of hemp-lime composites	Original Research	Constr. Build. Mater.	Hygrothermal and strength optimization

Table 2: Table 1: List of policy and technical documents

Author / Organization	Year	Title	Document Type	Focus Area
European Commission	2023	Hemp – Agriculture and Rural Development	EU Policy Overview	EU production trends, environmental benefits in construction
European Industrial Hemp Association (EIHA)	2020	Hemp – a Real Green Deal	Position Paper	Circular bioeconomy, carbon negativity, policy calls
EIHA / Hemp Carbon Standard	2025	Industrial Hemp Building Material Methodology	Methodology Document	Regulatory compliance, smart building integration
UNCTAD	2023	UNCTAD Policy Brief No. 110 – Industrial Hemp	UN Policy Brief	Market scaling, global bio-based material potential
Interreg Central Europe	2024	Hempcrete – Interreg Central Europe	Technical Guide	Performance properties and compliance with building regulations

4.1 Environmental and Carbon Performance

A majority of reviewed scientific studies converge on the carbon-negative potential of hemp-based construction systems. LCA-focused research such as that by Arrigoni et al. (2017) and Pretot et al. (2014) demonstrate that hempcrete walls can sequester significant amounts of CO_2, with values up to –79 kg CO_2e/m^2, especially when lime carbonation is considered. Similarly, Heidari et al. (2019) and Arosio et al. (2022) show that regionalized production and prefabrication can further optimize hemp's environmental profile.

From a policy perspective, the European Commission (2023) and EIHA (2020, 2025) position hemp as a critical resource in achieving EU climate goals, with potential sequestration rates of 9–15 tonnes CO_2/ha per season and wide compatibility with circular bioeconomy principles. These findings reinforce the viability of hemp as both a carbon sink and a low-impact material across various construction scales.

4.2 Thermal, Hygrothermal, and Mechanical Properties

Several experimental studies confirm hempcrete's favorable thermal insulation and moisture buffering capabilities. Seng et al. (2019), Mahmood et al. (2024), and Walker et al. (2014) show that hemp-lime composites perform well under real-world thermal loads and indoor environmental conditions, with strong hygrothermal regulation. However, limitations persist in structural applications, as hempcrete is inherently non-load-bearing and requires hybridization with timber or steel frames.

These laboratory findings are supported by the Interreg Central Europe (2024) technical guide, which outlines performance benchmarks and design parameters for compliance with modern building codes. Combined, these sources affirm hempcrete's readiness for mainstream application in insulation, wall infill, and retrofitting projects.

4.3 Life Cycle and Material Processing Strategies

Lifecycle-oriented papers—including those by Ip & Miller (2012) and Sinka et al. (2018)—highlight hempcrete's low embodied energy, durability, and potential for modular prefabrication. Techniques such as sol-gel treatment (Heidari et al., 2019) and binder substitutions with magnesium- or metakaolin-based additives (Sáez-Pérez et al., 2022; Daher et al., 2023) suggest viable paths for improving mechanical properties and extending the material's range of application.

The EIHA/Hemp Carbon Standard (2025) methodology formalizes these innovations into a regulatory framework, presenting pathways for standardized carbon accounting and certification schemes for hemp-based products in construction.

4.4 Strategic Frameworks and Global Policy Alignment

Recent policy briefs—such as UNCTAD's 2023 brief on industrial hemp—underscore hemp's emerging role in global sustainable material markets, especially in the context of climate-aligned trade and green industrialization. This aligns with grassroots momentum, as highlighted in The Guardian (2024), which reported the successful inclusion of hempcrete in the 2024 International Residential Code (IRC) in the United States.

The synergy between academic findings and policy frameworks demonstrates a maturing consensus: hempcrete offers environmental, thermal, and regulatory benefits that can directly support low-carbon and circular construction goals worldwide, as summarized in Table 3.

Table 3: Key findings of hempcrete as a building material

Focus Area	Key Findings
Environmental Performance	*Hempcrete sequesters up to –79 kg CO_2e/m^2; cultivation sequesters 9–15 t CO_2/ha.*
Thermal and Hygrothermal Behavior	*Excellent thermal insulation, moisture buffering, and indoor climate regulation.*
Mechanical Properties	*Non-load-bearing; structural applications require hybrid systems.*
Life Cycle Impact	*Low embodied energy; favorable LCA performance with potential for prefabrication.*
Material Innovations	*Improved properties through additives (e.g., sol-gel, metakaolin, magnesium binders).*
Policy and Regulatory Frameworks	*Supported by EU, UNCTAD, and inclusion in 2024 IRC; growing global momentum.*
Market Integration	*Growing commercial viability with guidance from EIHA and Interreg technical frameworks.*

5 DISCUSSION

The findings of this review confirm that hempcrete and other hemp-based building materials offer significant environmental, thermal, and regulatory advantages over conventional materials, especially in the context of climate-responsive construction. Through the integration of 15 academic studies and five major policy documents, this review presents a coherent case for the mainstreaming of hemp in building practices aimed at reducing carbon emissions and material waste. The carbon sequestration potential of hempcrete is among its most compelling attributes. Both empirical LCA studies (e.g., Arrigoni et al. 2017; Pretot et al. 2014) and policy frameworks (e.g., EIHA 2020; European Commission 2023) indicate that hempcrete can achieve net-negative embodied carbon, a rare and valuable trait in the current construction landscape. These findings align closely with international climate targets such as those under the EU Green Deal and UN Sustainable Development Goals (SDGs). Hemp's carbon storage occurs at multiple points in the life cycle: during cultivation, material processing, and through ongoing carbonation of the lime binder post-installation. This multi-stage carbon capture sets hemp apart from conventional materials like concrete or fiberglass, whose production phases are typically energy-intensive and emission-heavy. Furthermore, hemp's rapid growth cycle (3–4 months), low pesticide requirement, and phytoremediation potential reinforce its role as a regenerative resource, not merely a sustainable one.

