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DEPARTMENT OF GEOGRAPHY, TOURISM AND HOTEL MANAGEMENT

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What do they know? Is Climate Change Education Necessary in Primary Schools in Serbia

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ABSTRACT

Climate change is a global crisis exacerbated by human activity and a matter of urgent concern. There is a significant knowledge gap among primary school students in Serbia, as the topic of climate change is barely covered in the curriculum. This study examines their awareness, knowledge and attitudes. Of the participants, 96.6% are aware of climate change, but their knowledge and attitudes vary considerably. Some 80.10% expect climate change to have a significant impact on humans through floods (90%), droughts and temperature increases (85% each). Further results show that schools are a key source of information (35.10%), followed by television (30.10%) and the internet (14.90%). In summary, this study highlights the need for comprehensive, multidisciplinary climate education to address different levels of awareness, encourage informed and proactive responses and engage young voices in discussions about climate change.

Introduction

Climate change is a formidable global challenge that has garnered increasing attention in recent years. Scientific consensus underscores the substantial impact of human activities on climate change, making it an undeniable and urgent concern (IPCC, 2021). This global phenomenon, fueled by anthropogenic factors, is already reshaping our world. Understanding the drivers, consequences, and potential solutions for climate change is of paramount importance on a global scale. Recent research reports have underscored the critical role of evaluating society's awareness and understanding of climate change, emphasizing the need for effective climate education (Khatibi et al., 2021; Mebane et al., 2023). Climate change education (CCE) has emerged as an integral component of environmental education within the broader context of sustainable development (Bangay & Blum, 2010; Keller et al., 2019). This educational framework plays a pivotal role in fostering eco-social competences and motivating individuals to embark on personal and collective efforts to mitigate the effects of climate change. The primary goals of CCE extend beyond imparting knowledge to encompass inspiring behavioral changes. Instilling this knowledge in young children is particularly vital, as it empowers them to grasp the human impact on the environment and comprehend the consequences of their actions (Baarova & Hibszer, 2022).

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Geography educators, in particular, bear the responsibility of shaping students' attitudes, beliefs, and pro-environmental behaviors. Geography, as an academic discipline, is uniquely positioned to impart knowledge on atmospheric processes, climate factors, climate zones, the causes and ramifications of climate change, and the regions experiencing the manifold environmental, social, and economic consequences of climate change, such as droughts, floods, and mass migrations. The rich curriculum content of geography education makes it the ideal subject for instilling an understanding of atmospheric phenomena and environmental transformations (Baarova & Hibszer, 2022; Enke & Budke, 2023). While prior environmental crises often had localized or regional impacts, climate change stands as a global threat. Its ramifications extend to threaten global civilization as a whole. In addressing and averting such universal challenges, education becomes the linchpin of the solution (Nepraš et al., 2022; Sund, 2016). Consequently, in the context of the issues arising from human-induced climate change, we turn our attention to CCE (Armstrong & Krasny, 2020; Tibola da Rocha et al., 2020). Well-executed CCE emerges as one of the most potent and enduring strategies for mitigation (Azevedo & Marques, 2017). So, climate change has transitioned from being merely an environmental issue to becoming an essential and dynamic educational and societal concern, where students actively participate (Karsgaard & Davidson, 2021). The profound impact of education on enhancing climate literacy, understanding and the ability to address the repercussions of global warming cannot be overemphasized. The United Nations Framework Convention on climate change has underlined the pivotal role of education in formulating a robust global response to climate change. In this context, it is imperative to scrutinize the role of climate change education in primary schools, as it lays the foundation for future generations' climate literacy and their active involvement in mitigating this global challenge. By analyzing geography textbooks from five different publishers in Serbia it can be noticed that not enough attention is dedicated to this important global problem. In Serbia, in official curriculum only 1 out of 134 lessons (0.75%) from 5th to 8th grade is dedicated to climate change and its consequences.

In Europe, the imperative to enhance science education, particularly in the realm of climate change, is increasingly recognized (Léna, 2009). However, significant challenges persist in the incorporation of high-quality, unbiased climate change content into school curricula (Uherek & Schüpbach, 2008). Public perceptions regarding climate change across Europe are shaped by diverse factors such as socioeconomic status, education levels, and the influence of prominent figures like Greta Thunberg (Baiardi et al., 2021). These insights underscore the criticality of effective CCE in Europe and the necessity for concerted actions to address this pressing issue. Recent research underscores the multifaceted influences on public attitudes toward climate change, emphasizing the need for coordinated efforts at the EU level, particularly in education and information dissemination (Baiardi et al., 2021). Efforts are underway to formulate a European educational framework encompassing environmental, nature, and climate protection, with an emphasis on hands-on learning and interdisciplinary approaches (Tomaszewska et al., 2018). The significance of CCE in Europe is emphasized as a cornerstone of a broader initiative for Education for Sustainable Development, aimed at deepening learners' comprehension and empowering them to take meaningful action (Mochizuki & Bryan, 2015). Practical implementation of climate change education is deemed essential, necessitating the expansion and coordination of diverse educational initiatives across all educational domains (Becker, 2018). Ultimately, education emerges as a pivotal tool in fostering the knowledge, skills, and values crucial for sustainability, including the comprehension, mitigation, and adaptation to climate change (Krasny & DuBois, 2019; Martin et al., 2007).

Research into CCE in several countries in Southeast Europe has revealed various approaches. In Greece, innovative strategies such as combining digital storytelling with traditional lectures have shown promise in enhancing students' knowledge and fostering behavioral change (Theodorou et al., 2019). Bulgaria emphasizes the need for a comprehensive and systematic approach to CCE, advocating for the establishment of a network of diverse educational activities (Becker, 2018). In Croatia, there is a recognized need for more extensive education on climate change, particularly focusing on its economic and tourism impacts (Šverko Grdinić et al., 2018), aligning with global efforts stressing the significance of local action and education in addressing climate change (Becker, 2018). Meanwhile, in Serbia, attention is drawn to the necessity of improving media coverage of climate change, especially within journalism programs (Vujović & Ilić Krstić, 2022). However, there remains a lack of specific information on climate change education in formal schooling, suggesting potential enhancements through integrating local ecosystem impacts and policy questions into teaching activities as proposed by Monroe et al. (2013).

This paper, therefore, explores the knowledge of primary school children in Vojvodina province (Serbia) about this important world issue. It elucidates the significance of CCE in shaping young minds, fostering environmental awareness, and preparing the next generation to effectively combat climate change. The study delves into the current state of CCE in primary schools and its implications for development eco-social competences, shaping attitudes, and catalyzing behaviors pertaining to climate change. By investigating the links between education and climate change awareness. The aim of this research is to underscore the importance of effective CCE as a vital process for addressing and mitigating the impacts of climate change.

Data and methods

The central aim of this research was to determine the depth of primary school children's awareness concerning climate change and the repercussions it carries. Our initial premise revolved around the notion that climate change receives insufficient attention within the school curriculum, resulting in a lack of comprehensive information for children to grasp the full extent of its implications. This served as our primary hypothesis. Furthermore, our second hypothesis ventured to explore whether children's perspectives on climate change exhibited variations correlated with their age. Our study sought to investigate how these factors, including the curricular coverage of climate change, influenced the knowledge levels and attitudes of primary school children towards this pressing global issue.

Data collection

This study employed the field survey research approach, utilizing a questionnaire design specially for this study (Supplementary file). The data collection took place during the 2022/2023 school year and involved a random sample. After concluding the survey, a total of 632 fully completed questionnaires were obtained of which 17.1% were 11-year-old; 30.7% – 12-year-old; 28.5% – 13-year-oldand 22.7% – 14-year-old of which 296 (46.3%) were male and 336 (53.7%) were females. The respondents were diverse in terms of gender, age, educational institutions and residential locations (Table 1). The research was carried out in the Vojvodina province, situated in the northern region of the Republic of Serbia, encompassing both urban (62.7% of participants) and rural (37.3% of participants) settings (Fig.1). The participants willingly consented to take part in the study.

Table 1. Gender, age and residential locations of respondents

Grade	Total	Gender		Settlement type	
		Male	Female	City	Village
5th	106	60	46	31	75
6th	197	103	94	155	42
7th	184	83	101	119	65
8th	145	50	95	95	50

Research instruments

The research was conducted through an online survey. A two-part questionnaire was used in data collection. The

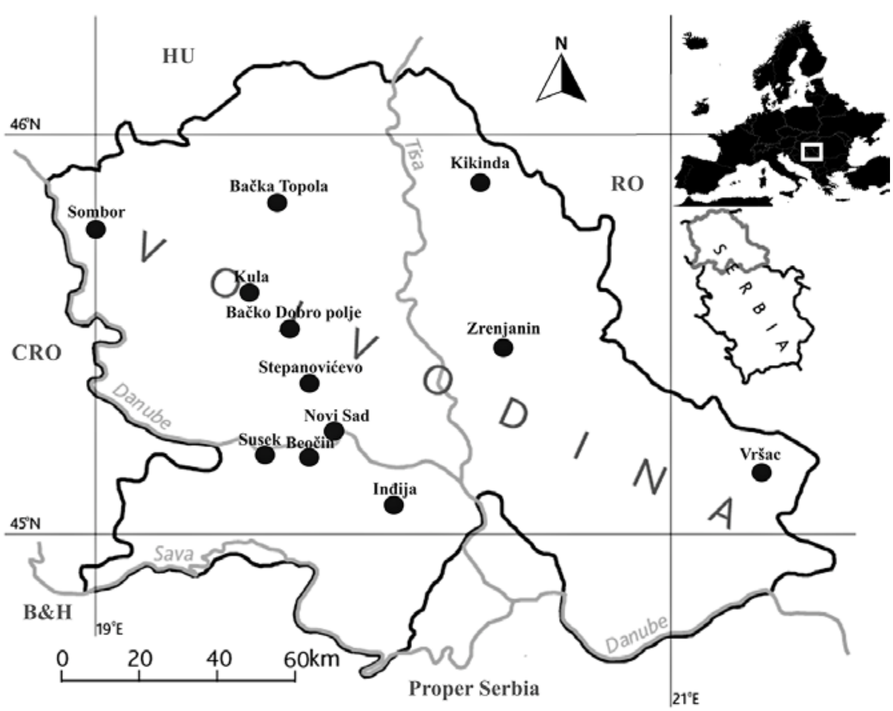

Figure 1. Geographical location of settlements where schools who participated in the study are located

first part collected mostly demographic data. Besides gender and grade, respondents were asked to write if the school that they live is in rural or urban settlement.

The second part of the questionnaire covered a range of essential inquiries related to climate change. Participants were asked about their views on the main cause of climate change, their self-assessment of climate change knowledge, and their preferred methods for educating themselves about this topic. They were also questioned about their exposure to climate change discussions in school and its potential impact on human lives. The survey delved into participants' interest in learning more about climate change, their perceptions of public awareness in Serbia, and their familiarity with specific consequences associated with climate change. Additionally, participants' beliefs in climate change, awareness of the Glasgow Climate Pact, and their willingness to further explore the consequences of climate change were queried. The questionnaire also sought to understand participants' views on the responsibility for addressing climate change issues, their conversations about climate change, and whether they believe young people should be actively engaged in climate crisis solutions. The survey concluded with questions about emotional responses to climate change, anticipation of future climate conditions, knowledge of the greenhouse effect and its primary cause, as well as preferences for self-education on the topic.

Data analysis

The data collected for this study were analyzed using the statistical software SPSS, version 20. Presented results were obtained according to different statistical analyses usually applied in similar researches: descriptive statistical analysis, ANOVA (one-way analysis of variance), including the determination of the significance of differences between specific groups conducted using the post hoc Scheffe test (Cvetković & Grbić, 2021; Karpudewan et al., 2015), these methods are appropriate for the research design as they enable the exploration of relationships between variables and facilitate the identification of significant patterns or trends within the dataset. The t-test analysis for independent samples was utilized to compare means between two groups, providing further insight into potential differences and associations (Cvetković & Grbić, 2021; Galway & Beery, 2022).

Significance of differences between particular groups can be established through the post hoc test, a technique designed to mitigate systematic errors that may arise from an increased number of comparisons between two arithmetic means. In this research, the Scheffe post hoc test, known for its stringent and frequent application, was employed (Agbangba et al., 2024). The sample fulfills basic conditions for parameter test application, i.e., data used in analysis originate from interval scale and they are normally distributed.

Results and discussion

ANOVA was used to define if there are statistically significant differences between dependent variables (school grade) and independent variable (several questions). Post-hock Scheffe test was applied to define significantly different variables.

Results show that 96.6% of participants have heard about Climate change, but the very next questions raise concern as 53.10% of participants consider that climate change is a consequence of natural climate cycles (Figure 2). Statistical analysis of participants answers shows significant differences at a level $p<0.05$ between 5th and 6th graders, where more 5th graders correctly stated that climate change is induced by human activity versus natural climate cycles that was most common answer among six graders ($F = 3.308$; $p = 0.047$). No statistically significant difference was observed among other grades. This result was expected as one lesson considering Climate change is located in 5th grade.

These results reveal an interesting division of opinions regarding the main cause of climate change. While a high percentage of students are aware of climate change, there are significant gaps in their understanding of its causes as 53.10 % attribute climate change to natural climate cycles,

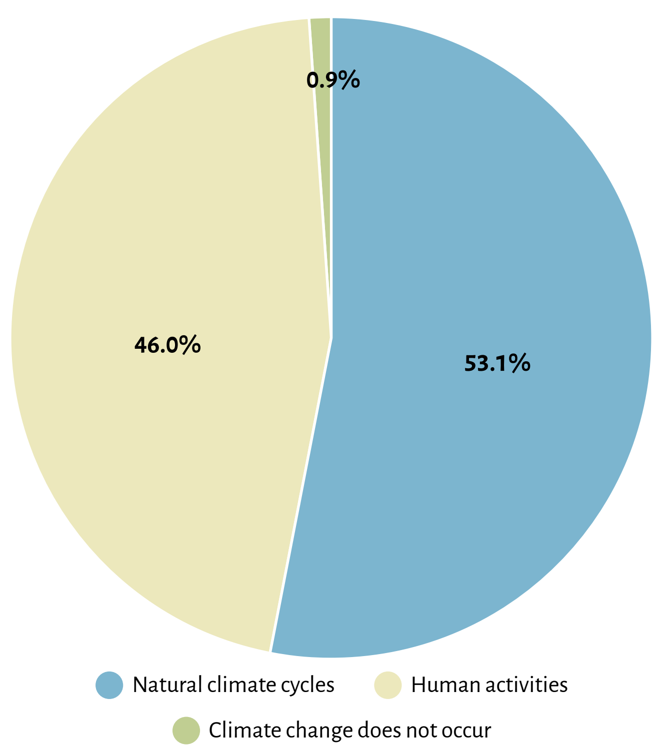

Figure 2. What is the main cause of climate change?

where 20.1% of 11-year-olds think this, 26.7% of 12-year-olds, 29.1% of 13-year-olds and 24% of 14-year-olds. Location of the school, did not show significant difference as 51.4% of answers were given by pupils that attend schools located in the cities and 48.6% attend schools in village. Similarly, research conducted in Spain has shown that pupils are aware of climate change, but lack overall understanding of climate change and the socio-economic consequences (Punter et al., 2011). Other research conducted in Study stated that only 13.6% of primary school children stated that human activities are the main cause of climate change. CCE study organized in South Africa have showed that while a high percentage of students were aware of climate change, many did not fully understand its causes and impacts (Kutywayo et al., 2022). This perspective suggests that a significant portion of the surveyed individuals may hold the belief that climate variations are primarily driven by natural factors, such as fluctuations in the Earth's climate system that have occurred throughout geological history.

On the other hand, 46% of the respondents attributed climate change to "Human Activities", specifically, 16.1% of the 11-year-olds, 32.7% of the 12-year-olds, 29.1% of the 13-year-olds, and 22.1% of the 14-year-olds identified human activities as the cause of climate change. In similar study conducted in Turkey, only about 25% of 11-12-year old participant, were aware of the causes of climate change (Akaygun & Adadan, 2021). Primary school students in Austria believe that climate change is mainly caused by humans and is happening now (Harker-Schuch et al., 2021). This viewpoint aligns with the widely accepted scientific consensus that human actions, particularly the emission of greenhouse gases, are the primary drivers of the observed changes in global climate patterns. It reflects the understanding that anthropogenic factors, such as the release of carbon dioxide and other greenhouse gases into the atmosphere, are significantly contributing to the current trends of global warming. Notably, a very small percentage, believed that "Climate change does not occur." This perspective contradicts the overwhelming scientific evidence that demonstrates the reality of climate change and its widespread impacts on ecosystems, weather patterns, and human societies. These findings emphasize the diverse range of opinions and beliefs about the causes of climate change among the survey participants. While there is ongoing scientific consensus on the role of human activities in driving climate change, it is clear that pupils' perceptions and understanding of this complex issue can significantly vary, potentially influenced by individual beliefs, education and exposure to information sources (Lekgeu & Davis, 2017; Levi, 2021; Nation & Feldman, 2021).

The results of the self-assessment of knowledge about climate change has revealed a range of findings (Fig. 3). A substantial portion, approximately 45.90%, expressed confidence in their understanding of climate change, suggesting a notable level of self-assuredness in their knowledge. On the other hand, a smaller percentage, 6.60%, considered their knowledge to be lacking or inadequate, highlighting a segment of the population that may require more information or education on the subject. Interestingly, a significant proportion, 41.90%, fell in the category of "Neither good nor bad," signifying a level of uncertainty or neutrality in their self-assessment. Additionally, a noteworthy percentage, 5.60%, admitted to not being sufficiently interested to seek out information about climate change, underscoring the importance of engagement and motivation in fostering awareness on this critical issue.

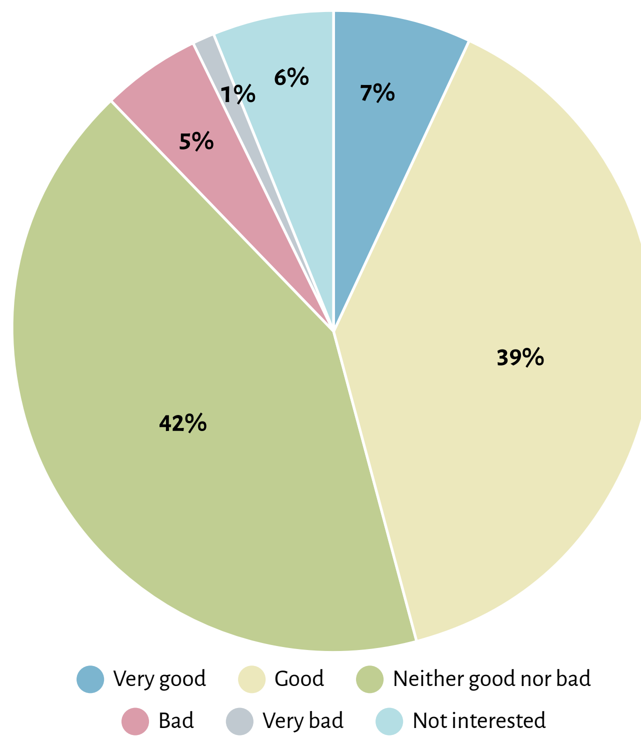

Figure 3. How would you assess your knowledge about climate change?

Results presented by Taber and Taylor (2009) and Karpudewan et al. (2015) also show that primary school students have a moderate level of awareness about climate change, with their knowledge and attitudes being positively influenced by hands-on activities and effective visual aids. However, there is a need for improvement in their knowledge, as a significant percentage of students still have misconceptions about the causes of climate change (Harker-Schuch & Bugge-Henriksen, 2013). In Slovenia for example, pupils in the 9th grade of primary school discuss the climate of their country through independent work, critical thinking, and the use of maps, pictorial material, and climatograms (Schauer, 2016). Overall, students generally feel confident in their ability to make a positive impact in relation to climate change (Taber & Taylor, 2009). These results reveal a diverse range of perspectives on climate change knowledge, reflecting the need for tailored educational approaches to address varying levels of awareness and interest.

The data on how respondents educate themselves about climate change provide valuable insights into the sources of information and platforms they rely on (Fig. 4). It is notable that a substantial portion, 35.10%, turn to schools as their primary source of education on climate change, emphasizing the significance of formal education in shaping awareness. Television follows closely, with 30.10% of respondents utilizing it as a key medium for learning about climate change. The internet, including various websites and online resources, is also a prevalent source, with 14.90% of respondents utilizing this vast platform. Social media platforms, with 14.60%, play a role in disseminating information and engaging users in discussions related to climate change. Additionally, a smaller percentage, 5.30%, identified other methods not explicitly listed, indicating the diverse range of resources people use to educate themselves about climate change. A range of studies have explored the primary sources of information about climate change for European primary school students. Akaygun and Adadan (2021) have emphasize the importance of experiential and inquiry-based learning activities in fostering a deeper understanding of climate change. However, Özdem et al. (2014) highlighted the influence of media and education in shaping students' perceptions, suggesting a need for accurate information in these sources. Uherek and Schüpbach (2008) further underscored the challenge of integrating high-quality and impartial climate change material into the curriculum. These studies collectively underscore the need for a multi-faceted approach to climate change education, with a focus on accurate information, experiential learning, and the integration of high-quality resources into the curriculum.