The consistent performance of hemp-lime composites in thermal insulation and moisture regulation has been widely validated across empirical studies (e.g., Seng et al. 2019; Mahmood et al. 2024; Walker et al. 2014). Hempcrete enables stable indoor temperatures and passive humidity control, reducing operational energy demands for heating and cooling. These characteristics make it particularly suitable for temperate, humid, and even Mediterranean climates, as highlighted in Interreg Central Europe's 2024 technical guide. However, hempcrete's non-structural nature remains a technical limitation. Its relatively low compressive strength necessitates the use of additional structural framing, which may affect cost, carbon balance, and design flexibility. Despite this, innovations in material blending (e.g., metakaolin, sol-gel coatings, and magnesium-based binders) are actively extending its mechanical performance envelope.

A key strength of this review lies in its triangulation of scientific findings with policy momentum. The inclusion of hempcrete in the 2024 International Residential Code (IRC) demonstrates growing regulatory recognition. Simultaneously, organizations such as EIHA and UNCTAD are pushing for hemp's integration into national and international standards for carbon accounting, climate adaptation, and circular economy development.

Nevertheless, market integration remains uneven, hindered by fragmentation in certification systems, limited awareness among builders, and a lack of centralized performance databases. As the EIHA/Hemp Carbon Standard (2025) methodology outlines, the path forward involves aligning innovation with standardization—establishing universally recognized metrics for carbon offsetting, mechanical benchmarks, and lifecycle claims.

Future research should also explore hybrid systems where hempcrete can be paired with renewable energy or digital design tools (e.g., 3D printing, parametric optimization) to fully leverage its regenerative properties in modern, high-performance buildings.

6 CONCLUSION

This review highlights the strong potential of hempcrete as a sustainable building material capable of addressing both carbon emissions and material waste in the construction sector. Drawing from a wide body of academic and policy literature, it is evident that hempcrete offers net-negative embodied carbon, excellent thermal performance, and aligns well with circular economy principles. Its ability to sequester CO_2 during both cultivation and application positions hempcrete as a rare example of a regenerative material. Recent policy developments, such as its inclusion in the 2024 International Residential Code, signal growing regulatory acceptance. However, barriers remain—including limited structural capacity, inconsistent standards, and market fragmentation. Overcoming these challenges will require continued research, updated building codes, and clearer lifecycle-based certification. With proper support, hempcrete could play a significant role in transforming the built environment toward climate resilience and sustainability.

REFERENCES

1. Arrigoni, Alessandro, Raffaella Pelosato, Federica Melià, Giulio Ruggieri, Silvia Sabbadini, and Giuliana Dotelli. 2017. Life Cycle Assessment of Natural Building Materials: The Role of Carbonation, Mixture Components and Transport in the Environmental Impacts of Hempcrete Blocks. *Journal of Cleaner Production* 149: 1051–1061. https://doi.org/10.1016/j.jclepro.2017.02.161.
2. Arosio, Valeria, Camilla Moletti, and Giuliana Dotelli. 2022. Life Cycle Assessment of a Wall Made of Prefabricated Hempcrete Blocks. In *Bio-Based Building Materials*, 436–442. Bäch: Trans Tech Publications Ltd. https://doi.org/10.4028/p-n1j58c.
3. Daher, Souheil, Abdelkrim Benazzouk, Hafedh Ben Hamed, and Thierry Langlet. 2023. "Performance Improved of a Lime and Hemp-Based Concrete Through the Addition of Metakaolin." *Fluid Dynamics & Materials Processing* 19(6): 1091–1113. https://doi.org/10.32604/fdmp.2023.027338.
4. EIHA / Hemp Carbon Standard. 2025. *Industrial Hemp Building Material Methodology*. Hürth: European Industrial Hemp Association. (https://hempcarbonstandard.org/wp-content/uploads/2025/04/Industrial-Hemp-Building-Material-Methodology-Consultation-Document.pdf).
5. European Commission. 2023. *Hemp – Agriculture and Rural Development*. Brussels: European Commission. Available at: https://agriculture.ec.europa.eu/farming/crop-productions-and-plant-based-products/hemp_en.
6. European Commission. 2025. *Construction and Demolition Waste*. Available at: https://ec.europa.eu/environment/topics/waste-and-recycling/construction-and-demolition-waste_en. (Accessed July 2025)
7. European Industrial Hemp Association (EIHA). 2020. *Hemp – A Real Green Deal*. Hürth: EIHA. Available at: https://eiha.org/wp-content/uploads/2020/09/Hemp-a-real-green-deal_EN.pdf.
8. European Industrial Hemp Association (EIHA). 2023. *Carbon Storage in Hemp and Wood: Raw Materials for Construction Materials*. Hürth: EIHA.
9. Heidari, Mohammad D., Mike Lawrence, Pierre Blanchet, and Benoît Amor. 2019. Regionalised Life Cycle Assessment of Bio-Based Materials in Construction; the Case of Hemp Shiv Treated with Sol-Gel Coatings. *Materials* 12(18): 2987. https://doi.org/10.3390/ma12182987.
10. Interreg Central Europe. 2024. *Hempcrete – Bio-Based, Low Carbon Construction*. Brussels: Interreg CE Project H4H. Available at: https://www.interreg-central.eu/news/hempcrete.
11. Ip, Kenneth, and Andrew Miller. 2012. Life Cycle Greenhouse Gas Emissions of Hemp–Lime Wall Constructions in the UK. *Resources, Conservation and Recycling* 61: 1–9.
12. Mahmood, Omar, Miroslava Kavgic, and Martin Noel. 2024. Hygrothermal and Mechanical Characterization of Novel Hemp-Lime Composites with Enhanced Consistency. *Construction and Building Materials* 450: 138720. https://doi.org/10.1016/j.conbuildmat.2022.138720.
13. Pretot, Stéphane, Florence Collet, and Catherine Garnier. 2014. Life Cycle Assessment of a Hemp Concrete Wall: Impact of Thickness and Coating. *Building and Environment* 72: 223–231. https://doi.org/10.1016/j.buildenv.2013.11.010.
14. Sáez-Pérez, M. P., J. A. Durán-Suárez, and J. Castro-Gomes. 2022. Improving the Behaviour of Green Concrete Geopolymers Using Different Hemp Preservation Conditions (Fresh and Wet). *Minerals* 12(12): 1530. https://doi.org/10.3390/min12121530.
15. Seng, B., C. Magniont, and S. Lorente. 2019. Characterization of a Precast Hemp Concrete. Part I: Physical and Thermal Properties. *Journal of Building Engineering* 24: 100540. https://doi.org/10.1016/j.jobe.2019.100540.
16. Steyn, W., et al. 2025. A Comprehensive Review of Hempcrete as a Sustainable Building Material. *Innovative Infrastructure Solutions* 10(1): 1–20.
17. The Guardian. 2024. It's Almost Carbon-Negative: How Hemp Became a Surprise Building Material. *The Guardian*, February 15, 2024. Available at: https://www.theguardian.com/environment/2024/feb/15/its-almost-carbon-negative-how-hemp-became-a-surprise-building-material.

18. UNCTAD. 2023. *Policy Brief No. 110 – Industrial Hemp: A Win-Win Crop for Climate, Biodiversity and Livelihoods*. Geneva: United Nations Conference on Trade and Development. Available at: https://unctad.org/system/files/official-document/presspb2023d4_en.pdf.
19. United Nations Environment Programme. 2022. *2022 Global Status Report for Buildings and Construction*. Nairobi: UNEP.
20. Walker, Richard, Stefano Pavia, and Ruth Mitchell. 2014. Mechanical Properties and Durability of Hemp-Lime Concretes. *Construction and Building Materials* 61: 340–348. https://doi.org/10.1016/j.conbuildmat.2014.02.065.
21. Tong, Wei, and Ali M. Memari. 2025. State of the Art Review on Hempcrete as a Sustainable Substitute for Traditional Construction Materials for Home Building. *Buildings* 15(12): 1988. https://doi.org/10.3390/buildings15121988.

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1.08 Objavljeni znanstveni prispevek na konferenci
Published scientific conference contribution

REFINING THE QUALITY OF SOLID FUEL FROM WASTE: INTERSECTIONS OF SEASONALITY, WEATHER, AND HUMAN BEHAVIOR

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ABSTRACT

This article investigates the complex interplay between seasonal variation, weather conditions, and human behavior in shaping the quality of solid fuel derived from municipal waste. Using multi-year data from the CEROP Waste Management Center in Puconci, Slovenia—combined with meteorological records from a nearby station—we analyzed key fuel quality parameters: calorific value, moisture content, and chlorine concentration. Measurements were examined across different seasons to uncover patterns, correlations, and underlying causes of variation.

The results indicate clear seasonal trends. Calorific value and chlorine content were consistently higher during the summer and early autumn months, likely due to the increased share of plastics and other high-energy materials in the waste stream. In contrast, the highest moisture levels were observed during winter, reflecting the influence of lower temperatures and ambient humidity on waste storage and drying. While precipitation did not directly correlate with any single parameter, it may contribute indirectly through its effect on ambient conditions. Notably, human activity emerged as a relevant factor—particularly in terms of seasonal consumption patterns and disposal behavior.

These findings highlight the importance of integrating environmental, climatic, and behavioral dimensions into solid fuel quality management. To ensure consistent fuel quality and environmental performance, waste-to-energy systems must be designed with adaptive strategies that account for seasonal fluctuations and social dynamics. The study contributes to a deeper understanding of the variability in waste-derived fuel and offers a foundation for more sustainable energy recovery solutions.

Keywords: *waste-derived solid fuel, seasonal variation, weather impact, fuel quality, human behavior, municipal waste management*

1 INTRODUCTION

Waste management stands among the most pressing environmental challenges of the 21st century. The ever-increasing volume of waste poses substantial risks to ecological balance and public health. While towering landfills are visually disruptive, the more insidious threat lies in the release of greenhouse gases—such as carbon dioxide (CO_2) and methane (CH_4)—which exacerbate climate change and undermine efforts toward planetary sustainability (Lackner and Jospe 2017; EPA 2017). Furthermore, waste disposal sites contribute to the contamination of air, soil, and water, with direct consequences for human health and biodiversity (Suzuki 2013; Forstnerič 2018; Silva and Lopes 2007).

Despite growing awareness, the EU still landfills a significant proportion of municipal solid waste, contrary to the hierarchy defined in Directive 2008/98/EC (European Parliament and Council 2008; Eurostat 2016). Recent improvements in waste separation, particularly regarding packaging materials, have enhanced rates of recycling and material recovery (Marin 2018; Eurostat 2018a). However, progress is uneven across regions, and illegal dumping or low-quality incineration remains a concern (Neuwahl et al. 2019).

In line with the waste hierarchy, landfilling is deemed the least favorable option, whereas waste prevention, reuse, and recycling take precedence. Energy recovery occupies a lower tier, but it remains a vital solution for handling residual, non-recyclable waste fractions (European Commission 2017; Fundacio ENT 2015). The use of alternative fuels in cement production is one of the promising energy recovery routes, as demonstrated by Kajic and Koprivc (2013) and Kara et al. (2008), who emphasized the substitution potential of RDF for fossil fuels.

Solid recovered fuel (SRF), as a refined alternative to traditional refuse-derived fuel (RDF), offers a pragmatic path forward. SRF is subject to stricter standards, ensuring lower emissions and more predictable combustion characteristics. Key quality parameters—such as calorific value, moisture content, and chlorine concentration—are tightly regulated and vary depending on end-user requirements (Leblanc 2019; Rixson 2018; Nadziakiewicz 2019). Pomberger et al. (2013) underline the importance of pre-treatment and sorting for achieving consistent fuel quality, while Samec (2013) emphasizes the role of thermal treatment in integrated waste management.

Waste-to-energy strategies, such as SRF production, also contribute to circular economy goals by utilizing residual fractions and reducing reliance on landfilling (ERFO n.d.; Eurostat 2019a). Moreover, as noted by Hultman and Corvellec (2012), effective waste management depends not only on technological solutions but also on behavioral, economic, and political dynamics.

This article investigates how environmental and social variables—specifically seasonality, weather conditions, and patterns of human activity—influence the quality of SRF. By unpacking these interconnected dynamics, we aim to inform more adaptive and sustainable waste-to-energy practices that respond not only to technical requirements but also to real-world ecological and behavioral conditions.