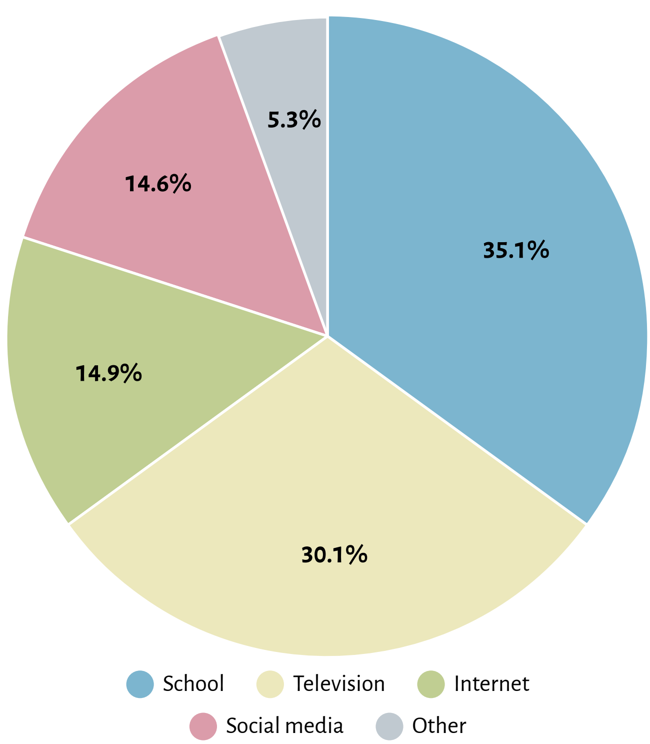

Figure 4. How do primary school students learn about climate change

Gender-related differences in gathering information regarding climate change topics were evident, with female students showing a tendency for receiving information through social media and teachers, while male students showed a tendency for television and teacher-based sources. The role of social media emerges as crucial in climate change education, facilitating information dissemination and fostering networks for knowledge exchange (Goritz et al., 2019; Robelia et al., 2011). Despite challenges such as state standards and divergent viewpoints, teachers remain integral to climate change education (Monroe et al., 2013). When compared results obtained with this study to the results reported for Valencia Region in Spain (Morote & Hernández, 2022), clear differences in between Vojvodina and Valencia Regions can be observed. In Vojvodina 30.10% of participants indicated that Television is their source of information about climate change while in Valencia 82.6% did the same. Study conducted in China reveal that most primary school children mainly get information about climate change from television and the internet (Wang et al., 2022). These findings underscore the importance of various channels and resources in disseminating knowledge about climate change, reflecting the need for a multi-faceted approach to public education and engagement on this critical issue.

The data regarding the school subjects where climate change and its consequences are discussed provide valuable insights into the curricular approach to this important topic. A significant majority, 48%, reported that they encounter discussions about climate change in their geography classes. This is in good accordance with results reported for Nigeria, where geography was highlighted as the most appropriate subject for learning about climate change (Onuoha et al., 2021). Several studies have shown that Geography is a crucial subject for teaching primary school children about climate change, as it provides a holistic understanding of the issue (Mitchell, 2023; Mwangu et al., 2017). Close behind, 46% of respondents mentioned biology as another subject where climate change is addressed. This dual emphasis on geography and biology highlights the multidisciplinary nature of climate change education, as it is explored through the lenses of both natural sciences and geography. Additionally, a smaller percentage, 6%, indicated that climate change discussions took place in subjects not specifically listed, indicating the potential for cross-disciplinary integration of climate change topics into the curriculum. A holistic approach to climate change education is crucial, as it encompasses various subjects and fosters a comprehensive understanding of the issue (Snow & Snow, 2010). This approach should extend beyond the classroom, involving a coordinated and institutionalized effort of the education system (Szczepankiewicz et al., 2021). Interactive visualizations, multidisciplinary and iterative refinements can enhance students' understanding of climate change (Svihla & Linn, 2012).

The responses regarding the anticipated impact of climate change on humans highlight a widespread belief in the potential severity of this issue. A significant majority, approximately 80.10%, expressed the view that climate change will indeed have a substantial impact on humans. This strong consensus indicates a prevailing concern about the consequences of climate change and its potential to affect human societies. On the other hand, a smaller percentage, 14%, held the perspective that climate change will not have a significant impact on humans, reflecting a less pessimistic outlook. Additionally, 5.90% of respondents believed that the situation will remain unchanged, suggesting a degree of uncertainty or neutrality. These findings underscore the need for comprehensive measures to address the potential impacts of climate change and engage in proactive strategies to mitigate its effects. Deeper analysis reveals that there are clear gender differences, with a higher proportion of women (51.6%) expecting significant impacts compared to men (48.4%). The differences are greatest in the 12-year-old age group, with 30.7% anticipating a significant impact, compared to just 15.8% of 13 and 14-year-olds. Interestingly, women in both urban and rural areas express greater concern about the effects of climate change than men. However, significant differences can be observed between urban and village dwellers, particularly among women: 67.9% in urban areas expect significant impacts compared to 32.1% in rural areas. This indicates a possible influence of the place of residence on the perception of the effects of climate change.

The responses regarding the desire to learn more about climate change topics show a significant interest in further education on this critical issue. A substantial majority, around 66.50%, expressed a clear desire to learn more about climate change, indicating a strong motivation to deepen their understanding of the subject. Other studies also suggest that primary school children exhibit an interest in understanding climate change through child-centered activities that can enhance both their knowledge and positive attitudes toward the environment (Karpudewan et al., 2015; Tolppanen & Aksela, 2018). Conversely, 33.50% of respondents indicated that they do not wish to learn more about climate change. These results reveal a noteworthy segment of the pupils with a keen interest in expanding their knowledge and awareness about climate change, emphasizing the importance of providing accessible and engaging educational resources on this topic to cater to diverse preferences and interests. There are clear gender differences, with a higher percentage of female than male pupils expressing an interest in learning more about climate change. More specifically, 40.35% of female said they wanted to learn more, while only 33.54% of male expressed the same opinion. Among the age groups, 11-year-olds showed the least interest in learning more about climate change. Compared to the other age groups, only 13.92% expressed a desire to learn more. Conversely, the proportion of respondents who would like to learn more about climate change is highest among 12-year-olds at 22.31%. In terms of where they live, people who live in cities show a greater interest in learning more about climate change than people in villages. For example, 47.63% of urban respondents expressed a desire to learn more, while only 26.27% of rural respondents expressed the same opinion.

The opinions expressed regarding the awareness of the impact of climate change among the residents of Serbia reveal a diverse range of perspectives (Figure 5). A significant percentage of pupils, approximately 37%, believe that the residents of Serbia are indeed aware of the impact of climate change. Previously published results show that more than half of Serbian citizens (56.7%) are aware about climate change (Cvetković & Grbić, 2021). This suggests a considerable level of optimism about the level of awareness in the community. Conversely, 33.20% of respondents expressed the view that the residents of Serbia are not

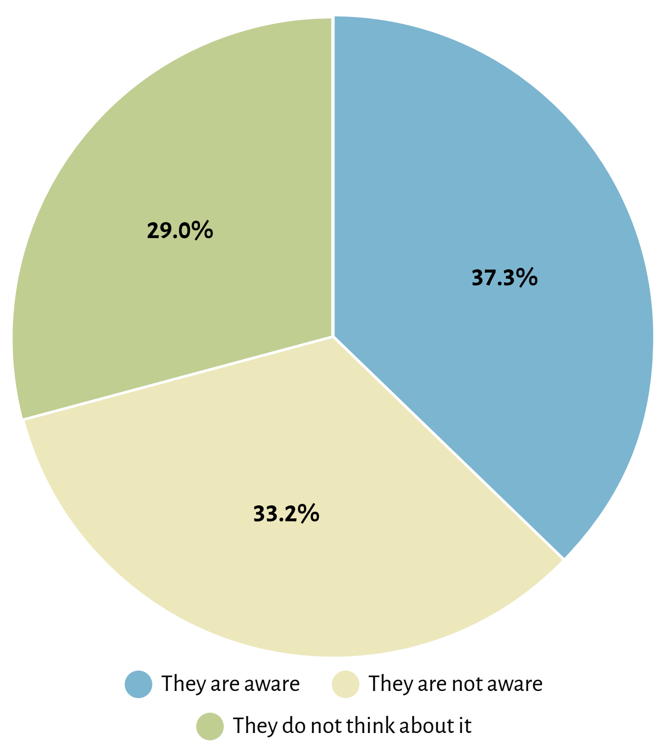

Figure 5. Pupils' Perceptions: Assessing Climate Change Awareness among Residents of Serbia

aware of the impact of climate change, indicating a sense of inadequacy in public knowledge and understanding. Additionally, 29.00% noted that people simply do not think about it, pointing to a segment of the population who may not have climate change on their mind. This result is considerably higher than results presented by Cvetković et al (2021) where only 14% of respondents stated that the issue of climate change is not important. Statistically significant difference was observed in answers between 5th and 8th graders, where younger pupils think that inhabitants of Serbia are aware of Climate change impact, while older pupils think that they are not aware ($F = 1.818$; $p = 0.17$). These varied responses emphasize the need for educational initiatives and awareness campaigns to ensure that all residents of Serbia are informed about the pressing issue of climate change and its potential consequences.

In Fig. 6, we can observe the responses regarding the consequences of climate change that participants have heard of. This was multiple choice questions where participants could select up to three consequences that were provided in the questioner. The for most causes that were the most recognized are floods (90%), droughts and temperature increase (85% respectively) and forest fires (80%). These findings reflect a broad and varied recognition of climate change impacts. Notably, a significant majority of participants reported awareness of key consequences, such as floods, droughts, temperature increases, forest fires, and rising sea levels. These high percentages signify a commendable level of public knowledge about these significant climate change-related effects. Moreover, the data reveals substantial awareness of other consequences, including declining river water levels, glacier melting, and changing precipitation patterns, although these topics gathered slightly lower recognition compared to the previously mentioned ones. However, it is noteworthy that ocean acidification was recognized by a smaller percentage of participants, indicating that this particular consequence may require more attention in climate education efforts. Generally, these findings collectively highlight the importance of comprehensive climate education to ensure that the pupils are well-informed about the full spectrum of climate change consequences, including those that may be less commonly known.

The responses to the question regarding the willingness to learn about the consequences of climate change demonstrate a relatively strong interest in acquiring more knowledge on this critical issue (Fig. 7). A significant majority, approximately 73.90%, expressed a clear desire to learn about the consequences of climate change, indicating a proactive approach to understanding and addressing this global challenge. Study conducted in 2015 reported that majority of pupils are willing and open to learn more about climate change in schools (Bello, 2015). Conversely, 26.10% of participants indicated that they are not interested in learning about these consequences, highlighting a segment of the population with limited motivation for further education on this topic. Again, statistically significant difference was observed between youngest and oldest students, where older ones stated that they are not interested in learning about climate change while younger once are more interested ($F = 0.697$; $p = 0.444$). These findings underscore the importance of tailored educational approaches to cater to varying levels of interest and knowledge, among pupils, regarding climate change consequences.

The responses regarding the perceived impact of climate change on one's future life reveal a mixture of opinions and levels of certainty (Fig. 8). A notable majority, approx-

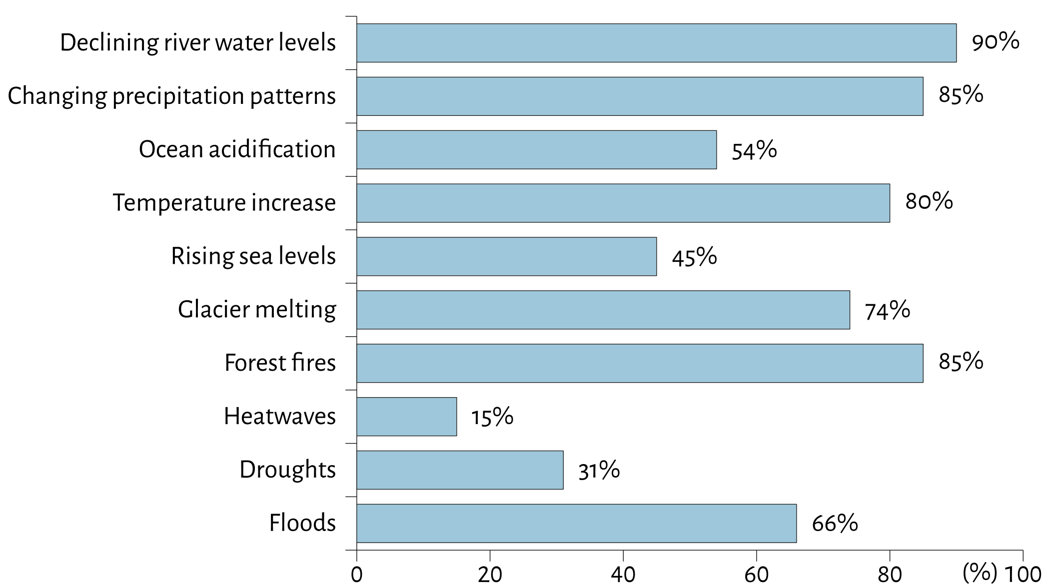

Figure 6. Pupils' opinions on the main consequences of climate change

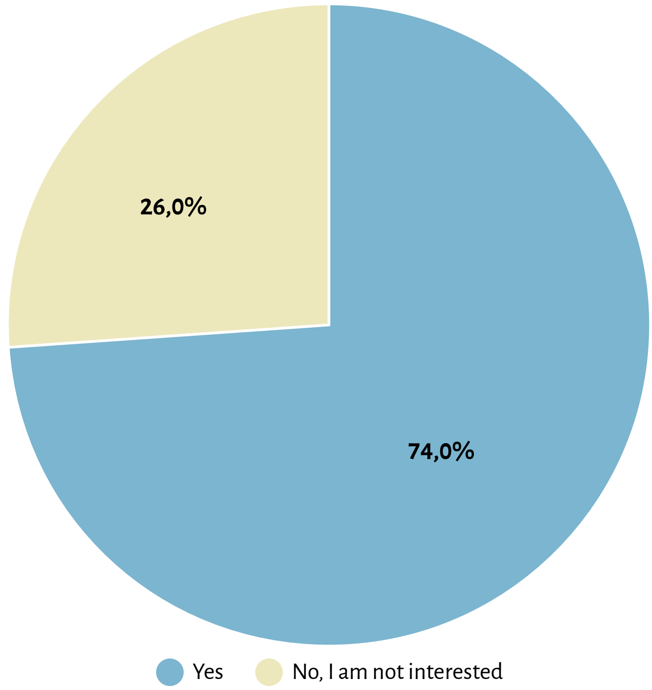

Figure 7. Pupils attitude towards learning about Climate change

imately 54.50%, believe that climate change will indeed affect their future life, underscoring a significant concern about the potential consequences of this global challenge. In contrast, a small percentage, 3.40%, do not anticipate any impact from climate change on their future. It is essential to note that a substantial portion, around 42%, expressed uncertainty by stating “I don't know,” suggesting a lack of clarity or information regarding the future implications of climate change. Interesting is that answers again differ between 5th and 6th graders, even thou previously we showed that 5th graders better understand that climate change are induced by human activity, 6th graders show a better understanding of the influence that changing climate will have on their future. This difference is statistically significant at the level of 95% ($F = 1.812$; $p = 0.020$).

Findings presented in fig. 8 highlight the complex and varied perspectives on the personal ramifications of climate change, emphasizing the need for robust climate education and awareness initiatives to inform individuals about the potential impacts and foster proactive responses to this pressing issue.

Pupils' feelings about climate change are presented in fig. 9 encompass a range of emotions and attitudes. Participants reported a spectrum of emotions, including fear, confusion, worry, disinterest, interest, and curiosity. Climate change awareness is often accompanied by negative emotions, such as fear and frustration about the future (Rushton et al., 2023). However, there is potential to mitigate these feelings through education and awareness-raising activities, which have been previously shown to increase pupils knowledge about climate change and foster more positive environmental attitudes (Karpudewan et al., 2015). Additionally, a portion of respondents expressed other emotions or attitudes not explicitly listed, reflecting the diverse array of individual responses to the complex issue of climate change. Generally, young people in Europe

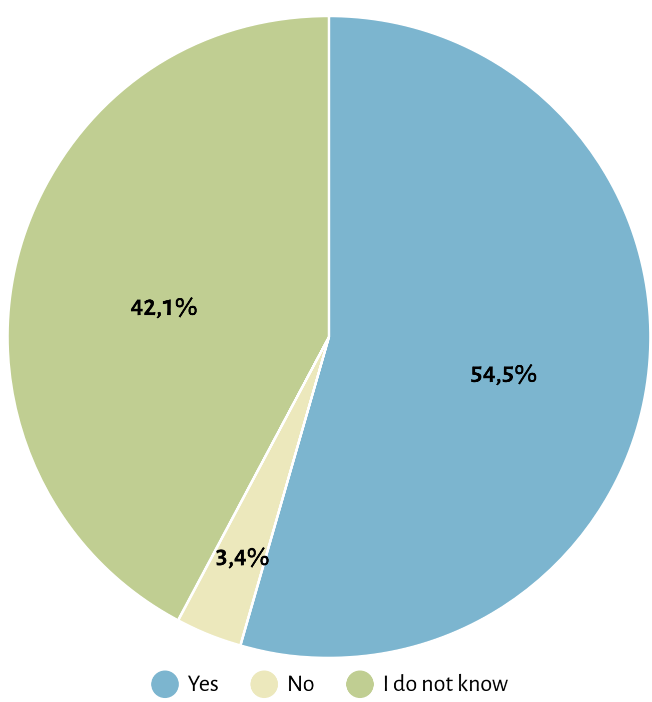

Figure 8. Pupils' opinions on whether climate change will influence their future

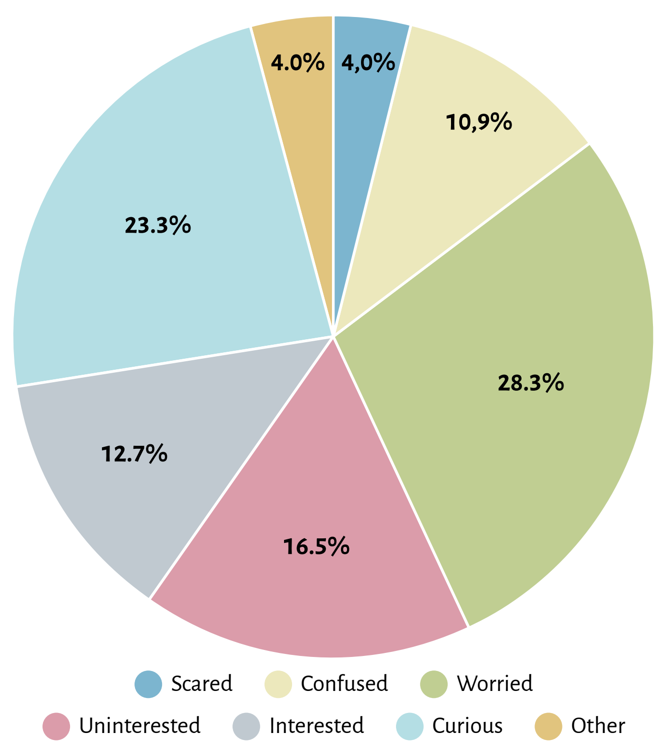

Figure 9. Pupils' sentiments regarding the consequences of climate change

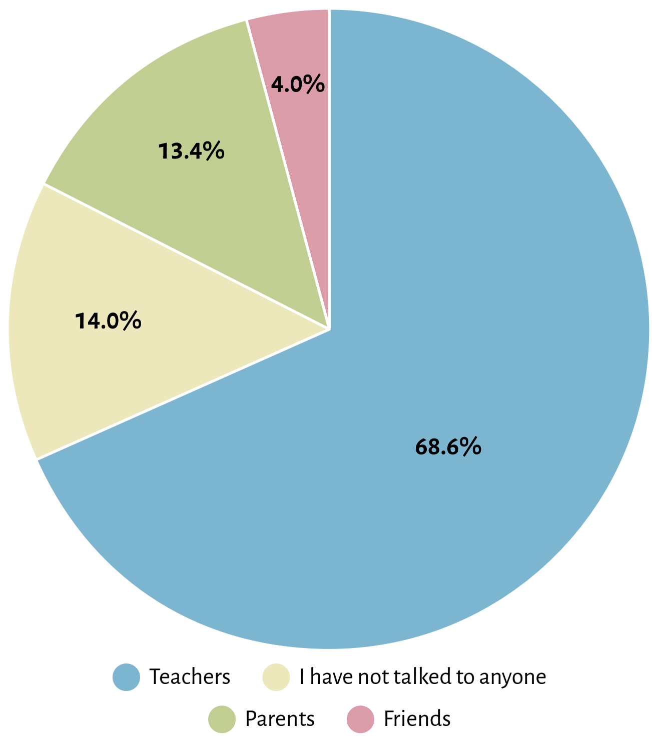

Figure 10. Pupils' responses regarding individuals with whom they have discussed the climate change

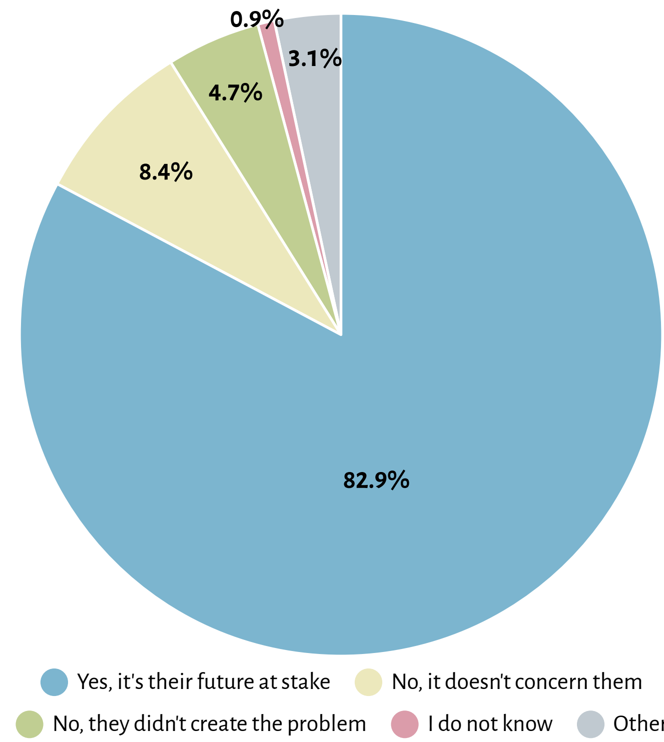

Figure 11. Pupils' opinions on whether young people should be involved in climate change actions

are less fatalistic about climate change, possibly showing the "meaning-focused coping" which enables that severity of climate change threat to be manageable (Smith & Leiserowitz, 2014). But negative feelings are still a prevalent theme of young people's perspectives about climate change (Corner et al., 2015). These findings highlight the need for comprehensive approaches to address both the knowledge gap and the varied emotional and psychological responses that individuals may have to climate change. Such inclusive strategies are crucial for effective climate communication and education.