2 PURPOSE AND GOALS

The purpose of this study is to investigate how seasonal variations, weather conditions, and human behavioral patterns influence the quality of solid fuel derived from municipal waste. By analyzing calorific value, moisture content, and chlorine concentration over multiple years, the study aims to identify key environmental and social factors that affect fuel performance and emissions.

The main goals are:

- To evaluate the seasonal trends in solid fuel quality parameters.
- To determine the relationship between meteorological data (temperature and precipitation) and fuel characteristics.
- To assess the influence of human activity patterns on waste composition and fuel quality.
- To provide insights for optimizing storage, processing, and combustion of solid fuel from waste, contributing to more sustainable energy recovery practices.

3 METHODS

3.1 Data Collection Methods and Techniques

This study employs a secondary data analysis approach, relying on existing datasets provided by CEROP (Waste Management Center in Puconci). The data, originally gathered for quality control and marketing of solid fuel derived from waste, offer a robust foundation for examining how fuel quality correlates with environmental and human variables. Given the diverse technical specifications of incineration systems, understanding these fuel properties is critical to minimizing emissions and ensuring efficient combustion (Rixson, 2018).

The dataset was compiled and processed using Microsoft Excel. Incomplete records were systematically excluded to preserve analytical accuracy. When multiple measurements were available for a single day, their mean values were calculated to streamline both graphical representation and statistical interpretation. All visual outputs, including graphs and trendlines, were generated using Excel.

The solid recovered fuel (SRF) produced by CEROP—available in 30 mm or 50 mm granulations—is stored in a covered outdoor warehouse. Samples are collected from multiple points at the bottom or at least 10 cm below the surface of the fuel pile. These samples are then ground using a Retsch SM 100 cutting mill, designed for processing soft, medium-hard, elastic, and fibrous materials. The mill uses interchangeable sieves with mesh sizes ranging from 0.25 to 2 mm to control particle fineness. During processing, the material is cut by a high-speed rotor and collected in an external container (Retsch 2020).

3.2 Instrumentation

Laboratory analysis at CEROP Puconci utilizes the following equipment to evaluate SRF quality:

- Retsch SM 100 cutting mill
- IKA C200 bomb calorimeter (CEN/TS 15400:2006)
- WTW pH/ION 340i ion-selective meter (EN 15408:2011)
- KERN MLS-a moisture analyzer (EN 15414-3:2011)

Sampling at the company CEROP d.o.o. is carried out in accordance with the sampling guidelines set out in the standard CEN/TS 15442:2006.

For determining calorific value, approximately 1 gram of the sample is compressed into a pellet without prior drying. The IKA C200 bomb calorimeter ignites the pellet within an oxygen-rich vessel using a glow wire, and the resulting combustion energy is measured automatically by the instrument (IKA 2016).

Chlorine content is measured using the WTW pH/ION 340i meter with an ion-selective electrode (ISE), which quantifies ion concentration directly in the sample (WTW 2003).

Moisture content is determined through thermogravimetric analysis using the KERN MLS-a analyzer, which calculates water content by comparing the sample's weight before and after controlled drying (KERN 2015). All the instruments were calibrated by the manufacturer.

3.3 Data Processing

Daily meteorological data—specifically average air temperature and 24-hour precipitation—were obtained from the publicly accessible archive of the Slovenian Environment Agency (ARSO). The chosen weather station, Murska Sobota-Rakičan, was selected due to its geographic proximity and climatological similarity to CEROP. Temperature data at 2 meters above ground (°C) and precipitation measured at 7:00 a.m. (mm) were processed in Excel alongside the SRF quality data (ARSO 2023).

All complete datasets from 2015 to 2019 were included in the analysis. Records with missing or unusable data were omitted to maintain the reliability of statistical outputs. Specifically, 4 records from 2016, 8 from 2017, 41 from 2018, and 2 from 2019 were excluded. All 2015 data were deemed complete and retained in full.

Calorific values were converted from kJ/kg to MJ/kg for consistency. Where daily values were duplicated, the average was used. Meteorological data were merged annually with fuel quality measurements to produce scatter plots with polynomial trendlines, facilitating the visual identification of seasonal or environmental patterns influencing SRF quality.

4 RESULTS

4.1 Calorific Value in Relation to Precipitation and Air Temperature

The analysis of solid recovered fuel (SRF) produced by CEROP Puconci in 2015, in conjunction with daily air temperature and precipitation data from the Murska Sobota-Rakičan station, reveals a distinct seasonal pattern (figure 1). The highest calorific values were recorded during the spring and summer months, while a noticeable decline occurred in the colder part of the year.

Average daily temperatures peaked in June (22.7°C), July (21.6°C), and August (21.8°C), while January exhibited the lowest average (–0.7°C). Precipitation followed a similar seasonal trend, with the highest values observed in summer, consistent with the continental climate typical of the region, which features dry winters and frequent summer showers or storms (ARSO 2023).

The trend continued in 2016, showing a similar pattern of declining calorific value in the second half of the year (figure 2). However, data collection was discontinued after October 25, creating a gap in the annual dataset.

For 2017, measurements available from June 12 to December 28 demonstrated relatively stable calorific values (figure 3), without major seasonal fluctuations—likely due to the shorter time span covered.

In 2018 and 2019, the highest calorific values again coincided with warmer periods, particularly the summer months, reinforcing the positive correlation between temperature and energy potential of the SRF(figure 4 and 5). Elevated precipitation levels during the same period may also influence these trends, either through waste composition changes or storage conditions (Rixson 2018).

Figure 1: Calorific value, chlorine content, moisture in RDF and humidity, daily precipitation totals, and average daily air temperatures in the year 2015

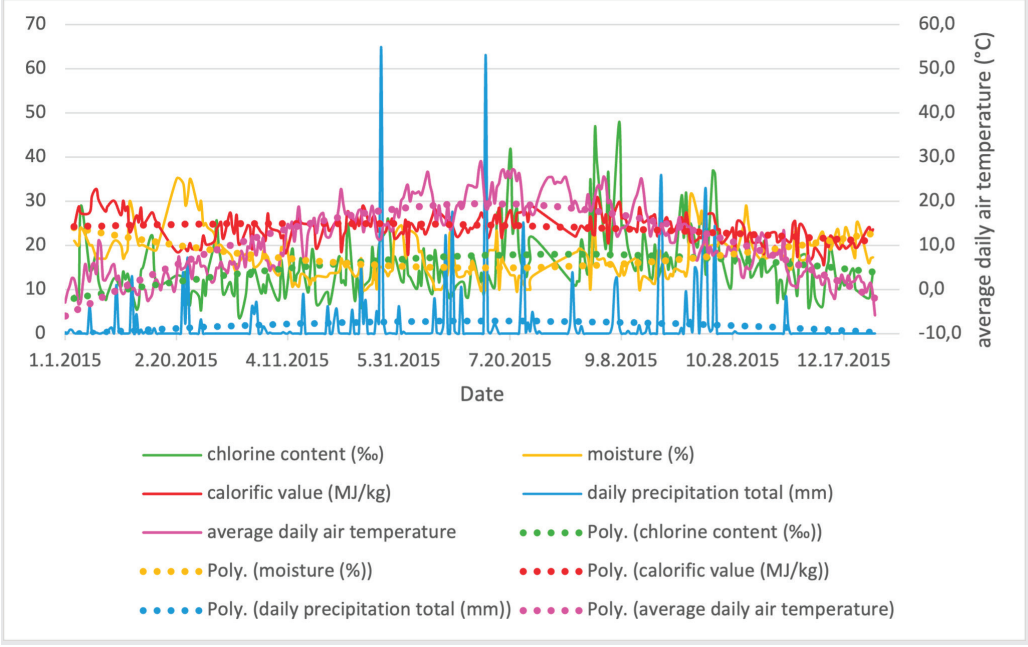


Figure 2: Calorific value, chlorine content, moisture in RDF and humidity, daily precipitation totals, and average daily air temperatures in the year 2016

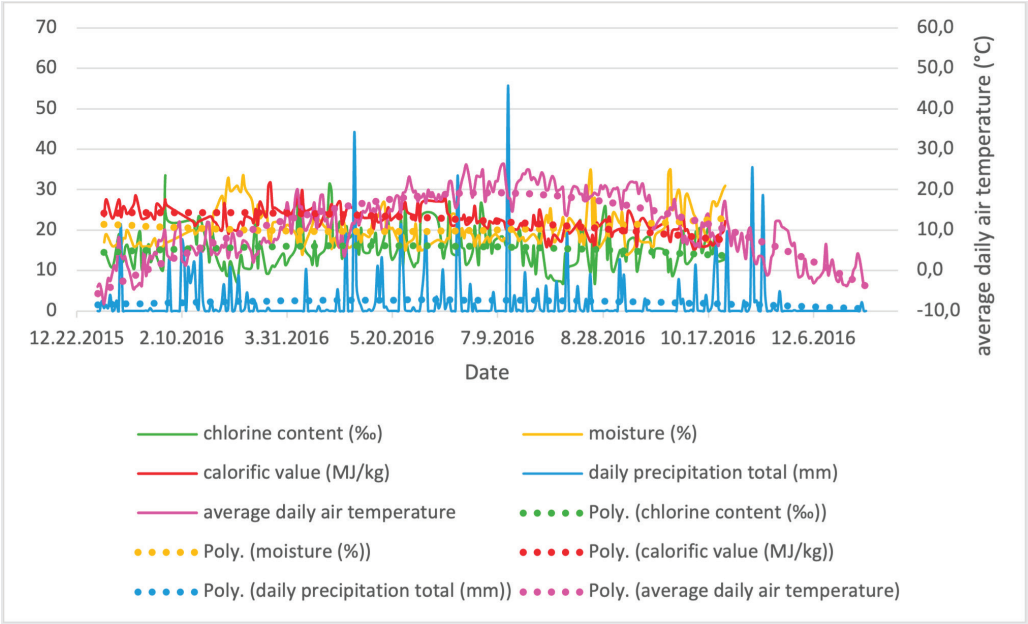


Figure 3: Calorific value, chlorine content, moisture in RDF and humidity, daily precipitation totals, and average daily air temperatures in the year 2017

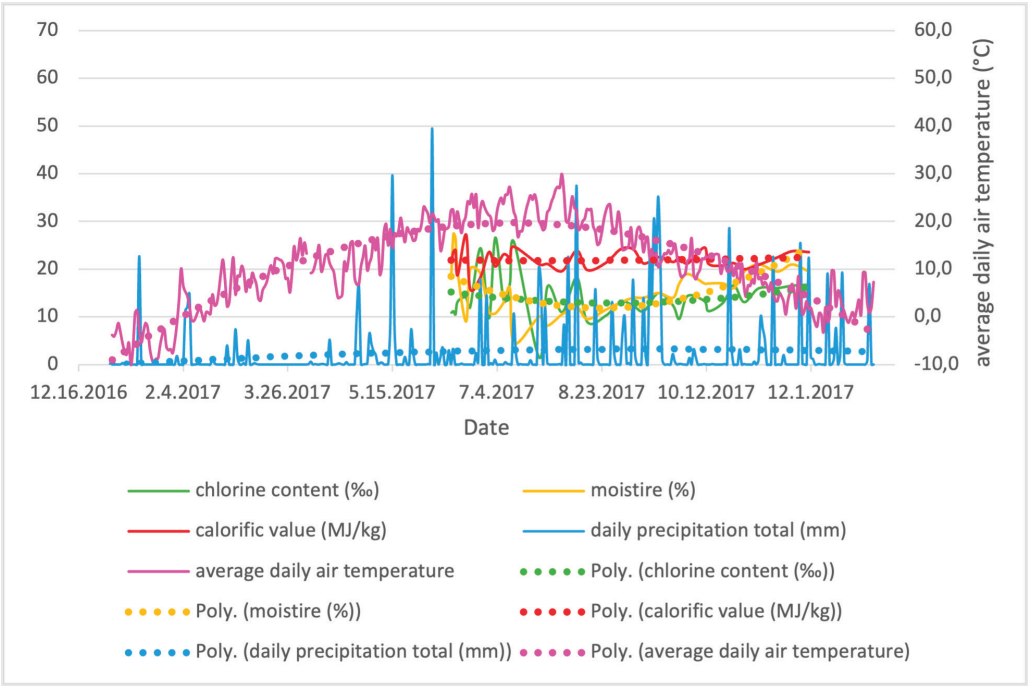


Figure 4: Calorific value, chlorine content, moisture in RDF and humidity, daily precipitation totals, and average daily air temperatures in the year 2018