The responses regarding individuals or groups with whom participants have discussed climate change indicate various sources of conversation and engagement on this topic (Fig. 10).

A significant majority, approximately 68.60% of the pupils reported having conversations with teachers, highlighting the role of educators in facilitating discussions and raising awareness about climate change. This is in good agreement with results reported in 2013 where teachers in primary school are highlighted as the primary source of information about climate change for primary school pupils (Ratinen et al., 2013). Conversely, 14% of pupils indicated that they haven't talked to anyone about climate change, emphasizing a need for increased dialogue and education on this issue. A smaller percentage, around 13.40%, mentioned parents as a source of conversation, suggesting the influence of family members in climate-related discussions. In comparison, 37.4% of primary schools students in Spain indicated family as their main source of information regarding climate change and only 44.5% stated that teacher are the main source of information (Morote & Hernández, 2022). Additionally, 4% of respondents cited friends as individuals with whom they have talked about climate change, indicating the role of peer interactions in fostering awareness. These results underscore the significance of educators and schools as key channels for climate communication, as well as the need for broader outreach and engagement efforts to reach those who have not yet had conversations about this critical global challenge.

The Fig. 11 presents responses to the question of whether young people should get involved in addressing the climate crisis. The data reveals a strong consensus, with approximately 82.90% of respondents advocating for young people's active participation in climate solutions. This coincides with results of the study conducted in Austria where more than 90% of primary school pupils believe that they must contribute to tackling climate change (Feldbacher et al., 2021). This reflects a widespread recognition that young individuals have a significant stake in the future impact of climate change.

Conversely, a smaller percentage, expressed the perspective that the climate crisis doesn't directly concern young people. Additionally, less than 5% of respondents indicated that young people should not be involved because they are not responsible for creating the problem. A very minor percentage, approximately 0.90%, reported

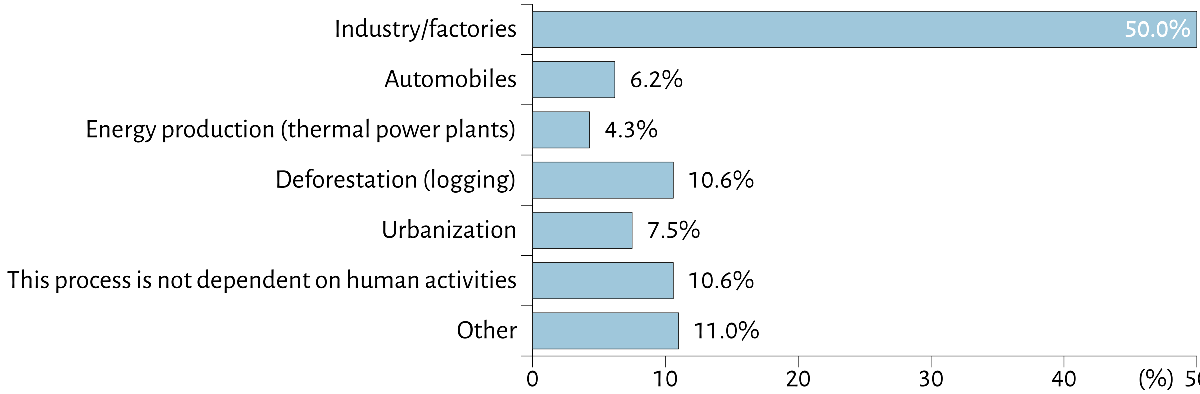

Figure 12. Pupils' opinions on the primary cause of climate change

not knowing whether young people should be engaged in climate solutions, highlighting a potential knowledge gap or uncertainty among this group. A further 3.10% selected "Other," which may encompass a range of nuanced opinions or alternative viewpoints on this matter. These findings emphasize the importance of including young voices in climate action discussions and suggest the need for continued efforts to foster youth engagement and understanding of their role in addressing the climate crisis (Campbell et al., 2013; Messiou, 2012).

The Fig. 12 presents responses to the question regarding the perceived main cause of climate change. The data reflects a variety of perspectives on this critical issue.

A significant percentage, approximately 50%, identified "Industry/factories" as the primary contributor to climate change, highlighting the role of industrial activities in influencing global climate patterns. A smaller percentage, around 6.20%, attributed climate change to "Automobiles," underscoring the impact of transportation emissions on the climate. Additionally, 4.30% pointed to "Energy production (thermal power plants)" as a significant factor in climate change. "Deforestation (logging)" was cited as a primary cause by approximately 10.60% of respondents, emphasizing the consequences of deforestation for climate stability. "Urbanization" was identified by 7.50% of participants, indicating the role of urban development in climate change. An interesting perspective emerges with 10.60% of respondents suggesting that climate change is not dependent on human activities, signaling a belief in natural factors contributing to climate variations. Furthermore, 11.00% chose "Other," indicating a diverse range of views and interpretations on the main cause of climate change. Majority of participants attributed the Climate Change and increase of the carbon dioxide atmosphere to automobiles and factories (Shepardson et al., 2009). In Spain, 70,1% of primary school children stated that pollution from factories is the main cause of Climate Change (Morote & Hernández, 2022). Gender differences are notable, with males attributing climate change more to automobiles (4.1%) compared to females (1.9%), while females attribute it more to industry (27.1%) compared to males (23.4%). Regarding age groups, variations exist in the perceived primary cause of climate change. For instance, industry is cited as the primary cause by 34.7% of respondents in cities compared to 15.8% in villages. Notably, there is a higher percentage of 14-year-olds in cities attributing climate change to urbanization (5.7%) compared to 14-year-olds in villages (1.9%). These findings suggest potential differences in environmental awareness and understanding among different demographic groups, underscoring the importance of tailored educational interventions to address misconceptions and promote a comprehensive understanding of climate change causality. These findings underscore the multifaceted nature of climate change causality and the need for comprehensive approaches to address the various contributing factors and their interconnectedness.

The responses to the question regarding awareness of the Glasgow Climate Pact show a substantial disparity in familiarity with this significant international climate accord. An overwhelming majority of respondents, approximately 90.40%, indicated that they have not heard of the Glasgow Climate Pact. In contrast, a notably smaller percentage, around 9.60%, are aware of this agreement. These results reflect the need for more extensive public outreach and education to ensure that people are informed about and engaged with critical global climate initiatives like the Glasgow Climate Pact, which play a vital role in addressing climate change challenges.

The involvement of young people in addressing the climate crisis is a critical issue, with significant potential for impact. Dunlop et al., (2021) and Sanson and Bellemo (2021) have highlight the role of schools and teachers in nurturing and responding to climate activism, with a focus on overcoming barriers and supporting young people's capacity for action. Narksompong and Limjirakan (2015) have emphasized the need for national policies to adequately educate and engage youth in climate change issues, while Van Den Hazel (2019) underscores the importance of youth as key actors in raising awareness and promoting sustainable practices. The responses regarding the perceived responsibility for addressing the issues that cause or result from climate change reflect a diversity of viewpoints (Fig. 13). A small percentage, approximately 1.90%, believe that the individual ("Me") holds this responsibility. A slightly larger percentage, around 4.70%, view youth as having a role in addressing climate change. Additionally, a minority of respondents, 2.20%, see politicians as responsible, while 24.85% attribute this responsibility to the government. A substantial portion, about 13.40%, places the onus on the international community, while 22.70% look to scientists to address climate change challenges. A noteworthy 24% believe that society as a whole share this responsibility. Furthermore, 6.05% cited other entities or factors not explicitly listed as responsible for addressing climate change issues. Several studies have explored the attitudes and knowledge of secondary school students towards climate change. Abd Hamid et al. (2021) as well have reported that while students were aware of climate change but this did not necessarily translate into action. Similarly, Holmqvist Olander & Olander (2017) noted that students had a general understanding of climate change as a system, but did not often consider their individual contributions. These diverse perspectives underline the complex web of actors and institutions involved in climate change mitigation and adaptation. Addressing this global challenge requires collective effort and cooperation among a wide range of stakeholders, as well as public engagement and awareness to facilitate effective climate action.

The t-test for independent samples compares the mean values between two different groups for the same continuous, dependent variable. Examining the responses of male and female students on climate change revealed nuanced and statistically significant differences in their perceptions and attitudes. Unique patterns emerged on several aspects that included the projected impact of climate change on people, awareness of residents of Serbia, emotional reactions to future climate conditions, communication dynamics about climate change, the role of young people in addressing the climate crisis, and preferences for learning about climate change issues. Notably, there was a significant gender gap in people's perceptions of the impact of climate change. The t-test results showed a mean difference of $t_{(95)} = -0.141$; $p = 0.038$, indicating different views on the severity of the consequences of climate change, with male students expressing greater concern. This is in contrast to the results of the global study reported in 2023 where it is stated that female primary school students are expressing greater concern and negative emotions about climate change, while male respondents are more optimistic (Clayton et al., 2023). There was also a notable gender difference in opinions about awareness of the effects of climate change among residents of Serbia, with a significant mean difference of $t_{(95)} = -0.178$; $p = 0.010$. This emphasizes the difference in views, especially the perception of male students, that the population of Serbia is insufficiently aware of climate change. Female students have expressed greater preference to learn about climate change, with a mean difference of $t_{(95)} = 0.064$; $p < 0.001$. This highlights the difference in levels of interest and curiosity, with female students expressing a greater desire to learn more about climate change. These findings highlight the importance of considering gender perspectives in climate change awareness initiatives, education campaigns and policy formulation. Tailoring communication strategies to address these divergent viewpoints can contribute to a more inclusive and effective approach in promoting climate change literacy and engagement.

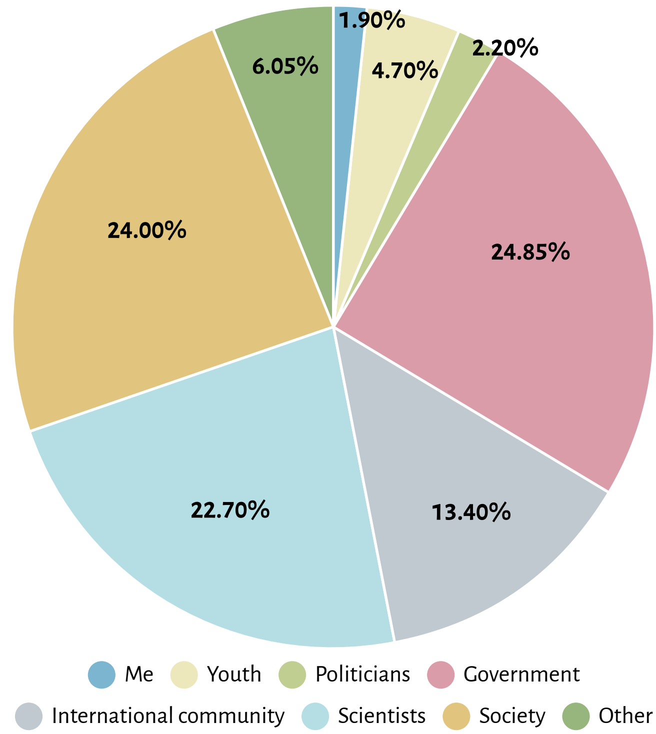

Figure 13. Pupils' opinions on who should address the issue of climate change

Conclusion

The comprehensive examination of primary school children's knowledge, attitudes, and perceptions regarding climate change has yielded valuable insights and observations. The results reveal a diverse landscape of awareness among the participants. While a significant majority have heard about climate change, a noteworthy proportion holds misconceptions, attributing it to natural climate cycles. This highlights the importance of targeted educational efforts aimed at providing accurate information about the drivers of climate change to young individuals. Participants' self-assessment of their climate change knowledge indicates a wide range of confidence levels. While many express confidences, some acknowledge knowledge gaps or a lack of interest. This diversity underscores the need for tailored educational approaches that cater to varying levels of awareness and motivation for climate change awareness. The study identifies schools as the primary source of climate change knowledge, followed closely by television and the internet. This emphasizes the pivotal role of formal education in shaping young minds and fostering awareness. However, the prevalence of alternative resources like social media highlights the need for diversified approaches to disseminate climate information effectively. The multidisciplinary approach to climate change education, primarily through geography and biology classes, underscores the need for a holistic understanding of this complex issue across various subjects. The strong consensus among participants regarding the potential severity of climate change's impact on humans indicates a prevailing concern. This underscores the importance of comprehensive measures and proactive strategies to mitigate climate change effects. The desire of a majority of participants to learn more about climate change topics emphasizes the need for accessible and engaging educational resources catering to diverse preferences and interests. Opinions about the awareness of climate change's impact among the residents of Serbia vary, underlining the importance of educational initiatives and awareness campaigns to inform the public about the issue and its potential consequences. While there is broad recognition of various climate change-related impacts, some consequences have lower recognition levels, particularly ocean acidification, suggesting a need for more focused attention in climate education efforts. The willingness to learn about climate change consequences is strong, but a segment expresses disinterest or a lack of motivation, highlighting the importance of tailored educational approaches for different individuals. The diverse perspectives on the potential impact of climate change on one's future life underline the need for robust climate education and awareness initiatives to inform individuals and foster proactive responses. The broad range of emotional and psychological responses to climate change emphasizes the need for inclusive strategies to address the knowledge gap and diverse reactions to this complex global challenge.

In conclusion, this study underscores the need for targeted climate education efforts, diversified information sources, and comprehensive, multidisciplinary approaches to address varying levels of awareness and interest among primary school children in Northern Serbia. Furthermore, it highlights the importance of encouraging young voices in climate action discussions and fostering informed and proactive responses to the pressing issue of climate change.

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Supplementary file: Survey created and used for this study

Climate Change Awareness Survey

1. Gender
   [] Female
   [] Male

2. Grade
   [] 5
   [] 6
   [] 7
   [] 8

3. Name the locality where your school is located (Not the school's name, just the name of the town/city).
   ____

4. Have you heard about climate change?
   [] Yes
   [] No

5. What is the main cause of climate change?
   [] Natural climate cycles
   [] Human activities
   [] Climate change does not occur

6. How would you assess your knowledge about climate change?
   [] Very good
   [] Good
   [] Neither good nor bad
   [] Bad
   [] Very bad
   [] I am not interested enough to educate myself

7. How do you educate yourself about climate change?
   [] Social media
   [] School
   [] Television
   [] Newspapers
   [] Websites on the internet

8. Which school subject have you discussed climate change and its consequences in? (Open-ended)
   [] Geography
   [] Biology
   [] Chemistry
   [] Physic
   [] Other: _______________________

9. Do you think climate change will have a significant impact on humanity?
   [] Significant impact
   [] Will not have an impact
   [] Nothing will change

10. Would you like to learn more about climate change?
    [] Yes
    [] No

11. In your opinion, are the residents of Serbia aware of the impact of climate change?
    [] They are aware
    [] They are not aware
    [] They do not think about it

12. What consequences of climate change have you heard of? (Multiple answers possible)
    [] Floods
    [] Droughts
    [] Heatwaves
    [] Forest fires
    [] Glacier melting
    [] Sea level rise
    [] Temperature rise
    [] Ocean acidification
    [] Changes in precipitation patterns
    [] Decrease in water levels in rivers and lakes

13. Would you like to know more about climate change and its consequences?
    [] Yes
    [] No

14. In your opinion, will climate change affect your future life?
    [] Yes
    [] No
    [] I don't know

15. How do you feel when it comes to climate change? Are you:
    [] Scared
    [] Confused
    [] Worried
    [] Uninterested
    [] Interested
    [] Curious
    [] Other: ___________________

16. With whom have you discussed climate change?
    [] With friends
    [] With teachers
    [] With parents
    [] I have not discussed it with anyone

17. Should young people get involved in solving the climate crisis?
    [] Yes, it's their future at stake
    [] No, it's not their concern
    [] No, they did not create the problem
    [] I don't know
    [] Other: _____________________

18. In your opinion, what is the main cause of climate change? (Choose three answers)
    [] Industry/factories

[] Automobiles
[] Energy production (thermal power plants)
[] Deforestation
[] Urbanization
[] This process does not depend on human activities
[] Other: ____________________

19. Have you heard of the climate agreement from Glasgow?
[] Yes
[] No

20. In your opinion, who is responsible for addressing the problems resulting from climate change?
[] Me
[] Young people
[] Politicians
[] Government
[] International communities
[] Scientists
[] Society
[] Other: ____________________

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The Impact of the Economic and Social Shocks (Crises) of the 2000s on Gross Value Added in Central-Eastern Europe

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KEYWORDS

crises
territorial inequality
spatial autocorrelation

ABSTRACT

Territorial economic and social disparities remain a major problem for the European Union today, especially in Eastern Europe. The aim of this study is to analyse the impact of the economic and social shocks of the 2000s (the economic and financial crisis of 2008-09 and the COVID-19 pandemic) on the economies of four Central Eastern European countries (Czech Republic, Slovakia, Poland, Hungary). The study presents county-level differences in gross value added with classical descriptive statistics, inequality indices, convergence analyses and spatial autocorrelation. The results show that the impact of the shocks of the 2000s varies across counties, which led to different paths of recovery. Spatial autocorrelation is significant, but patterns remain stable through the period of exogenous shocks.

Introduction

Economic and social disparities at territorial level are a major problem in Europe today (European Parliament, 2019; Iammarino et al., 2019). No two regions have the same characteristics and starting conditions, which in the long run leads to significant disparities (Henderson & Thisse, 2004; Nemes Nagy, 1990). The European Union already mentions the importance of territorial cohesion in the preamble of the Treaty of Rome (1957), which laid the foundations for integration, and this is formally confirmed in the Single European Act of 1986, which elevates regional policy to the level of Community policy as a top priority of integration (Soós, 2020). Regions may differ not only in their initial conditions and socio-economic characteristics, but also in their short- and long-term development paths. In today's globalised world, the factors of production, information and various economic processes (e.g. working capital, trade) are spread globally, but the resulting benefits are very unequal. Local specificities are increasingly important in these rapidly changing circumstances and can contribute to improving the resilience of regions.

Like other external shocks, crises tend to have a significant impact on the development of countries and regions, and sometimes change their development paths. However, the effects can vary widely depending on the type of external shocks (economic, financial, health problems (diseases, epidemics), natural disasters, political conflicts) and the resilience of regions in such circumstances is not uniform.

The aim of the study is to analyse the impact of the economic and social shocks of the 2000s (the economic and financial crisis of 2008-2009 and the pandemic starting in 2020) on the economies of four Central and Eastern European (CEE) countries (Czech Republic, Slovakia, Poland and Hungary), based on the gross value added indicator.

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The aim is to examine whether different types of shocks have different impacts on the economies of the NUTS3 regions of the countries and to what extent the disparities within and between countries change.

Theoretical background

The study of convergence in economic growth theories is not a recent phenomenon, one of the main goals of the EU since the beginning of integration has been the convergence of peripheral regions, a need that has been reinforced by the successive accessions (and the growing disparities that have accompanied them). Over the last decade, rapid and intense technological change and global economic integration have presented regions with new challenges. As a result, the development paths of some regions have improved, while others have failed to adapt to the new challenges. The analysis of territorial disparities is not a recent phenomenon, several researchers have already examined the positive convergence potential and catching-up potential of peripheral regions (e.g. the convergence process of nation states in Barro & Sala-i-Martin, 1992; Quah, 1996; Sala-i-Martin, 1995). In catching up, we need to distinguish between two different processes, which are positive and negative convergence (Szendi, 2016). “Catching up is positive when relatively less developed regions catch up with more developed ones, and negative when the indicators of more developed regions approach those of lagging regions” (Nagyné Molnár, 2007).

In the literature, different types of convergence analyses are used to detect trends in inequalities (e.g. sigma, beta, and gamma tests), which try to explain the development paths of given regions. Sigma convergence examines the dispersion of GDP between regions, i.e. whether the dispersion of incomes decreases over time (Kocziszky & Szendi, 2020). However, it is inherently sensitive to changes in the extreme values, for example, it also reflects the economic decline of relatively more developed regions (the negative catching-up mentioned above) as convergence. The basic idea of beta-convergence is linked to Solow’s neoclassical model, which assumes that the rate of economic growth depends essentially on the growth rates of capital stock and labour (Andrei et al., 2023) and calculates with the change in average GDP relative to the base period. There are two trends in the literature on this method: absolute and conditional beta convergence. The absolute convergence theory states that less developed countries tend to grow faster in absolute terms towards a future steady state, i.e. there is a negative relationship between the initial level of development and the growth dynamics. In this theory, all regions converge to the same steady state. In contrast, conditional beta-convergence assumes that there are significant differences between regions in terms of initial conditions, available factors, and characteristics, so that there is no common steady state for each region, but each region converges towards its own development path (Eckey & Türck, 2007; Mankiw et al., 1992; Szendi, 2016). Based on the above, Quah (1996) analysed the club convergence theory in his work and found that the GDP per capita of nations does not converge towards the same steady state, but that values cluster (due to different initial conditions and differences in income distribution across economies) and convergence is observed in these clusters, which are called convergence clubs.

According to the European Commission’s latest Cohesion Report, since 2000, the impact of substantial structural and territorial funding has reduced disparities between EU Member States (i.e. convergence has accelerated), but internal regional disparities between regions have increased (European Commission, 2022). In 2021, the highest GDP per capita among EU Member States was in Wolfsburg (GER) at NUTS3 region (county) level with €172,100, while the lowest was in Silistra (BG) with €4,200, a 40-fold difference (Eurostat, 2023a). The same situation within the four Visegrad countries (Czech Republic, Slovakia, Hungary, Poland) under study is as follows. The highest value is linked to Prague (CZE) with 44,300 EUR/person and the lowest to the county of Nógrád (HUN) with 6,400 EUR/person. Here the difference is 7x. This indicates a rather large disparity for the Central and Eastern European region as a whole. In NUTS3 level, the inside country differences are the highest in Poland (5.7-fold in 2020), followed by Hungary, Slovakia and the Czech Republic, with 4.59; 3.77; 3.57-fold gap respectively.

Crises can have a major impact on the development of regions, so their analysis is significant as they can have a major impact on the inequalities between them. The European Investment Bank examined the impact of the 2008-09 economic and financial crisis on territorial processes. Their analysis shows that regional economic convergence slowed down significantly in 2008-09, after nearly a decade of rapid convergence (European Investment Bank, 2012), i.e. the catching-up process was slowed down by the economic crisis. Looking at a crisis of a different nature, the OECD (2020) study finds that the COVID-19 crisis highlighted the widening of regional differences in economic growth in Europe. Palomino et al. (2020) measured the impact of policies that emphasised social distancing during the pandemics on poverty and wage inequality in Europe and found that poverty increased, and wage losses occurred during the crisis. This is why it is important to analyse the impact of different types of crises on economic development indicators.

Methodology and data

The aim of the research is to examine patterns and trends in gross value added (GVA) as an indicator of economic development. GVA can be defined as the output (at basic prices) minus intermediate consumption (at purchaser prices), thus reflecting the level of economic growth. Indeed, value added is the difference between output and intermediate consumption (Eurostat, 2023b).

The research aims to highlight the extent to which the crises of the 2000s (external shocks) affected the development of certain regions and whether different types of crises had different effects on the level of development of regions. The territorial unit analysed will be the NUTS3 (county) level in four Central and Eastern European (CEE) countries (Czech Republic, Slovakia, Hungary, Poland). The CEEC region is relatively underdeveloped compared to the EU's northern and western member states and its catching-up is critical for the EU's complex development (Gorzelak, 2020). It is therefore important to examine how external shocks affect the convergence process of these regions. Due to the way the shocks run, the study covers several periods, firstly, the effects of the first and second waves of the 2008-09 economic and financial crisis (assuming that this was a "W" crisis as most of the literature suggests, e.g. Strauss-Khan, 2020), and secondly, the effects of the first wave of the COVID-19 pandemic in 2020[1]. The whole period under study is from 2005 to 2020, which can provide a complex overview of the processes.

The methods used in the analysis are classical descriptive statistics, different types of convergence analysis (sigma, beta and gamma) and spatial autocorrelation analysis, which examines whether neighbourhood effects are significant in the development process.

Results

The logic of the analysis was as follows. First, I checked the distribution of gross value added data in the NUTS3 counties of the four Central and Eastern European countries under study, using basic statistical methods, and checked the changes in the values of the indicator during the crisis periods. After that I examined the inequalities between and within countries in the frames of convergence analyses to get an insight of the complex convergence processes in the region. The last step was to analyse the spatial autocorrelation between counties and the role of neighbourhood effects.

Distribution and patterns of gross value added

Looking at the distribution of the data, there are significant west-east differences within the four countries both at the beginning and end of the period analysed, with the highest values of GVA in the Czech Republic, western Slovakia, some metropolitan areas of Poland and western Hungary, and the lowest values in eastern Slovakia, Hungary and Poland (Figure 1).

The change in the pattern shows that some areas have been able to improve significantly compared to the regional average (e.g. the regions of Sibiu, Eperjes and Banská Bystrica [SVK], Olomouc [CZE], some Polish regions such as the city region of Poznan, Warsaw Eastern Region [POL]), while others underperform compared to the base year (e.g. Karlovy Vary and Ústí nad Labem district [CZE], or, along with others, Borsod-Abaúj-Zemplén, Heves, Hajdú-Bihar or Komárom-Esztergom counties [HUN]). How-

[1] The lack of data for Polish counties does not yet allow for a second wave analysis.

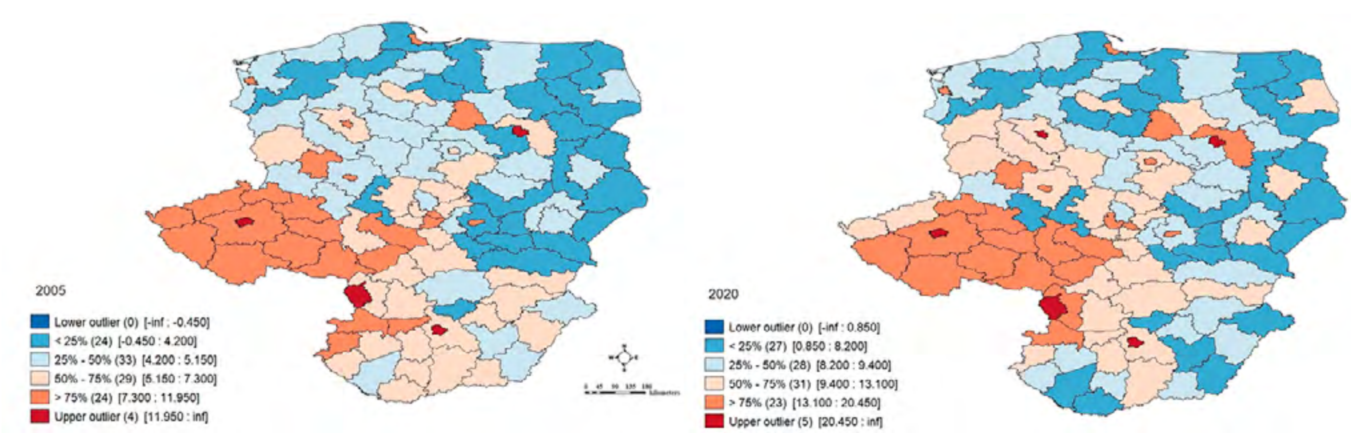

Figure 1. Change in specific gross value added (thousands of EUR per capita) in 2005 and 2020
Source: Based on Eurostat data

ever, it is also true that value added has increased in all the regions examined, so in absolute terms regional performance is improving.

The analysis of the extreme values (maximum and minimum) showed that there was no significant change between the best and worst positions, neither the economic and financial crisis nor the first wave of the pandemic had a major impact on the situation of the best and worst performing counties in the four countries. The only change is linked to the county of Nógrád (HUN), which is in the worst position since 2008, when its performance grew at a slower pace than the gross value added of the former "leader" (worst performer) Nowotarski region (Southern Poland). There was no change in the top position, with the Czech capital, Prague, having the highest per capita GVA over the whole period (Table 1).

Table 1. Extreme values of regional specific gross value added (EUR)

	maximum		minimum	
2005	Prague (CZ)	21780.27	Nowotarski (PL)	3419.68
2008	Prague (CZ)	32439.82	Nógrád (HU)	4121.19
2010	Prague (CZ)	31467.74	Nógrád (HU)	3731.169
2012	Prague (CZ)	30754.29	Nógrád (HU)	3608.669
2019	Prague (CZ)	42523.49	Nógrád (HU)	5551.547
2020	Prague (CZ)	39878.32	Nógrád (HU)	5342.12

To explore the effects of the crises, I have created three time periods to review the impact of the different shocks on the regions. The first period runs from 2008 to 2009, covering the first wave of the economic and financial crisis ('period A'), the second from 2011 to 2012, covering the second wave of the economic and financial crisis ('period B'), and the third covers the first wave of the COVID-19 pandemic from 2019 to 2020 ('period C'). The results show that in period A there were huge declines in county-level gross value added data in almost all areas, with the Hungarian and Polish counties particularly performing extremely poor. The largest declines on the Hungarian side were in Fejér, Veszprém, Komárom-Esztergom and Győr-Moson-Sopron counties (with declines of 22.8%; 18.02%; 18.92% and 18.06% respectively), but Borsod-Abaúj-Zemplén, Békés and Vas counties also experienced specific GVA declines of more than 15%. Among the Polish counties, three regions stand out where the decline in output due to the crisis is close to or even exceeds 20%: Sieradzki (20.87%), Pulawski (19.7%) and Sosnowiecki (19.05%) in the eastern and southern counties of the country. The only area in the whole region that managed to maintain a positive trend during this period was the Bratislava district with a growth rate of 3.9% compared to 2008. The average decrease was 14.8% in Hungary, 12.26% in Poland, 8.03% in the Czech Republic and "only" 4.03% in Slovakia (thanks to the performance of the Capital Region) (Figure 2).

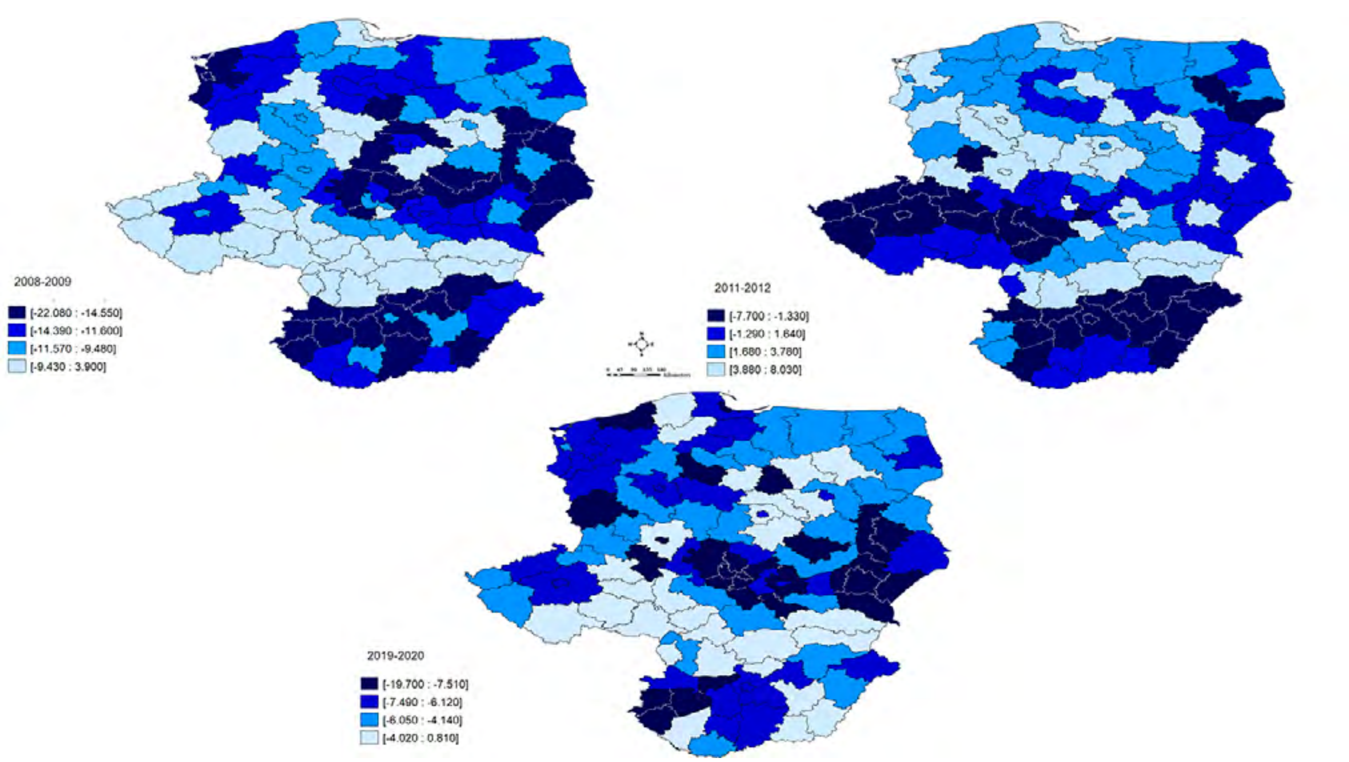

Figure 2. Changes in GVA due to crises

Note: upper left – first wave of the economic and financial crisis (2008-2009); upper right – second wave of the economic and financial crisis (2011-2012); bottom – first wave of pandemics (2019-2020)

Source: Based on Eurostat data

In period B, the impact of the second wave of the crisis was smaller. During this period all districts of Slovakia, except 10 counties in Poland (the remaining 63 regions) and six Hungarian counties, showed a positive trend. It was one of the highest in the city region of Wroclaw, with a maximum of over 8%. The most severe problems were in Hungary (e.g. Komárom-Esztergom, Győr-Moson-Sopron, Heves and Nógrád counties with a loss of more than 5%) and in one Czech county, Pardubice (7.7%). Period C, which quasi measures the short-term effects of the pandemic, shows a more heterogeneous picture than before. With the exception of Poland, one county in each country remained positive in the first wave (all with an increase of less than 1%; CZE: Vysocina district, HUN: Jász-Nagykun-Szolnok county, SVK: Kassa district). The largest decreases were suffered by Poland (6.75%), Hungary and the Czech Republic, with average decreases of 6.18 and 3.63% respectively. In Slovakia the figure was around 2.27%.

Inequality indices (Hoover and Theil index)

The Hoover index is an indicator of inequality that shows "how much or what percentage of the quantity of one characteristic or socio-economic indicator needs to be reallocated in order for its spatial distribution to be equal" (Molnár, 2007). The indicator is usually interpreted in percentage form. Results close to zero imply a homogeneous distribution, i.e. the distribution of indicators is the same across territorial units, while values close to 100 indicate a completely different distribution (Nemes Nagy, 2005). It can be calculated using the following formula:

$$H = \frac{1}{2}\sum_{i=1}^{n} |x_i - f_i| \tag{1}$$

- where Σf_i=100%, Σx_i=100%, for the distribution of the two indicators examined.

The Hoover index as a measure of concentration shows for the four countries under study, that 18.84% of gross value added would have had to be reallocated between the NUTS 3 counties in 2005 in order to bring the distribution of value added into line with the population share of the counties, whereas by 2020 the same value had fallen slightly to 18.42%. The values suggest that the first wave of the economic and financial crisis caused the greatest increase in inequalities between areas, while the other crises caused only small changes. However, the reduction in disparities, by 0.5 percentage points, indicates positive trends (a slight convergence of the region).

A further variant of inequality indicators, the so-called Theil index, is an indicator derived from entropy, which can also be interpreted as an indicator of redundancy, measuring the disorder of the share of the indicator in the total volume of the indicator under study (Nemes Nagy, 2005). The value of this indicator ranges between zero and ∞, where zero indicates an equal distribution and higher values indicate a higher level of inequality (OECD, 2016). It therefore reaches its minimum value when all GVA values are equal and its maximum value when GVA in a region is aggregated (Major & Nemes Nagy, 1999). It can be calculated using the following formula:

$$R = \frac{1}{n}\sum_{i=1}^{n} \frac{y_i}{\bar{y}} log\left(\frac{y_i}{\bar{y}}\right) \tag{2}$$

- where y_i specific indicator in territory i, while y_i is the weighted average of (Nemes Nagy, 2005).

Looking at the results of the Theil index, its values show a slightly different trend from the inequality index seen previously. The value is 0.13-0.14 for the region (indicating relatively low levels of inequality and low levels of data disorder), and has increased slightly over the period under study, with only a few centuries of changes in the values due to crisis events.

Convergence processes of gross value added in Central-Eastern Europe

Convergence analysis was used to look at the catching-up process using three methods (sigma, beta and gamma convergence analysis). The basic difference between the methods is that the sigma convergence is sensitive to outliers due to the use of the average value, and its value can also decrease if there is a decline in the value of more developed areas, so it is worth using the other two methods. Beta convergence, on the other hand, also indicates the reliability of the model with its R^2 value and the fit of the OLS model, while gamma convergence shows changes in the ranking of areas without being sensitive to outliers. However, it does not provide information on the internal structure of the reordering. So, there is a need for the complex application of the three methods.