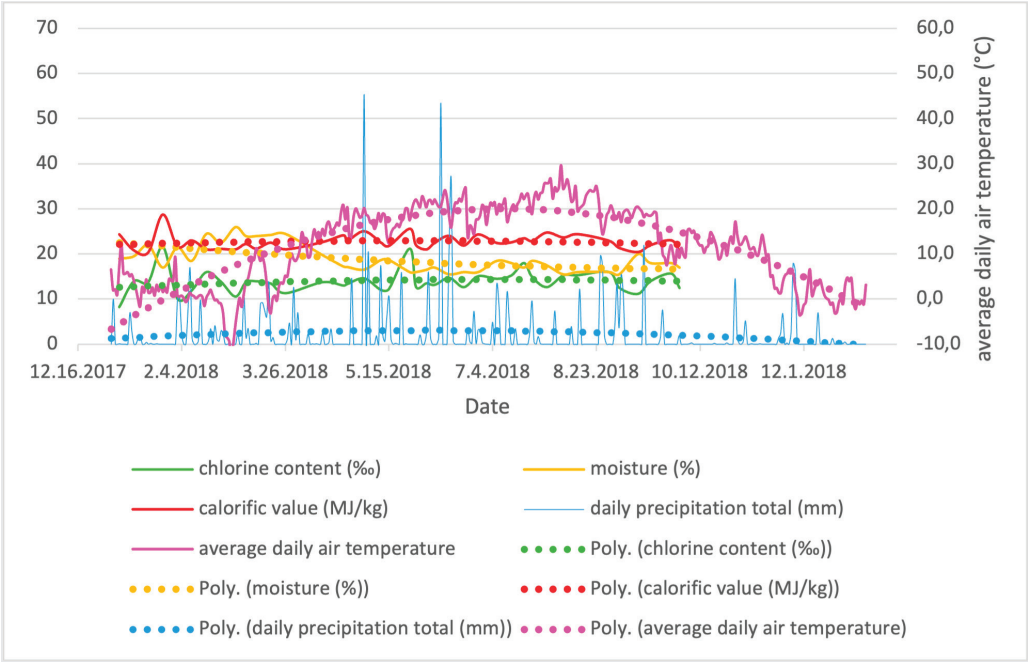
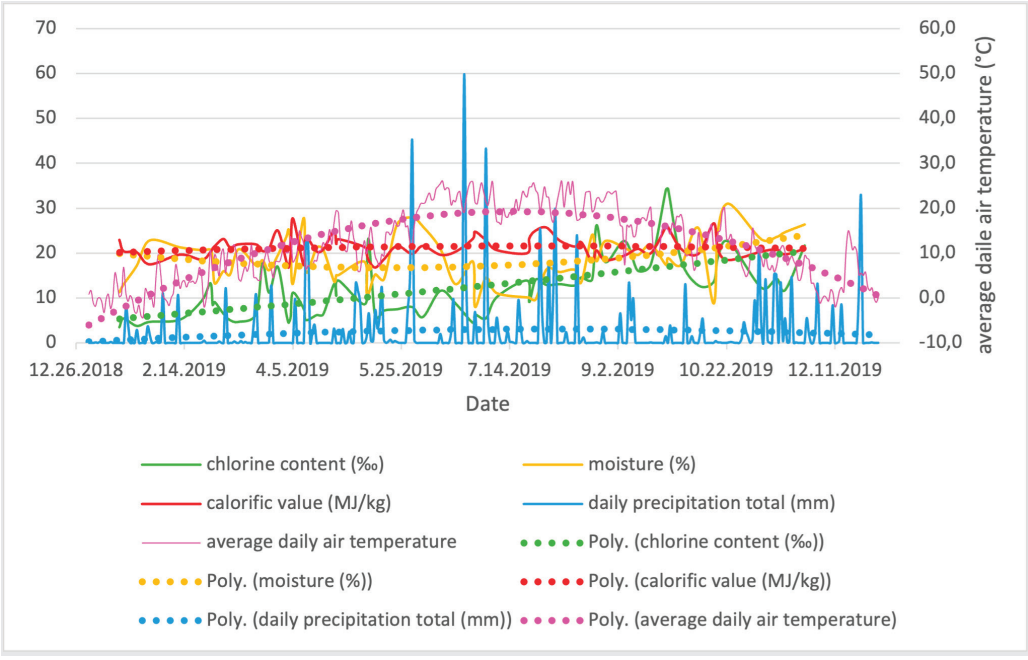


Figure 5: Calorific value, chlorine content, moisture in RDF and humidity, daily precipitation totals, and average daily air temperatures in the year 2019



4.2 Moisture Content in Relation to Seasonal Factors

The moisture content of SRF displayed an inverse seasonal pattern compared to calorific value. Higher moisture levels were consistently recorded during the winter months, while lower levels were observed during summer. This suggests a strong inverse relationship between air temperature and fuel moisture, with precipitation playing a secondary role.

These findings align with prior research, indicating that ambient humidity, storage ventilation, and temperature significantly affect moisture retention in SRF (KERN 2015). The continental climate of the region, marked by cold, dry winters and warm, humid summers, further substantiates this seasonal fluctuation.

4.3 Chlorine Content, Precipitation, and Temperature Interplay

The chlorine content in the solid fuel also followed a seasonal rhythm, with peaks generally occurring in late summer or early autumn, and lowest values registered in early winter or spring.

Interestingly, the increase in chlorine levels appears to follow the summer peak in temperature, suggesting a potential lagged relationship between ambient heat and chlorine concentration in waste-derived fuels. This could be linked to the breakdown of chlorinated compounds in warmer conditions or to changes in waste composition during summer months (WTW 2003). Elevated precipitation during summer may also contribute, either through leaching or redistribution of chlorinated particles in stored waste (Leblanc, 2019).

The data from 2015 to 2019 clearly demonstrate that the quality of solid fuel derived from waste is significantly affected by seasonal weather variables—namely temperature and precipitation. Three key quality parameters—calorific value, moisture content, and chlorine concentration—all exhibit measurable seasonal variation. These findings underscore the importance of monitoring environmental conditions and adapting production and storage strategies accordingly.