A basic method of convergence analysis is sigma convergence, usually measured by trends in the coefficient of variation (CV) indicator. If the relative dispersion of gross value added relative to the average decreases over time, then the phenomenon of sigma convergence is fulfilled (Szendi, 2016). The indicator can be calculated as the ratio of the dispersion to the average value.

$$CV = \frac{st.deviation}{average} \tag{3}$$

The results show that the CV indicator vary from year to year, but when looking at the whole time span, the following can be confirmed. At the within-country level, Slovakia and Hungary showed sigma convergence, the Czech Republic showed sigma divergence, while Poland showed a slight sigma divergence or rather stagnation. At the cross-country

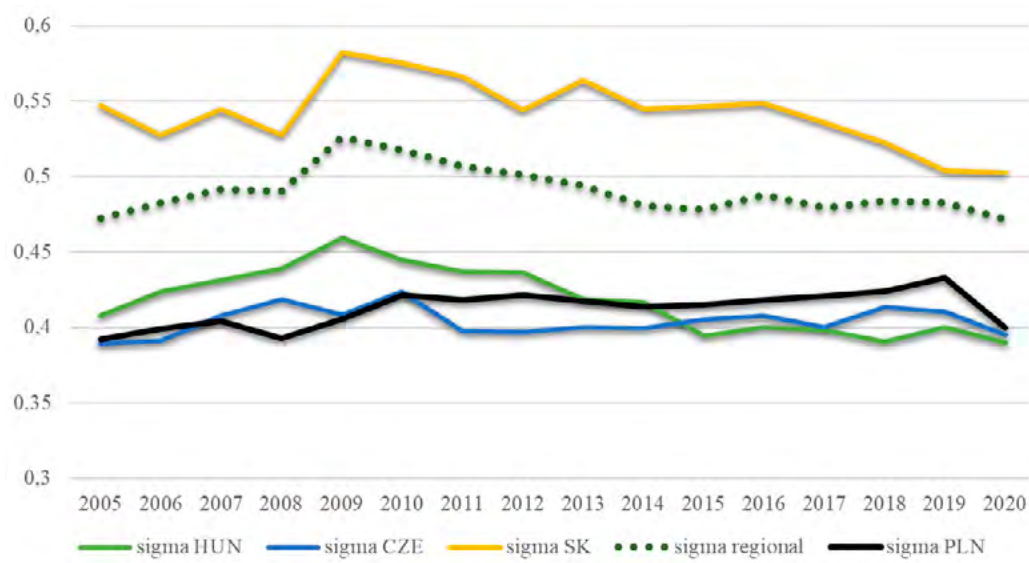

Figure 3. Sigma convergence within and between countries (2005-2020)
Source: Based on Eurostat data

level, we see sigma convergence over the whole period (Figure 3), which suggests a catching-up process between territories, but it could also be the result of uneven development (where more developed territories face more problems than less developed ones). The sigma convergence indicator is therefore adequate but does not by itself provide sufficient data to fully reveal the convergence process (Andrei et al., 2023), as it may also indicate a decline when the initially more developed areas are in a recession. Therefore, I have checked the beta and gamma convergence values.

To examine beta-convergence, we check the regression equation between the annual growth rate of GVA per capita and the GVA in the initial year. If the beta coefficient is negative and significant, then beta-convergence is satisfied (Ferkelt, 2005). In the analyses, similar to the previous study, I have reviewed the trends at both the national and regional levels, with the following results.

Beta convergence has been tested without the distorting effect of the capital regions, which has indicated a slightly stronger convergence process among the territories with R^2 of 5.52%.

The model results show that the linear equation explains 2.6% of the variance of the values (Table 2 and Figure 4), while the F-statistic value confirms the null hypothesis, which supports the validity of the model (significant at the 10% level). The multicollinearity condition is 4.44, which is lower than the benchmark value of the indicator, suggesting that there is no confounding degree of multicollinearity between the variables (Tóth et al., 2023). To test the normality of the residual, I used the Jarque-Bera test. The

Table 2. Beta convergence results of gross value added in the Visegrad countries (NUTS3)

REGRESSION OLS METHOD			
	Coefficient	Std. error	Prob.
Constant	4.96219	0.220241	0.00000*
Log of "initial year"	-0.0580751	0.033171	0.08272**
R-squared		0.026639	
F-statistic		3.06523	
Prob(F-statistic)		0.0827218**	
Multicollinearity Condition Number		4.448751	
Jarque-Bera test		3.3469	0.18760
Breusch-Pagan test		0.4249	0.51448
Koenker Bassett test		0.4226	0.51562
Log likelihood		-161.468	
Akaike info criterion		326.936	
Schwarz criterion		332.408	
half-life	11.6		

**Significant at 1%*
***Significant at 10%*

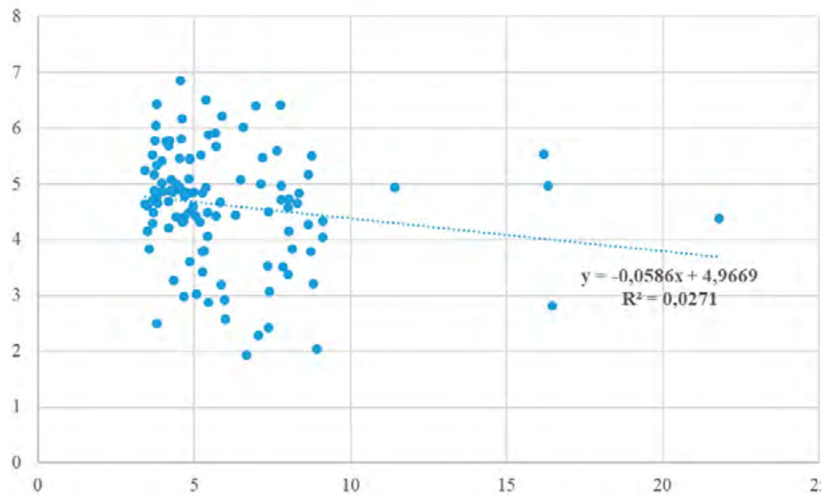

Figure 4. Interregional beta convergence between countries (2005-2020)
Source: Based on Eurostat data

associated probability value for this test is 18.76%, which indicates that we cannot reject the null hypothesis, i.e. the robustness of the data under test can be verified.

Overall, the results are uneven based on beta convergence, as shown also by the sigma. In Hungary and Slovakia there was beta convergence between counties, but the dispersion of the data is very unequal. The Czech Republic and Poland show beta divergence between 2005 and 2020. However, beta convergence has been achieved in a total of 115 NUTS3 regions in the four countries. An analysis of annual growth rates of value added shows that the Slovak and some Polish regions have grown fastest in regional terms.

A significant measure of the convergence process is the half-life, defined as the time needed for economies to complete half of the deviation from their steady state (Arbia et al., 2005). In the case of the OLS model it is 11.6 years.

The concept of gamma convergence was introduced by Boyle and McCarthy (1999) in the context of economic analysis. The index measures how the ranking of each area has changed compared to the base year:

$$\gamma = \left(\frac{var(RGDPC_{ti} + RGDPC_{t0})}{var(RGDPC_{t0} \cdot 2)} \right) \quad (4)$$

where *var* (*RGV AC*)denotes the variance of GVA per capita, while t_i is the current year under consideration, t_0 is the base year.

The gamma convergence shows decreasing variance in all territories and scales analysed (i.e. catching up), and small ranking shifts both within and between countries (Table 3).

In the case of convergence analyses, however, it should be noted that different crisis situations and shocks may lead to different trends, as the periods A, B and C mentioned above had a major impact on the development of the regions. Looking at the periods, in terms of sigma and beta convergence, the first wave of the 2008-2009 crisis (A) resulted in greater divergence both nationally and in the wider region, with the exception of the Czech Republic, while periods B and C brought divergence and convergence. Gamma convergence is more sensitive to the crises, with all three periods showing decreasing divergences in the region as a whole. The countries, with the exception of Slovakia (where the ranking remains constant during the crisis), experienced more severe rearrangements (Hungary and Poland convergent trends, while the Czech Republic showed increasing divergences in all three periods). These results may be related to the relative position of the areas and the changes in their position, so the examination of the neighbourhood effects is significant.

Table 3. Beta and gamma convergence analysis of regional gross value added

	Beta convergence	Gamma convergence
Hungary	y = -0.0558x + 3.3739 R^2 = 0.0649	2005: 2.244 2020: 2.215
Slovakia	y = -0.0563x + 6.4319 R^2 = 0.3604	2005: 2.155 2020: 2.107
Czech Republic	y = 0.0052x + 4.26 R^2 = 0.001	2005: 2.241 2020: 2.228
Poland	y = 0.0024x + 4.9446 R^2 = 0,0000005	2005: 2.247 2020: 2.205
Cross-country level	y = -0.0586x + 4.9669 R^2 = 0.0271	2005: 2.233 2020: 2.212

Source: Based on Eurostat data

Spatial autocorrelation analysis

The importance of the role of space in the analysis of spatial inequalities is significant in the light of the first law of geography: “everything is related to everything else, but near things are more related than distant things” (Tobler, 1970).

Spatial autocorrelation is a method of studying spatial interactions by examining whether the spatial distribution of individual values of gross value added is random or follows some regular pattern (Dusek, 2004). Autocorrelation can be measured globally (using the Moran I index) and locally.

Moran I statistics can be used to test both global spatial autocorrelation and local spatial autocorrelation. Therefore, I tested the global autocorrelation of the value added under 999 permutations (Table 4).

Table 4. Spatial autocorrelation diagnostics based on Moran I (2020)

	Moran I/ Degrees of Freedom	Value	Prob
Moran's I (error)	0.5361	8.7733	0.00000
Lagrange Multiplier (lag)	1	73.0781	0.00000
Robust LM (lag)	1	6.0810	0.01366
Lagrange Multiplier (error)	1	69.7115	0.00000
Robust LM (error)	1	2.7144	0.09945
Lagrange Multiplier (SARMA)	2	75.7925	0.00000

The index of global autocorrelation (0.53) indicates a moderately strong positive autocorrelation, which supports the extension of the analysis to neighbourhood effects. It also implies that gross value added in each county is positively related to its neighbours. Looking at the variation, there was no significant shift in the Moran I value over the period analysed (initial year 2005: 0.479).

Among the tools of the local spatial econometric methods, I chose the Local G* indicator, which is an indicator of the local spatial autocorrelation of each data point. The indicator is not sensitive to spatial outliers (and thus does not indicate spatial outliers, such as Local Moran I) and can be calculated using the following equation.

$$G_i^*(d) = \frac{\sum_{j=1}^{n} w_{ij} x_j}{\sum_{j=1}^{n} x_j} \quad (5)$$

where d is the neighbourhood distance, and w_{ij} is the weight matrix, which is a queen-contiguity neighbourhood matrix (with symmetric distribution). Positive G_i^* represents the local clustering of high values (hot spots), while negative G_i^* represents local clustering of low values (cold spots).

The results show that local spatial autocorrelation is significant in several areas. In general, it is true that the crises have not led to a substantial change in the distribution of clusters (Figure 5), with an overall reduction in

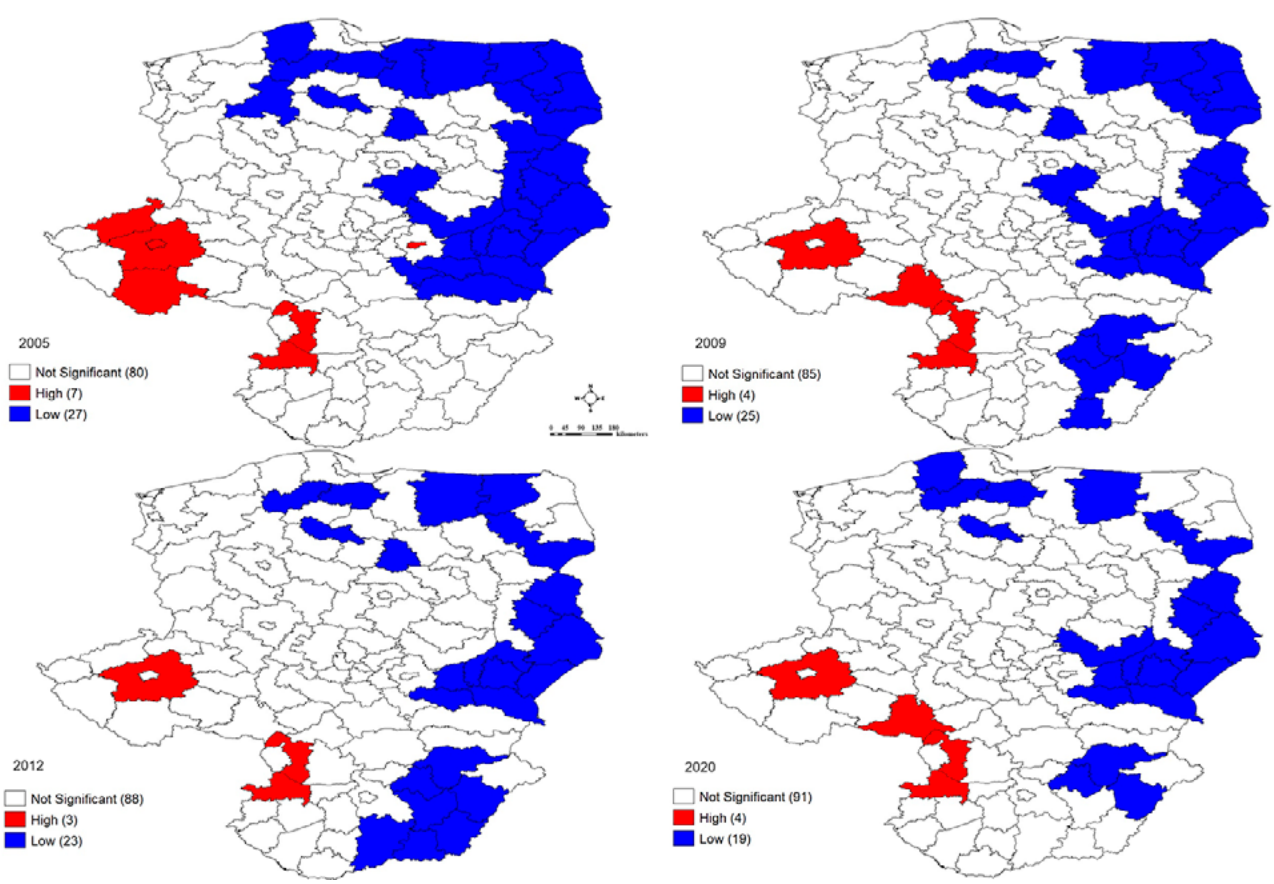

Figure 5. Analysis of the local spatial autocorrelation of GVA 2005, 2009, 2012, 2020
Source: Based on Eurostat data

the number of clusters but no significant change in the location of hot and cold spots. The following areas have been hot spots in all periods: the District of Trnava (SVK), Stredny Czechy (Central Bohemia, CZE), Győr-Moson-Sopron County (HUN). In addition to these, other Czech districts have periodically appeared as hot spots.

The range of cold spots is broader: most of Eastern Poland throughout the period (e.g. Elcki, Bialski, Lubelski or Olstynski districts), the district of Eperjes at the beginning of the period, and from 2009 onwards several Hungarian counties (e.g. Borsod-Abaúj-Zemplén, Heves or Hajdú-Bihar are stable members of the group), which were also formed partly because of the crises.

The spatial autocorrelation analysis thus demonstrates that the spatial distribution of data and the role of neighbourhood effects are important for economic development, but less sensitive to external shocks. The spatial patterns are fairly stable, but the results may be modified by the addition of other areas to the study area (e.g. integration of Romania or Bulgaria). Since the spatial autocorrelation is significant, it is worth extending the results of the previous convergence study to include spatial effects, so I tested the role of neighbourhood relations in beta-convergence. This is because, if the spatial units are related, the traditional OLS regression estimation may not yield reliable results.

Two of the most common methods for econometric modelling of spatial autocorrelation are the spatial lag model and the spatial error model (Varga, 2002). Spatial lag is the weighted average of the neighbouring values of a given observation unit.

General form of the spatial autoregressive model (Gerkman & Ahlgren, 2011):

$$y = X\beta + \rho W y + u \tag{6}$$
$$u = \lambda M u + \varepsilon$$

ρ and λ scalar spatial autoregressive parameters. Two special cases can occur if either ρ=0 or λ=0. If ρ=0, then the model is a spatial error model (contains a spatially lagged error term), and if λ=0 the model is a spatial lag model (contains a spatially lagged dependent variable).

The spatial error model (SEM) assumes that only the error terms in the regression are correlated, while the spatial lag model (SLM) examines how the GVA growth rate of regions depends on their own initial value added level and how this is affected by the growth rates of neighbouring regions (Andrei et al., 2023).

To select the appropriate spatial autocorrelation model, I used the classical procedure presented by Anselin (2005), which allows to decide between the SLM model and the SEM model based on Lagrange Multiplier tests. Since both the LM-Lag and LM-Error models are significant (p-value 0.0000), the robustness tests are considered. The significance of the lag model is lower among the robust tests, I decided to use it. This assumes that there is autocorrelation between different levels of the dependent variable. The results of the model are shown in Table 5.

Table 5. Parameters of the spatial lag model

	Value
Mean dependent variable	4.61368
S.D. dependent variable	1.01101
Lag coefficient (Rho)	0.746646
R-squared	0.526283
Sigma-square	0.484203
S.E of regression	0.695847
Log likelihood	-129.329
Akaike info criterion	264.657
Schwarz criterion	272.866
W_log annual growth rate	0.746646 (0.0000)
Constant	1.26648 (0.00032)
Log of "initial year"	-0.020726 (0.36701)
Half-life	34.31

Since the analysis of R^2 is not relevant in spatial regression models (Anselin, 2005), I considered the values of the Log-Likelihood, the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC). When comparing the Log-Likelihood values of OLS (-161.46) and SLM (-129.32), a higher value is observed for SLM. This is also supported by the Akaike Information Criterion (AIC) and the Schwarz Criterion (SC).

The model estimates the spatial autoregressive coefficient to be 0.74, which is significant at p-value (0.0000). The spatial lag model and the classical LOG model of GVA differ slightly. However, the spatial lag model suggests a slower catch-up than the OLS estimate (based on the constant and log base values), which can be underlined by the half-life values (this latter is 34.31 years by the spatial lag).

Conclusion

The aim of the study is to test the convergence and autocorrelation of gross value added in Central-Eastern Europe. The results show that the impact of the shocks of the 2000s varies from one region to another, with some areas being able to increase their level of value added even in times of crisis. Almost all areas were deeply affected by the first wave of the economic and financial crisis, but the second wave and the first wave of the pandemic had a relatively smaller impact. In general, Hungary and Poland experienced the strongest downturns, followed by the Czech Republic and Slovakia, except in 2012 when the Czech Republic was one of the worst hits. Analyses of convergence at the intra- and inter-country level show that between 2005 and 2020, sigma convergence was mostly achieved between countries and within the four-country region, while beta convergence was achieved in Hungary, Poland and Slovakia, and in an interregional context. This indicates that the ranking of areas within countries has also changed, as evidenced by the gamma convergence of values. The difference in the results for sigma and beta convergence suggests that there has been a negative convergence process between regions over the period under study, i.e. the more developed regions have seen their indicators decline and converge with those of less developed areas. The spatial autocorrelation is significant in the area, but there is no significant change in the pattern of hot and cold spots, so the spatial patterns are not very sensitive to external shocks. The different nature of the areas and their initial conditions suggest that they have followed recovery paths from crises of different intensities. Thus, the first and second waves of the economic and financial crisis and the pandemic have had an uneven impact on the region's departments, which has further increased spatial disparities. Their convergence is best described by a spatial lag model.

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A Parametric Approach for Evaluating Solar Panel Insolation in Urban Areas: Courtyard Design Case Study

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KEYWORDS

stand-alone solar panel
insolation
ladybug
parametric approach
building shade

ABSTRACT

Stand-alone solar panel orientation (tilt and azimuth angles) for potential locations in built-up urban areas, significantly influences the level of insolation received by the panel. One way to maximize energy production involves finding the optimal orientation for each location to ensure the highest insolation for a certain number of solar panels in urban areas. The general rule used in practice is to orient the panels towards the south and calculate the horizontal tilt angle based on the latitude. However, in built-up urban areas, a more comprehensive analysis of other factors is needed, such as solar radiation levels, weather data, and shading cast by nearby buildings. In this research, a parametric approach aimed at determining the optimal orientation of stand-alone solar panels for a predefined set of potential locations is designed. Input parameters are the geometry of nearby buildings, solar panel shape, and weather data for the urban location. The approach's adaptability to different geographic locations and urban environments is achieved by adjusting input data. Comparative analysis between insolation values with the optimal orientation of solar panels and those commonly employed in practice is used for evaluation. The proposed approach is applied to determine the tilt and azimuth angles of fixed stand-alone solar panels in urban courtyards in order to improve decisions regarding the distribution of solar panels in urban planning practice. This study examines solar panel insolation in simplified geometrical representations of some urban areas with courtyards.

Introduction

The orientation and locations of solar panels is an important aspect in architectural and urban design due to their capacity to harness and convert solar energy into electrical energy (Moghadam et al., 2011; Moghadam & Deymeh, 2015; Ashetehe et al., 2022). This research focuses on the fixed stand-alone solar panels, as fixed panels have been shown to be the most cost-effective (Michaelides et al., 1999; Mousazadeh et al., 2009; Kanyarusoke et al., 2015). Many studies (Elminir et al., 2006; Berrill & Blair, 2007; Gunerhan & Hepbasli, 2007; N'Tsoukpoe, 2022; Bahrami et al., 2022) have recommended that fixed solar panels in the northern hemisphere should be oriented south-facing with the optimum tilt angle that depends on latitude.

Solar radiation is site-specific, with monthly, seasonal, and yearly variations, and the optimal orientation and location of solar panels for capturing maximum solar radiation is different in each urban location (Yadav & Chandel, 2013). Recent studies aim to enhance the location

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(Moghadam & Deymeh, 2015; Díaz-Dorado et al., 2011) or alter the tilt angle of the solar panel (Tang & Wu, 2004; Nfaoui & El-Hami, 2018; Jing et al., 2023), and some studies analyze both the tilt angle and orientation of solar panels (Kacira et al., 2004; Skeiker, 2009; Jafarkazemi & Saadabadi, 2013; Markam et al., 2016) in order to improve energy efficiency. In built-up urban areas, the complex surroundings make predicting the optimal orientation and location accurately harder, emphasizing the importance of considering all three parameters in solar simulations: location, tilt and azimuth angles.

Geometry of the built environment have impact on urban surface level of insolation (Bajšanski et al., 2019; Milošević et al., 2017). However, in dense urban areas, the built environment acts as a barrier affecting solar panel insolation, leading to a substantial reduction in a solar panel's power (Ratti et al., 2005; Vulkan et al., 2018) even a small part of it is shaded (Karatepe et al., 2008; Ibrahim, 2011; Aslani & Seipel, 2023). Studies by Xie (2023) and Zhang (2019) emphasize the significance of the built environment for solar potential, highlighting the correlation between urban morphology and the possibility of orienting and locating solar panels.

In the studies done by Moghadam and Deymeh (2015) and Siraki and Pillay (2012) impacts of shading from the built environment on the insolation level of stand-alone solar panels are considered. However, the research is confined to urban areas surrounded by two tall buildings, providing recommendations specific to these scenarios. Díaz-Dorado's (2011) study demonstrates the importance of considering shading for the best location of photovoltaic solar trackers on a building with an irregular shape. Amado and Poggi (2014) employ urban shadow simulation to quantify the solar energy potential of photovoltaic systems in the urban context, aiming to enhance city energy performance.

In this study, a parametric approach is used to determine the tilt and azimuth angles of fixed stand-alone solar panels in order to maximize the insolation of a panel. The case study demonstrate how this approach is used to optimize other courtyard elements layout. By importing urban location data, weather data, and a 3D model of the courtyards, this approach simulates insolation levels of stand-alone solar panels for predetermined urban areas in any city and urban morphology. The geometry of the courtyards, cast shadows, location data, and weather data specific to the corresponding urban location are taken into account in the simulation. The approach is applied in different courtyards, aiming to enhance decisions regarding the distribution of solar panels and other urban elements in urban planning practice.

Apart from previously mentioned research that pertains impacts of shading from the built environment on the insolation level of stand-alone solar panels, method presented in this research takes account distribution of other urban elements as a part of urban design process. Method is designed to fit the modeling workflow commonly used by urban designers. The advantage of our approach over alternative approaches (such as models that quantify the solar energy potential of photovoltaic systems) is the ability to combine 3D modelling, parametric design and environmental analysis in the same CAD environment familiar to architects and urban planners in urban planning practice. Compared to PVsyst and other similar software, the integration of Rhinoceros, Grasshopper and Ladybug, used in this study, allows application of the optimization algorithms of the other urban elements which use solar panel energy in CAD environment.

Method

In order to calculate solar panels insolation for each predetermined location in some courtyards, a parametric approach consists of following phases:

1. Import the 3D geometry of the courtyard
2. Solar panel orientation procedure
3. Solar panels insolation simulation and calculation
4. Export numerical results

The first phase is modelling geometry representing the courtyard in any 3D modelling program. The 3D model includes:

– buildings geometry that can affect the shading of the solar panel;
– a set of points representing all possible solar panel locations.

Buildings and points are fixed and can be created in or imported to Rhinoceros 3D, a computer-aided design (CAD) program, to provide a digital environment for parametric study. Buildings are modelled as non-transparent solid forms that casts full shadows. Geometric characteristics of buildings are base shape, height and façade details that influences solar panel insolation. The points can be created as set of points distributed along the given path or grid. Each point represents a potential solar panel location, numbered from to . Buildings and points are referenced inside the Grasshopper (Rhinoceros plug-in), a visual programming language, and visualised into Rhinoceros 3D. Simplified representation of the buildings and potential solar panel locations are presented in Figure 1.

The second phase refers to the automatic change of the orientation of the solar panel inside the Grasshopper. All the

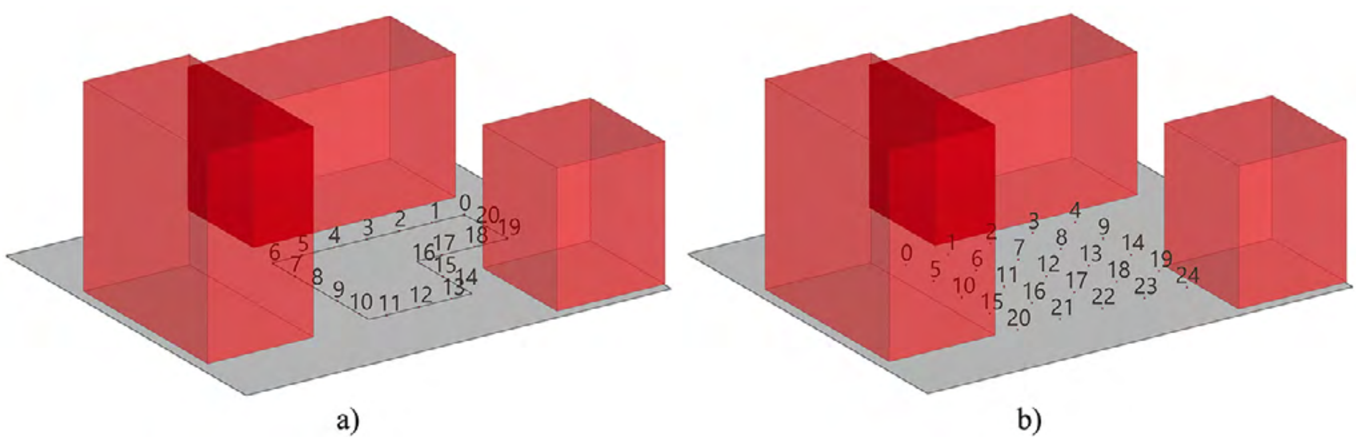

Figure 1. Representation of referenced buildings geometry and potential solar panel locations as a set of numbers distributed along: a) polygonal path; b) grid

possible combinations of locations, tilt and azimuth angles are generated and linked to a solar panel represented as a plane in Grasshopper. Solar panel is generated as a rectangular shape, and its orientation is determined with parameters of tilt angle (β) and azimuth angle (γ). The tilt angle β rotates around *y-axis* and its value varies from 0° (horizontal surface) to 90° (vertical surface), for the step of 1° where 0° $\leq \beta \leq$ 90. The azimuth angle γ, rotates around the z-axis and its value varies for the full circle rotation from 0° to 359°, for the step of 1°, -180° $\leq \gamma \leq$ 180°. The azimuth angle is measured clockwise, with zero due south, -90° for eastward, +90° for westward, and ±180° for northward-oriented surfaces (Figure 2). The number of tilt angles is 91 (0-90) and the number of azimuth angles is 360 (0-359).

The process for automatically changing solar panel tilt and azimuth angles in order to maximize solar panel insolation was created. To examine all combinations of tilt and azimuth angles for a solar panel, the number of tilt angles is cross-referenced with the number of azimuth angles. The number of combination for one location is multiplication product of all tilt and azimuth angles - 32760. The total number of combinations for all locations is the multiplication product of the number of tilt angles, the number of azimuth angles, and the number of all possible locations.

The third phase is the simulation and calculation of insolation in Ladybug, an environmental analysis software (Grasshopper plug-in). Ladybug can take into account geometry of buildings, weather data and any time and year period of analysis set. The Ladybug software calculates the average insolation of a solar panel in kWh/m^2.

In order to perform the simulation of insolation, it is necessary to introduce a sky matrix value. To calculate the sky matrix value, which describes the radiation coming from each patch of the sky dome, the following input data from the weather file must be considered: location data, such as longitude, latitude and elevation, direct normal and diffuse horizontal radiation and the period of the year. The analysis period of the year can be set to take into account different hour intervals for each month. Since the panel's tilt and azimuth angles are fixed, we analysed the entire year period. The analysis period is chosen from sunrise to sunset for each month (World Data Info, 2023). For this study, the geographical location of Belgrade, Serbia (44°82' N and 20°28' E) was selected. According to the Köppen-Geiger climate classification (Kottek et al., 2006; Fricke et al., 2022), Belgrade has a Cfa climate with a mean annual insolation value of 2112 hours, a maximum monthly value in July with 291

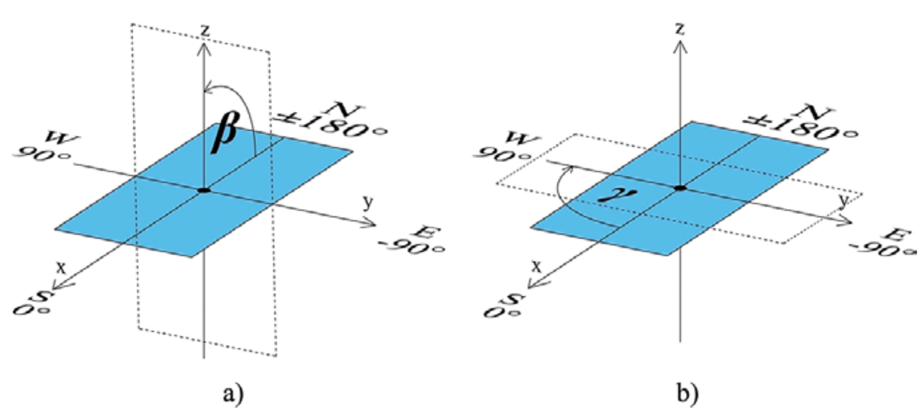

Figure 2. Solar panel a) tilt angle b) azimuth angle

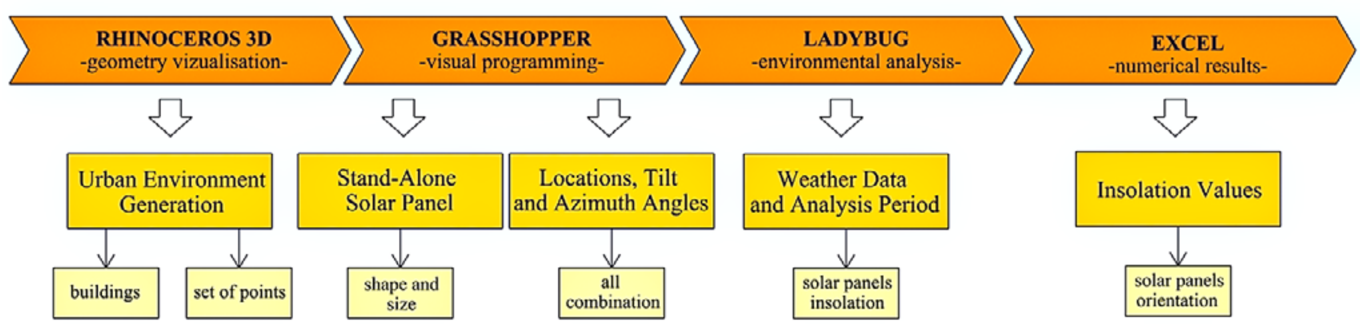

Figure 3. Workflow representation based on the used CAD software applications

hours, and a minimum in December with 65 hours (Stojaković et al., 2020).

The solar simulation is performed for each combination of tilt and azimuth angles at one location. 3D geometry of the buildings is fixed on site, whereas the tilt and azimuth angles are automatically changed and solar simulation are performed. When the solar simulation is finished for one fixed tilt and one azimuth angle, the process repeats solar simulation for the same fixed tilt and another azimuth angle. The process lasts until the list of all combination of the tilt and azimuth angles is finished. A list of insolation values is created for each combination of tilt and azimuth angles for one solar panel location. The maximum insolation value implies the optimal orientation of the solar panel for given location. After calculating the insolation values at one location, the location of the solar panel automatically changes, and a calculation of the insolation values for each combination of tilt and azimuth angles at a new location is performed. The process calculates insolation values until all predetermined solar panel locations are examined.

The fourth phase is the export of all numerical results in order to detect the all values of insolation, which corresponds to the certain location and orientation of the solar panel for a created courtyard, selected location, weather data and analysis period.

The workflow of the designed approach is presented in Figure 3, illustrating the relationship between various CAD software applications. The proposed approach for evaluating solar panels insolation in urban courtyards takes into consideration 3D creation of buildings and points, which is done in the Rhinoceros software environment. In the Grasshopper, visual programing software application, the parametric definition for automatically changing solar panel orientation and location was created. The geometry of solar panel with certain tilt and azimuth angles appears into Rhinoceros as a surface that receives the solar energy. Geometry of the buildings, solar panel and weather data are used in the Ladybug, environmental software application, performing calculation of solar panels insolation. In the end the data is imported into Excel for statistical data analysis, comparison and detecting optimal solution.

Results and Discussion

Method presented in previous section is further tested on two case studies. First , the influence of building height and orientation of generic rectangular block is tested in order to demonstrate the variability of solar panel insolation improvement depending of the environment properties. After that, the method is applied to the example that demonstrates it's ability in urban courtyard design.

A simple urban block with courtyard

To test the intensity of the shade from surrounding buildings on the insolation of solar panels, we initially conducted a test on a simplified urban block with courtyard. This test is done to demonstrate the approach application and to investigate how variability of the surrounding buildings influence the distribution insolation improvement. Buildings are situated on a flat surface and form a square courtyard, measuring 30 m × 30 m. Four buildings are positioned around the courtyard. In this example a standard 72 cell configuration of rectangular solar panel measuring 1.9 m (length) by 1 m (width) (Solar Panel Size, 2023) is used. The distance between the center of the solar panel and the ground level is 4 m.

The influence of the height of buildings on solar panels insolation

In order to detect the range of building heights that have a significant influence on the insolation values of solar panels, we used a simple closed urban block measuring 30 m × 30 m. The heights varied from 0 m to 60 m. Nine panels were evenly distributed between buildings. The average insolation of a panel is calculated for different (mutually equal)

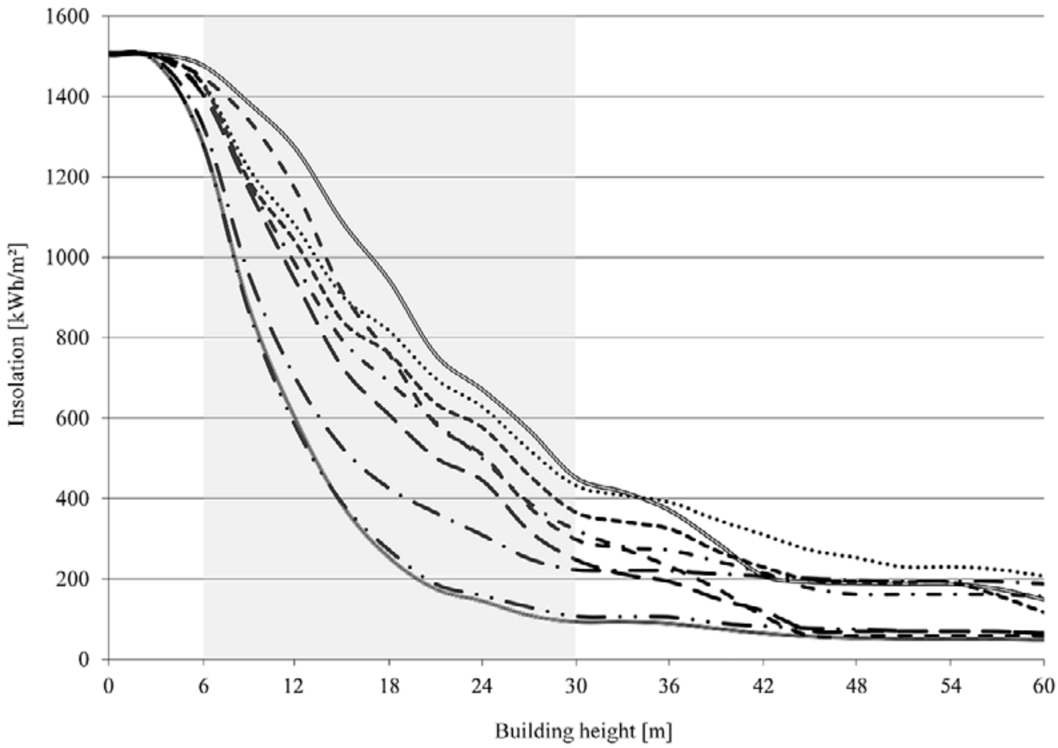

Figure 4. Correlation between buildings heights and solar panel insolation

building heights. The influence of building shade for all nine panel locations is shown in Figure 4. When the buildings' height is lower than the height of the panels, all solar panels are exposed to solar radiation all the time, and building shade has no effect. On the other hand, when the buildings' height is above 30 m, the solar panels are mostly in the shade, and the average insolation varies from 2.3% to 20% of the maximum insolation value. Due to this analysis, building heights of less than 6 m and greater than 30 m are considered irrelevant for this urban block morphology.

Table 1. The type of variations with corresponding building heights

Variations									
I	II	III	IV	V	VI	VII	VIII	IX	X
Buildings heights [m]									
30	15	21	30	21	15	6	6	21	30
6	6	15	21	15	30	15	21	6	15
15	21	30	6	6	21	21	30	15	6
21	30	6	15	30	6	30	15	30	21

The influence of tilt and azimuth angles on the insolation of solar panels

The tilt and azimuth angles of solar panels are the most significant factors influencing the insolation level. To evaluate the solar panel insolation obtained by a parametric approach and according to general rule, we tested geometric variations of a simple urban block:

- Variation of building heights, and
- Variation of block orientation in relation to the west-east direction.

For the same simple urban block, ten variations (I-X) were created with variable building heights of 6 m, 15 m, 21 m and 30 m (Table 1).

Heights were assigned to each building, based on the results obtained in the previous analysis. This simple urban block is further oriented into three different directions (Figure 5a, 5b and 5c). Sixteen potential solar panel locations are evenly distributed across the courtyard of an urban block. A total of 30 variations of a simple urban block were made, each with sixteen panels. This makes a total of 480 panel simulations for a simple urban block. For each panel, simulations of tilt and azimuth angles are performed.

For the selected geographical location (Belgrade, Serbia), according to the general rule, the tilt angle of fixed solar panels is the value of the latitude ($\beta = 45°$) with an orientation to the south ($\gamma = 0°$). To evaluate the improvement of insolation, the best insolation values obtained by the parametric approach and the insolation values of panels oriented according to the general rule ($\beta = 45°$, $\gamma = 0°$) were compared.