Such adaptive management can enhance energy efficiency, reduce emissions, and align more closely with environmental standards and end-user requirements (Retsch 2020; IKA 2016). Understanding these seasonal dynamics is essential for advancing sustainable waste-to-energy systems and improving the overall reliability and performance of solid recovered fuels.

5 DISCUSSION

The analysis of data collected from the Puconci Waste Management Center over multiple years highlights the significant influence of environmental and human factors on the quality of solid fuel derived from municipal waste. These findings are consistent with previous studies, which have shown that seasonal and weather-related fluctuations can affect both the physical and chemical properties of waste materials used in energy recovery (e.g., Rixson, 2018; Leblanc, 2019).

One of the most evident patterns observed was the increase in calorific value during summer and early autumn. This can be attributed to the higher presence of plastics and packaging waste during warmer months when outdoor activities, tourism, and consumption of pre-packaged goods intensify. These materials typically have higher energy content, contributing to a higher calorific value. This aligns with broader research indicating that waste composition shifts in warmer months due to lifestyle changes and consumer behavior (Marin, 2018).

Conversely, the moisture content was consistently highest during winter, which is likely influenced by lower ambient temperatures and increased humidity. Cold air holds less moisture, but once it enters storage areas with fluctuating temperatures and reduced ventilation, condensation can form, leading to increased moisture absorption in stored fuel. This trend is well-documented in studies on biomass storage, where insufficient protection from ambient moisture significantly affects fuel usability and combustion efficiency (Retsch, 2020).

Interestingly, chlorine content peaked during late summer and early autumn, a result that likely corresponds with the same increase in plastic content, particularly PVC and other chlorinated polymers. These materials contribute to higher chlorine levels, which can pose challenges during combustion, such as corrosion of equipment and the formation of dioxins if not properly con-

trolled. This reinforces the importance of maintaining tight quality control of input waste and improving upstream waste sorting.

While precipitation did not show a direct correlation with any of the three measured parameters, it may still play an indirect role by affecting the overall moisture conditions in storage environments or influencing the collection, transport, and temporary storage processes. These nuanced effects could be better captured in future studies with real-time humidity and precipitation data at the storage site.

Perhaps most importantly, the data suggest that human dynamics—namely, behavior, consumption patterns, and waste disposal habits—play a substantial role in determining the composition and thus the quality of solid fuel. These dynamics are often overlooked in technical analyses, yet they directly shape the characteristics of waste streams. For instance, the increase in disposable items during holidays or seasonal events leads to greater volumes of combustible, plastic-based waste.

From a practical standpoint, these findings highlight the importance of seasonal adaptation in waste-to-energy operations. Facilities producing solid recovered fuel (SRF) must account for seasonal quality variation by adjusting storage methods, sampling protocols, and even pricing models. More consistent control over input waste quality through public awareness campaigns, household-level separation, and covered storage facilities could mitigate some of these seasonal fluctuations and result in a more stable, high-quality fuel.

Moreover, the implementation of predictive models using meteorological and behavioral indicators could help optimize production schedules and maintenance of incineration or co-incineration equipment. Anticipating when chlorine levels are likely to rise, for instance, could allow for proactive management to prevent corrosion and emissions issues.

In conclusion, this study expands our understanding of how environmental and social factors interact in the context of waste-derived fuel. It supports the view that effective resource recovery is not only a technical or infrastructural challenge but also one deeply embedded in seasonal rhythms and human behavior. Addressing these interdependencies is key to developing more sustainable and resilient waste management systems.

6 CONCLUSION

This research examined how seasonal patterns and external factors—primarily air temperature, precipitation, and human behavior—influence key quality parameters of solid fuel derived from municipal waste at the CEROP Puconci facility. The production of solid recovered fuel (SRF) plays an increasingly vital role in sustainable waste management, particularly by providing an alternative to landfilling for non-recyclable waste fractions. However, for this process to be environmentally and economically viable, consistent and high-quality fuel must be produced.

The analysis over multiple years revealed clear and recurring seasonal trends. The calorific value of solid fuel was highest in the warmer months, likely due to increased plastic content in the waste stream—especially during summer when consumption patterns favor plastic packaging, outdoor events, and disposable materials. Conversely, in colder months, the calorific value dropped, reflecting a more organic-rich and moisture-laden waste composition.

The moisture content followed an inverse pattern, with the highest levels during the winter. These results suggest that low air temperatures and elevated relative humidity during winter prevent effective drying of the waste, even during covered storage or intermediate handling. Moisture in fuel reduces its energy content and increases emissions during combustion, emphasizing the need for climate-responsive storage and processing solutions.

The chlorine content, another critical quality parameter due to its impact on equipment corrosion and toxic emissions, also peaked in late summer and early autumn. This trend may again reflect seasonal shifts in the type of waste collected—especially the increased proportion of plastic packaging, which often contains chlorine-bearing compounds.

These patterns highlight that the production of high-quality SRF is not a static process but one influenced by both natural cycles and societal rhythms. The findings reinforce the necessity of dynamic management practices in waste-to-energy operations—ones that account for weather variability, consumption trends, and material flows.

From a broader perspective, this study emphasizes the importance of interdisciplinary thinking in waste management. Waste is not simply a material problem—it is embedded in culture, climate, economy, and behavior. Understanding the interactions between these domains enables better forecasting, planning, and technology design for future SRF systems.

Recommendations summary

To improve consistency in SRF quality, it is recommended that waste processing facilities:

- Invest in covered or climate-controlled storage to reduce seasonal moisture variation.
- Develop standardized sampling and reporting protocols to enable transparency and comparability across producers.
- Promote greater material separation at the source, particularly for plastics and organics.
- Investigate economic aspects of SRF production, including the feasibility of local usage to reduce reliance on exports and maximize national energy self-sufficiency.

Ultimately, the transformation of waste into energy-rich fuel must go hand in hand with rigorous quality control, climate adaptation, and public engagement to support circular economy goals and environmental protection.