A histogram showing the improvement for panels in all variations is presented in Figure 6. In most cases (66 % of all cases), the improvement was between 0.5 % and 25 %,

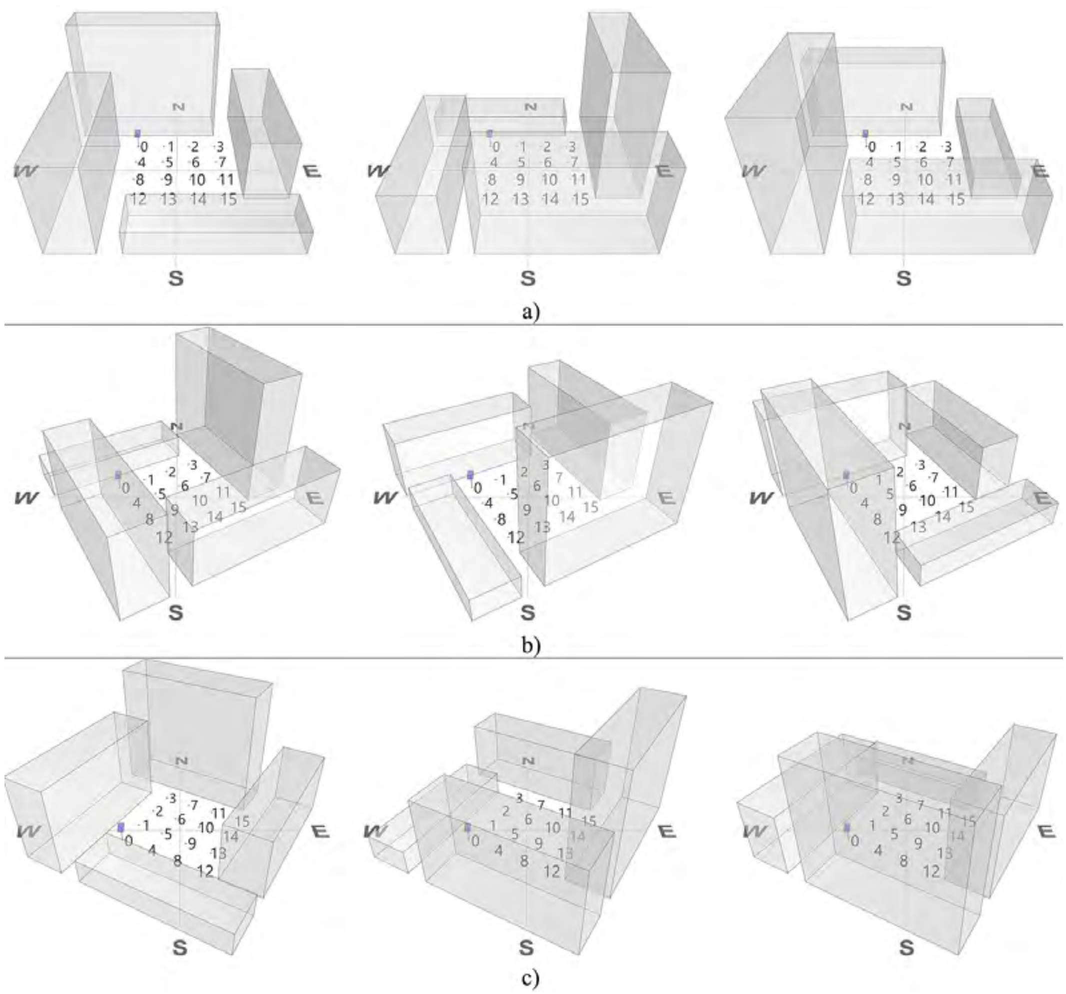

Figure 5. Examples of different variations of simple urban block oriented into direction: a) N-S; b) 30° NW-SE; c) 60° NW-SE, with sample of solar panel orientation at location no. 0.

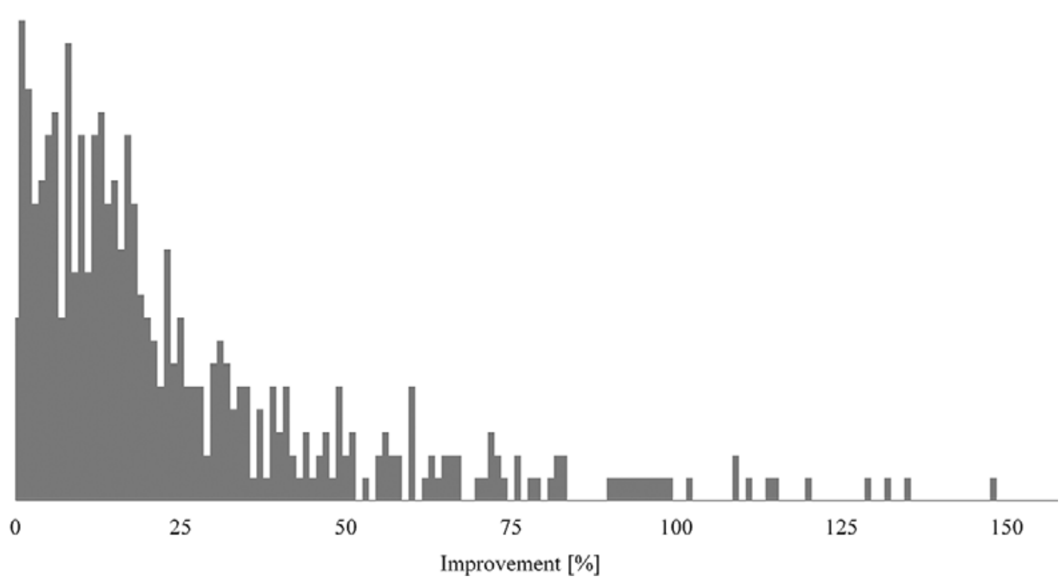

Figure 6. Percentage of insolation improvement for each panel in all variations after the use of the parametric approach in the simple urban block with courtyard

while in some cases (32.3 % of cases), the improvement is much higher, ranging from 25 % to 148 %. Only 1.7 % of the cases had an improvement of less than 0.5 %.

The average improvement for each urban block variation ranges from 45.71 kWh/m² to 169.31 kWh/m², which is from 4.3 % to 29.6 % better than the insolation values of panels oriented according to the general rule. The average insolation improvement in all variations is 116.68 kWh/m² (18.3 % with a standard deviation of σ = 8.2 %). The improvement depending on the variation of building height and rotation angle of simple urban block is shown in Table 2.

Courtyard surrounded by real buildings representation

We apply the approach to another courtyard design and examine its potential for creating layout with certain number of solar panels with maximal insolation. The proposed approach for optimizing the tilt and azimuth angles for potential locations of solar panels, was applied on an urban block with a real buildings representation with a courtyard (Figure 7a). In the middle of the open space between the buildings, there is a hexagonal playground, and solar panels have to be located around it. Twelve possible solar panel locations are specified with

Table 2. Improvement of solar panel insolation according to the parametric approach and according to general rule with different orientation of the simple urban block with courtyard

Buildings heights variation	Orientation of the simple urban block	Parametric approach	General rule	Improvement	
		[kWh/m²]	[kWh/m²]	[kWh/m²]	[%]
I	N-S	921.51	792.77	128.75	16.24
II		741.77	572.46	169.31	29.58
III		803.47	670.55	132.92	19.82
IV		1100.72	1055.01	45.71	4.33
V		1001.21	936.30	64.91	6.93
VI		851.67	705.63	146.04	20.70
VII		609.15	485.28	123.87	25.53
VIII		609.65	476.52	133.13	27.94
IX		870.20	716.09	154.11	21.52
X		1078.89	1022.06	56.83	5.56
I	NW-SE	786.25	665.07	121.18	18.22
II		621.11	480.57	140.53	29.24
III		899.56	799.04	100.52	12.58
IV		1087.54	1017.63	69.91	6.87
V		941.37	824.14	117.23	14.22
VI		987.31	883.55	103.76	11.74
VII		600.90	473.72	127.18	26.85
VIII		690.22	552.26	137.97	24.98
IX		726.89	584.73	142.16	24.31
X		1014.99	914.06	100.93	11.04
I	NW-SE	702.34	585.79	116.56	19.90
II		569.07	445.43	123.64	27.76
III		953.11	904.94	48.17	5.32
IV		1015.23	898.37	116.86	13.01
V		814.34	656.98	157.36	23.95
VI		1061.58	1006.05	55.54	5.52
VII		657.74	510.56	147.18	28.83
VIII		820.82	683.63	137.18	20.07
IX		618.69	487.43	131.25	26.93
X		915.47	765.74	149.73	19.55

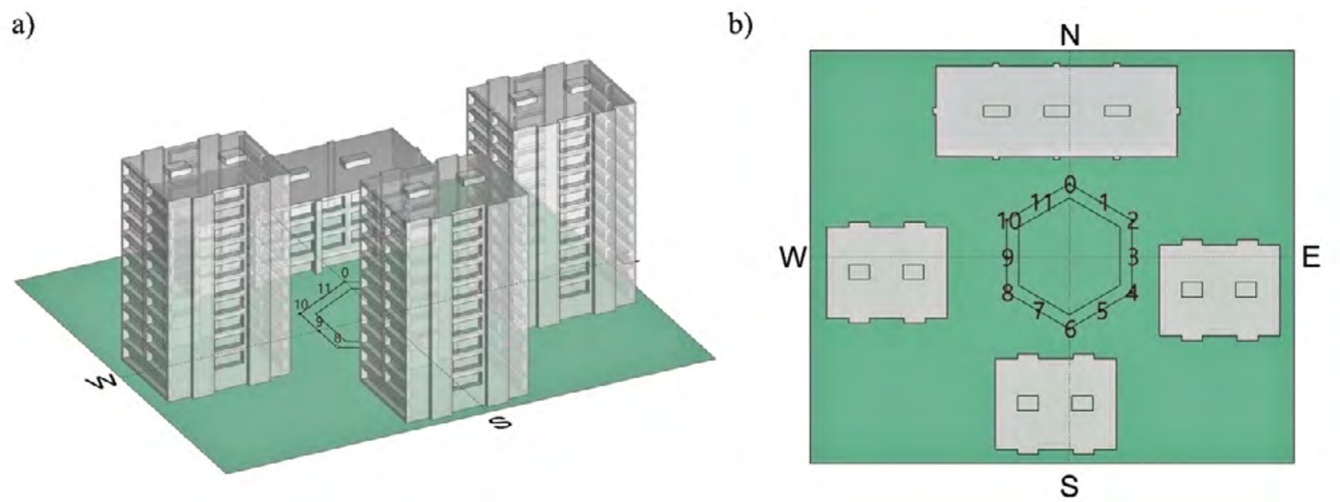

Figure 7. a) 3D view of courtyard with surrounding buildings. b) Top view of courtyard with potential solar panel locations

the same distance from the edges of the playground (Figure 7b).

In this urban area it is observed that the optimal tilt angles β and azimuth angles γ of the solar panel for each location are different, which is not aligned with the general rule ($\beta = 45°$, $\gamma = 0°$). The distribution of the insolation levels for panel orientation on twelve locations is shown in Figure 8. Optimal angles (the maximum point of the function) are displayed in the image for each panel.

According to the numerous studies (Chang, 2010; Stanciu & Stanciu, 2014; Asowata et al., 2012) in the northern hemisphere, the optimal orientation for stand-alone solar panels is south facing and optimum tilt angle would be same as the latitude angle of the location. The optimal tilt and azimuth angles that are presented in the Table 3 indicates that the greatest improvements of solar panel insolation is made when the solar panel is tilted and oriented at optimum angles are $\beta = 5°$ and $\gamma = -60°$. It is obvious that

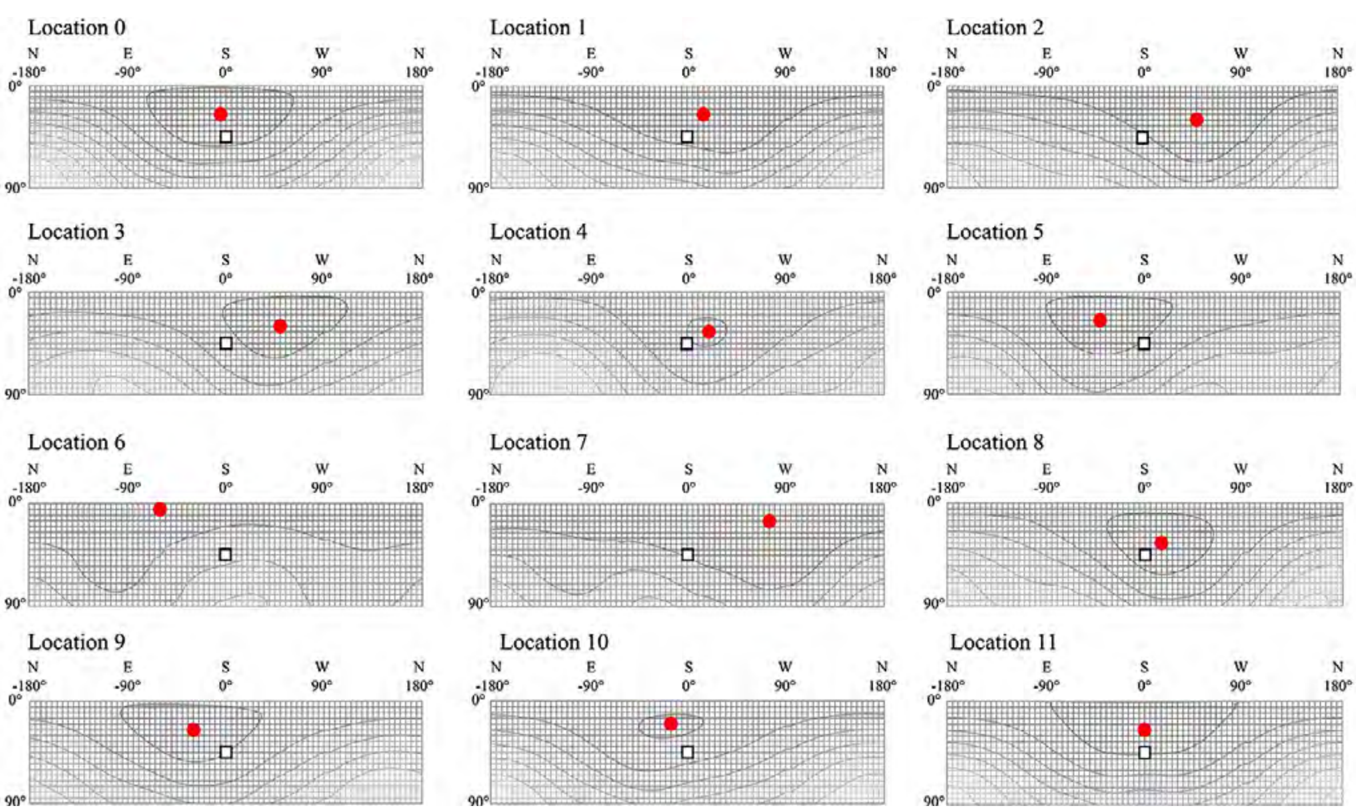

Figure 8. Distribution of insolation levels depending of the tilt and azimuth angles. Red circle shows maximal insolation obtained by approach and black square shows the values recommended by general rule

Table 3. Solar panels insolation during the entire period of the year at potential locations. The maximal insolation is at location no. 0

Location	Parametric approach			General rule		[%]
	Maximal insolation [kWh/m²]	β [°]	γ [°]	Maximal insolation [kWh/m²]	[kWh/m²]	
0	839.74	28	-1	839.74	36.54	4.35
1	735.38	25	15	735.38	59.41	8.08
2	686.46	30	50	686.46	100.56	14.65
3	568.77	30	50	568.77	74.95	13.18
4	594.42	35	20	594.42	15.41	2.59
5	594.95	25	-40	594.95	38.43	6.46
6	325.98	5	-60	325.98	125.35	38.45
7	505.01	15	75	505.01	79.3	15.7
8	731.94	35	15	731.94	16.08	2.20
9	702.14	25	-30	702.14	45.24	6.44
10	747.7	20	-15	747.7	62.38	8.34
11	806.42	25	0	806.42	50.65	6.28

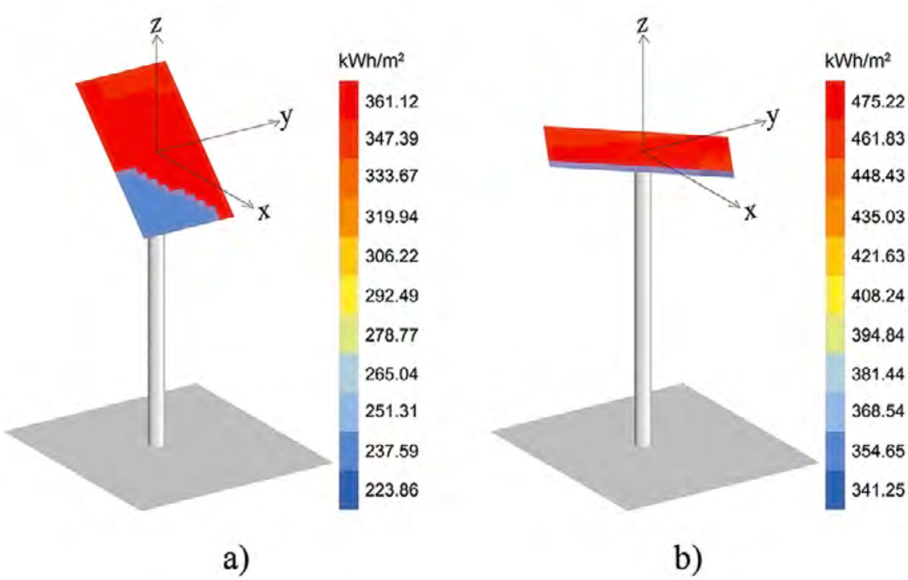

Figure 9. 3D view of solar panel insolation for location no.6 oriented according to: a) general rule; b) the parametric approach

general recommendation from the literature cannot be applied for solar panels in built-up urban areas, due to buildings affect the shading of the solar panels.

The average improvement of solar panel insolation obtained by the parametric approach for the entire year period, compared to orientations commonly used in practice, is 58.69 kWh/m², representing an 10.6 % improvement. The most significant improvement in solar panel insolation was observed at location no. 6, with a value of 125.35 kWh/m² (38.45% better than the insolation value of a panel oriented by the general rule).

In order to illustrate the solar panel insolation for location no. 6, the 3D view of solar panel is presented in Figure 9a and 9b.

The maximum insolation of the solar panel is detected at location no. 0 with a tilt of β_{opt} = 28° and an eastward orientation of γ_{opt} = -1°. The improvement of solar panel insolation for location no. 0 is 36.5 kWh/m², corresponding to a 4.35 % better result than the insolation value of a panel oriented by the general rule.

In cases where solar panel orientations can be adjusted during the year, optimization can be done separately for

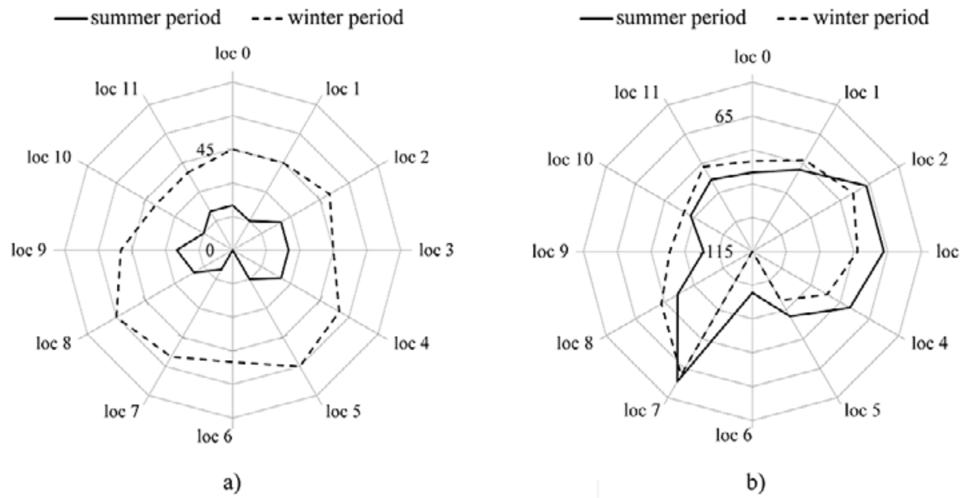

Figure 10. Comparison of the optimal: a) tilt angles; b) azimuth angles for summer and winter period

different periods of the year (seasons or months). We conducted analyses for two year segments, summer months and winter months. Optimal tilt angles for the summer period range from 0° to 25°, and for the winter period, from 40° to 60° (Figure 10a). Azimuth angles for both periods varied in the same range, from 85° to south and from south to -110° (Figure 10b). The similar results noticed in numerous studies (Duffie et al., 2020, Shariah at al., 2002; Hussein at al., 2000) where suggested and concluded that the optimum tilt angle (β_{opt}) is taken to be equal to the latitude of the location (φ), while for summer $\beta_{opt} = \varphi$+15° and for winter $\beta_{opt} = \varphi$-15°.

The average improvement in the summer period is 14.4 % (with a standard deviation of σ = 7.6 %), and in the winter period, it is 10.7 % (with a standard deviation of σ = 18.2 %).

Distribution of solar panels along the simple polygonal shape

In urban planning practice, the certain number of solar panels should be placed in urban area on equally mutual distance. In previously analyzed block, three solar panels should be placed in a layout around the playground, spaced evenly. The maximum insolation value for all locations is shown in Figure 11a. We analyzed the total insolation for layouts in which nearby panels are separated by at least two 'empty' locations. All possible layouts of panel locations are presented in Table 4.

The best layout that provides the maximum insolation value suitable for three solar panels for summer and winter months is locations no. 2, 8, and 11 (Figure 11b). The total insolation of this layout is 12% higher than the average maximal insolation for all other layouts. The insolation of solar panels oriented by the general rule is shown in Figure 12a, and insolation of solar panels oriented by the approach is shown in Figure 12b.