REFERENCES

1. Agencija Republike Slovenije za okolje (ARSO). 2020. *ARHIV – opazovani in merjeni meteorološki podatki po Sloveniji*. https://meteo.arso.gov.si/met/sl/archive/ (accessed May 19, 2020).
2. EPA (U.S. Environmental Protection Agency). 2017. *Climate Change Indicators: Greenhouse Gases*. https://www.epa.gov/climate-indicators/greenhouse-gases (accessed November 12, 2019).
3. ERFO (European Recovered Fuel Organisation). *The Role of SRF in a Circular Economy*. https://www.erfo.info/images/PDF/The_role_of_SRF_in_a_Circular_Economy.pdf (accessed January 12, 2020).
4. European Commission. 2017. *The Role of Waste-to-Energy in the Circular Economy: Communication From the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions*. https://ec.europa.eu/environment/waste/waste-to-energy.pdf (accessed January 25, 2021).
5. European Parliament and Council. 2008. *Directive 2008/98/EC on Waste and Repealing Certain Directives*. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0098&from=EN (accessed March 23, 2021).
6. Eurostat. 2016. *Landfill Rate of Waste Excluding Major Mineral Wastes*. https://ec.europa.eu/eurostat/web/products-datasets/-/t2020_rt110 (accessed January 12, 2020).
7. Eurostat. 2018a. *Recycling Rate of Municipal Waste*. https://ec.europa.eu/eurostat/web/products-datasets/product?code=sdg_11_60 (accessed January 12, 2020).
8. Eurostat. 2019a. *Municipal Waste Statistics*. https://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics (accessed November 12, 2019).
9. Forstnerič, Leja. 2018. Kako odpadki vplivajo na okolje in zdravje ljudi in kako jih zmanjševati? *Live for Heartwarming*. https://liveforheartwarming.com/blog/kako-odpadki-vplivajo-na-okolje-in-zdravje-ljudi-in-kako-jih-zmanjsevati/ (accessed January 18, 2019).
10. Fundacio ENT. 2015. *Air Pollution from Waste Disposal: Not for Public Breath*. Brussels: Zero Waste Europe.
11. Hultman, Johan, and Hervé Corvellec. 2012. The European Waste Hierarchy: From the Sociomateriality of Waste to a Politics of Consumption. *ResearchGate*. https://www.researchgate.net/publication/235932856_The_European_Waste_Hierarchy_from_the_sociomateriality_of_waste_to_a_politics_of_consumption (accessed December 21, 2019).
12. IKA. 2016. *Calorimeter System C 200*. https://www.ika.com/en/Products-Lab-Eq/Calorimeters-Oxygen-Bomb-calorimeter-csp-330/C-200-cpdt-8802500/ (accessed February 5, 2020).
13. Kajic, Petra, and Martin Koprivc. 2013. Uporaba alternativnih goriv in materialov v cementni industriji. In *Celovito ravnanje z odpadki*, 181–187. Moravske Toplice: Zveza ekoloških gibanj Slovenije.
14. Kara, Mustafa, Esin Günay, Yasemin Tabak, Şenol Yildiz, and Volkan Enc. 2008. The Usage of Refuse Derived Fuel from Urban Solid Waste in Cement Industry as an Alternative Fuel. In *New Aspects of Heat Transfer, Thermal Engineering and Environment*, edited by E. L. Cussler et al., 172–177. Rhodes: WSEAS.
15. Lackner, Klaus S., and Christophe Jospe. 2017. Climate Change is a Waste Management Problem. *Issues in Science and Technology*. https://issues.org/climate-change-is-a-waste-management-problem/ (accessed January 12, 2020).
16. Leblanc, Rich. 2019. The Waste Management Hierarchy. *The Balance Small Business*. https://www.thebalancesmb.com/reduce-reuse-and-recycle-the-waste-management-hierarchy-2878202 (accessed January 12, 2020).
17. Marin, Andrei. 2018. Recycling of Municipal Waste. *European Environment Agency*. https://www.eea.europa.eu/airs/2018/resource-efficiency-and-low-carbon-economy/recycling-of-municipal-waste (accessed January 12, 2020).
18. Nadziakiewicz, Jan. 2019. *Energy Recovery from Waste*. Gliwice: Chair of Installations and Systems for Waste Utilization.
19. Neuwahl, Frederik, et al. 2019. *Best Available Techniques (BAT) for Waste Incineration*. Luxembourg: Publications Office of the European Union. https://eippcb.jrc.ec.europa.eu/sites/default/files/2020-01/JRC118637_WI_Bref_2019_published_0.pdf.

20. Pomberger, Roland, Josef Adam, Alexander Curtis, Joseph Kulmer, and Andrej Gomboši. 2013. Izločevanje odpadkov primernih za snovno predelavo v postopku proizvodnje alternativnega goriva iz odpadkov. In *Celovito ravnanje z odpadki*, 99–104. Moravske Toplice: Zveza ekoloških gibanj Slovenije.
21. Retsch. 2020. *Cutting Mill SM 100*. https://www.retsch.com/api/?action=product_pdf&productId=10&id=2296508&L=0 (accessed February 5, 2020).
22. Rixson, Chris. 2018. Improving the Quality of SRF/RDF. *Recycling & Waste World*. http://www.recyclingwasteworld.co.uk/opinion/improving-the-quality-of-srf-rdf/167018/ (accessed January 20, 2020).
23. Samec, Niko. 2013. Pomen termične obdelave odpadkov v konceptu celovitega ravnanja z odpadki. In *Celovito ravnanje z odpadki*, 131–132. Moravske Toplice: Zveza ekoloških gibanj Slovenije.
24. Silva, Sofia, and A. Miguel Lopes. 2007. Environmental Aspects and Impacts of a Waste Incineration Plant. *ScienceDirect*. https://www.sciencedirect.com/science/article/pii/S1876610217352001 (accessed December 2, 2019).
25. Suzuki, David. 2013. The Problems with Incinerating Waste. *The Georgia Straight*. https://www.straight.com/news/421761/david-suzuki-problems-incinerating-waste (accessed January 13, 2020).
26. WTW. 2003. *Operating Manual pH/ION 340i*. https://www.manualslib.com/manual/1488717/Wtw-Ph-Ion-340i.html (accessed February 5, 2020).

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