For all combinations of three panel locations and for a whole year period, compared to the average insolation value of solar panels that would be oriented in the same locations according to the general rule, the average improvement is 9.18%, with a standard deviation of σ = 3.8%. Rhinoceros software and its existing plug-ins and addons enable the optimization of urban parameters and urban elements design and position with various optimization techniques by using the parametric approach. This is an advantage compared to many software applications, such as Matlab and PVsyst (Benghanem, 2011; Shrivastava et al., 2023) that cannot be applied to optimize additional urban elements and they are limited only to estimate the energy yield and optimize the solar panels system design. Hence, the urban planning strategies and designs problems can be solved and carried out in a sophisticated manner by using parametric tools suitable for architects and urban planners.

Taking into account that solar panels provide shade, they are used to find optimal benches locations. In order to use optimal solar panels layout obtained by parametric approach, we propose additional procedure for optimizing benches near the solar panels. The solar panels and surrounding buildings can provide shade for benches during the hottest summer period (June, July, and August, from 10 UTC to 19 UTC). After positioning the solar panels, we identified the optimal location for benches to be placed near selected solar panels and oriented towards the playground area. A predefined set of 166 bench locations is arranged as points along the lines around the solar panel. Each bench's potential center point is connected with the corresponding point representing its location. The geometry of the bench is automatically adjusted as locations change, and simulations of insolation are performed. Therefore, after each alteration in bench location, the bench's insolation is calculated. The minimum insolation value corresponds to the optimal bench location (Figure 13).

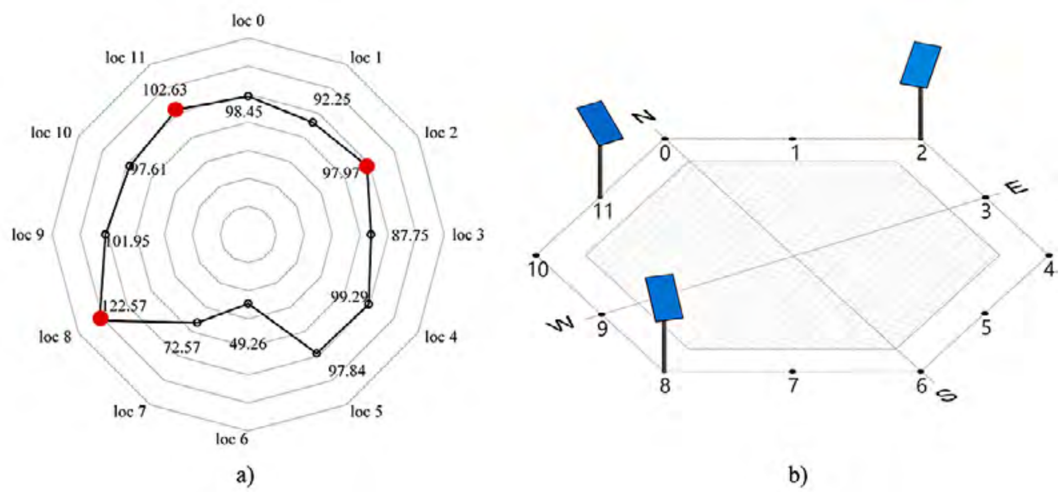

Figure 11. a) Maximal panel insolation for all locations. Selected combination is marked with red circles. b) Solar panel positions with maximal insolation level for whole year period at locations no. 2, 8 and 11

Table 4. Insolation for different combinations of three solar panel locations

Locations	Parametric approach	General rule	Improvement	
	[kWh/m²]	[kWh/m²]	[kWh/m²]	[%]
0 4 8	744.71	722.03	22.68	3.14
1 5 9	725.18	677.49	47.69	7.04
2 6 10	682.81	586.71	96.1	16.38
3 7 11	695.03	626.73	68.3	10.9
0 3 8	756.01	713.48	42.53	5.96
0 5 9	752.34	712.27	40.07	5.63
1 4 9	717.31	677.29	40.02	5.91
1 6 10	685.41	603.02	82.39	13.66
2 5 10	743.49	676.37	67.12	9.92
2 7 11	742.81	665.96	76.85	11.54
3 6 10	635.04	547.48	87.56	15.99
3 8 11	749.61	702.37	47.24	6.73
4 7 11	683.73	635.28	48.45	7.63
4 9 0	744.49	712.11	32.38	4.55
5 8 1	725.39	687.42	37.97	5.52
5 9 2	722.56	661.14	61.42	9.29
6 9 1	664.51	587.83	76.68	13.04
6 11 3	650.71	567.05	83.66	14.75
7 10 2	727.13	646.39	80.74	12.49
7 0 3	701.43	637.84	63.59	9.97
8 11 2	797.37	741.61	55.76	7.52
8 1 4	717.54	687.24	30.3	4.41

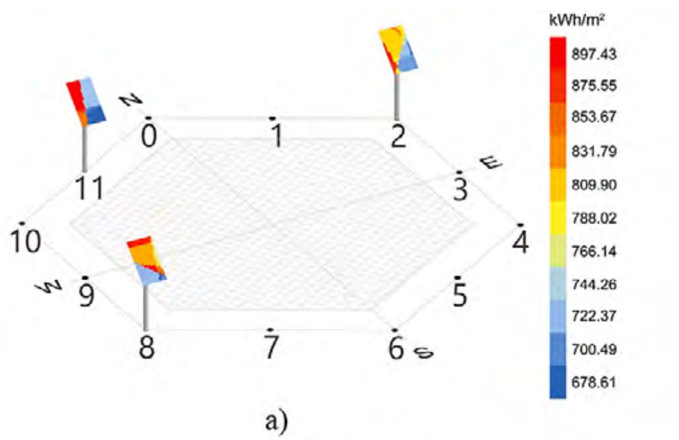

Figure 12. 3D view with insolation simulation of solar panels oriented by: a) general rule; b) the parametric approach

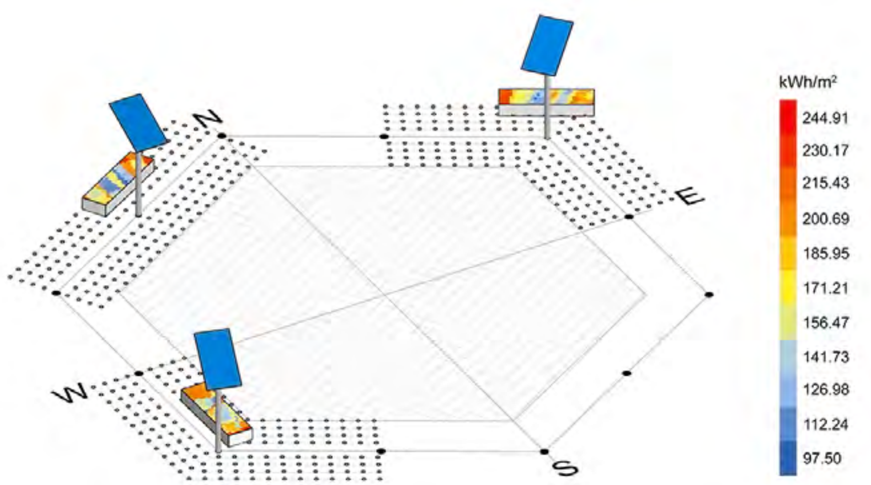

Figure 13. Locations of the benches with minimal insolation level

Insolation values for all bench locations around solar panel locations no. 2, no. 8, and no. 11 are shown in Figures 14a, 14b, and 14c, respectively. The minimum insolation of the bench positioned around solar panel location no. 2 is 187.74 kWh/m², for the bench placed around solar panel location no. 8 insolation is 136.62 kWh/m² and for the bench positioned around solar panel location no. 11, the minimal insolation value is 196.68 kWh/m². Distribution of the insolation levels in all bench locations is shown in Figure 14 and it can be noticed that if the bench would be placed without prior simulation it would be likely that the insolation would be higher. In optimal positions bench is 30%, 32% and 25% less insolated than in the worst case and 17%, 20% and 16% compared to average value (for solar panel locations no.2, no. 8 and no. 11 respectively).

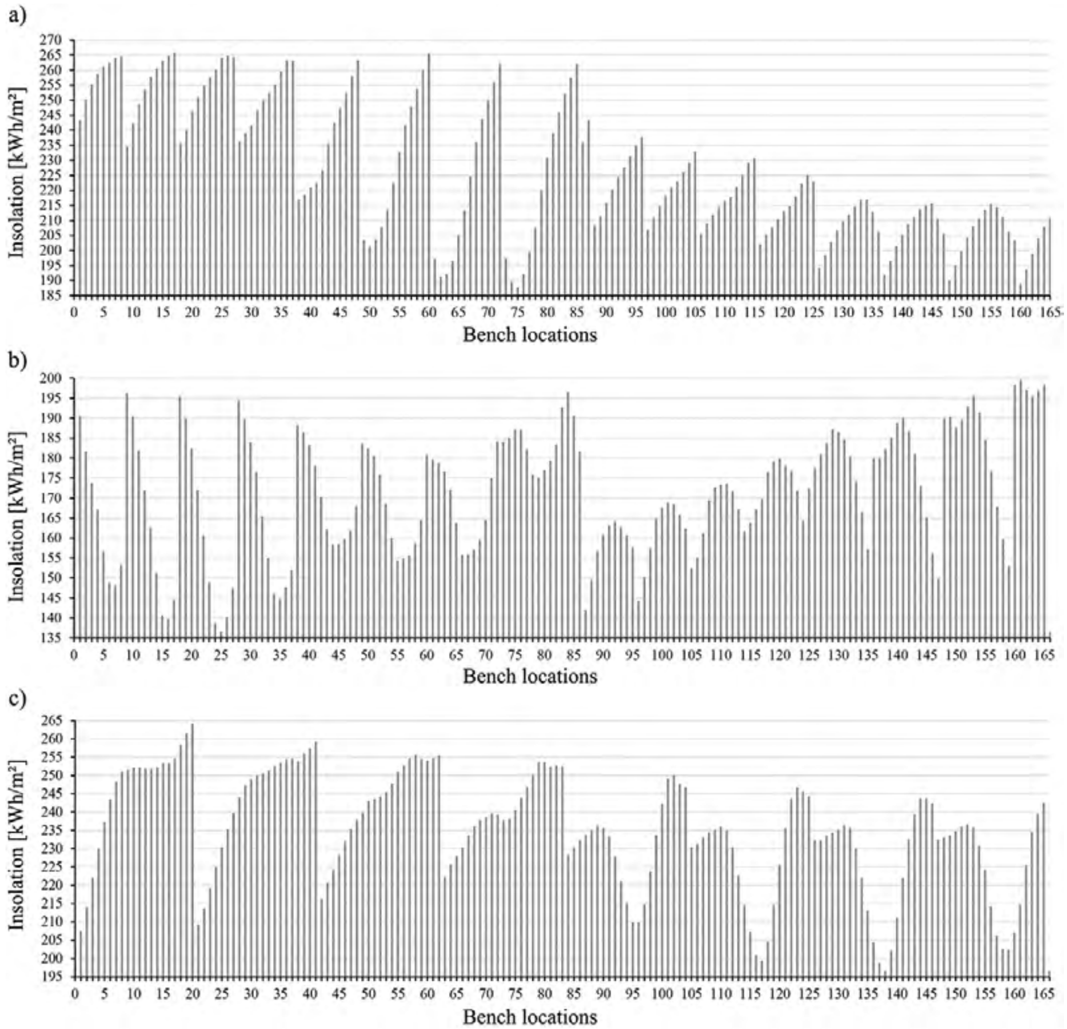

Figure 14. Insolation values of bench placed near solar panel location a) no. 2; b) no. 8; c) no. 11

Conclusion

In this research, it is demonstrated how a parametric approach for changing the location and orientation of stand-alone solar panels, can be used to create environmentally conscious urban design and can be used to improve the insolation of a solar panels and other urban elements. The method proposed in this study has the possibility to incorporate several input data, including a 3D model of surrounding buildings, solar panel geometry and potential solar panel locations, and various weather data simulating diffuse radiation measured for a specific geographic location. This enables the application of the proposed approach to any built-up urban area. The approach illustrates how digital technologies and a combination of different CAD software applications for 3D modeling, parametric modeling, and solar simulations, familiar to architects and urban planners, can be efficiently used to develop optimization guidelines applicable in urban planning practice. Introduce other urban elements in urban courtyard design needed for urban planning process by using results of solar panels orientation and location is the crucial advantage of this approach, compared to the models that only quantify the solar energy potential of photovoltaic systems, which are limited to estimate the energy yield and optimize the solar panels system design. Furthermore, our approach is a valuable contribution for urban planning strategies in the beginning of urban design process in order to create comfortable open spaces for residents.

The results of this research contribute to the understanding of the importance of adequate stand-alone solar panel distribution in open urban courtyards. Using this approach, an improvement in solar panel insolation of up to 38% was observed compared to the solar panel insolation that would be achieved if the panel was oriented according to the guidelines applied in practice. The results show that the application of the parametric approach increases the possibility of solar panel insolation for different scenarios: fixed (simulations for the entire year), non-fixed solar panels (simulations for different seasons), and solar panel layout. The optimal orientation and location of solar panels influence the overshadowing of other urban elements, such as bench.es. Therefore, selecting the best orientation and location of the benches contributes to favorable comfort conditions in open urban spaces. The possibility of creating sustainable urban environment by using various urban elements such as solar panels and benches is shown. Their adequate integration into current urban design and infrastructure is important for creating healthier and more sustainable urban spaces for local communities and future generations.

A limitation of approach presented in this paper is that although the influence of trees could be added, it can only be presented as a full shadow casting solid, meaning that characteristics such as crown density, leaf transparency and foliage period cannot be taken into calculation. It is only possible to generate trees as solid forms that cast a full shadow.

In future research, we intend to use the proposed approach for optimizing various urban parameters. A large area of solar tree with multiple panels acting as non-transparent structure, cast a full shadow and can mitigate overheating of urban areas, such as playgrounds, parking lots, and footways. By employing multi-objective optimization process, we aim to optimize simultaneously the maximal insolation of the solar tree and minimal insolation of the urban area.

Acknowledgments

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Shift-Share Analysis of Local Economy's Competitiveness: Case Study of the Varaždin-Koprivnica Region, Croatia

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KEYWORDS

the Varaždin-Koprivnica Region
regional competitiveness
local competitiveness factor
manufacturing

ABSTRACT

This study researches local economy's competitiveness in the Varaždin-Koprivnica Region (North-Western Croatia) in the period between 2009 and 2020. Shift-share method has been used which measures the deviation between the regional development and the development of total national area and tends to explain whether it is the result of exogenous or endogenous conditions. Data on the number of employed people and Gross Value Added were used as points of reference for the competitiveness. The results showed the above average regional development which is the result of the influence of endogenous or local conditions indicating that the region has competitive advantages. Manufacturing is the most competitive activity. The analysis revealed intra-regional disparities as well.

Introduction

One of the main goals of regional and local policies is to shape strategies for the improvement of local community's competitiveness (Krželj-Čolović, 2015). According to one of the definitions, regional competitiveness represents the capability of region to create high and raising income and improve the life of its inhabitants (Meyer-Stamer, 2016). Strengthening of regional competitiveness is one of the strategic goals of the National development strategy of the Republic of Croatia until the year 2030 (Croatian Parliament, 2021). The document emphasizes that the focus of spatial dimension of regional development policy is the strengthening of abilities of the cities which should be the carriers of development in their area of gravity.

The competitiveness of regions is closely connected to regional development (Bednáriková, 2022). While the economies of certain regions are declining, the others are managing to keep their competitiveness. The ability of regions to attract innovative and creative people and offer high-quality cultural programs are important characteristics of regional competitiveness advantage (Kitson et al., 2004). The basis of economic development and competitiveness in globalized world is the knowledge, skills and the ability to learn. In the economy based on knowledge, the organizations and regions that learn get the crucial role (Maskell, 2001; Matatkova & Stejskal, 2012). The emphasis is on local knowledge and creativity. Regional competitiveness depends on local processes of creating knowledge when individuals and companies learn about new technologies and how to exchange information (Malecki, 2004). Since human resources is the initiator of econom-

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ic growth, the differences in the development of regions are significantly the consequence of uneven investments in human resources, knowledge and inovations (Huggins et al., 2013; Jagódka & Snarska, 2023).

Porter (1998) sees the improvement of knowledge and creativity through clusters as the key initiators of regional competitiveness. In the process he emphasizes the role of clusters oriented to export. Nowadays, industrial clusters are the instrument of regional policy, which means the tool to support the competitiveness of regional economy (Matatkova & Stejskal, 2012; Jagódka & Snarska, 2023).

There are several ways to approach measuring of regional competitiveness taking into consideration different models and methods of the analysis and competitiveness indicators (Tijanić, 2020). In Croatia, National competitiveness committee in cooperation with UNDP developed Regional competitiveness index of Croatia which was used to value the competitiveness of Croatian NUTS-2 and NUTS-3 regions between the years 2007 and 2013 (NCC, 2014). According to this index, the most competitive NUTS-3 regions are located along the west Croatian border: The City of Zagreb, County of Varaždin, County of Međimurje in central Croatia and County of Istria on the coast. Less competitive NUTS-3 regions are in the east part of Croatia (County of Požega-Slavonia, County of Vukovar-Sirmium, County of Virovitica-Podravina) and the mountain part of Croatia (County of Lika-Senj) and County of Sisak-Moslavina. European Committee developed EU Regional Competitiveness Index (RCI) which shows the strengths and weaknesses of European NUTS-2 regions, and since 2013 it has been calculated for Croatian regions as well (European Commission, 2013). Northern Croatia is the most competitive among Croatian NUTS-2 regions.

The aim of the study is to research local economy's competitiveness in the Varaždin-Koprivnica Region for the period between 2009 and 2020. The following hypothesis was established: the region has local competitive advantages and is above average national level of competitiveness. Besides the general goal, several more substantial research tasks have been set:

- measure the difference in development dynamics of the region and total national area,
- establish whether the difference in development dynamics is the result of exogenous (structural) or endogenous (local) conditions, and whether the region holds competitive advantages,
- identify competitive activities of the region,
- to examine possible existence of intra-regional disparities.

Varaždin-Koprivnica Region is a part of NUTS-2 Northern Croatia region, which covers three NUTS-3 regions: County of Varaždin, County of Međimurje and County of Koprivnica-Križevci (Fig. 1). The river Drava is the skeleton of that region. The region is located near the Hungarian and Slovenian border, and at the same time in the vicinity of Austria. Good traffic connection with the listed countries and the capital city Zagreb as well as the tradition of entrepreneurship and manufacture (Savić et al., 2021) had a positive impact on its economic development. In 2021, the population of the region was 365,958 (9.5% of Croatian population) in the area of 3,732 km2 (6.6% area of Croatia). 9.2% of the employed people in Croatia are concentrated there (CBS, 2022).

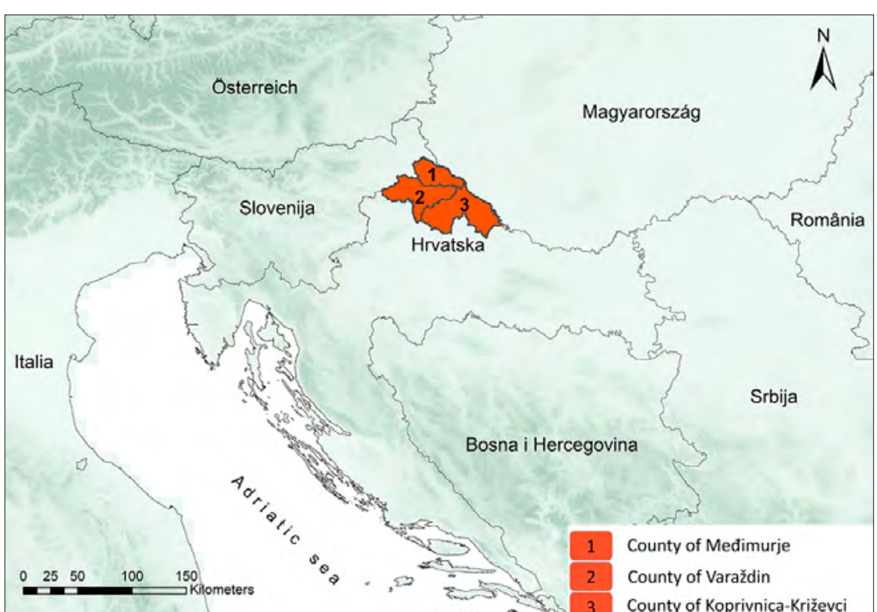

Figure 1. Analysed area of research

Data and Methods

Shift-share analysis was used in order to answer the research questions. It is a technique used for measuring which tries to explain the difference in development dynamics between a smaller and a larger area (in this case the region and Croatia). Data of the number of employed people (in legal entities) and Gross Value Added (GVA) collected and published by Croatian Bureau of Statistics were used as the indicators of development dynamics.

Regional, structural and local factors were calculated in the shift-share analysis. Regional factor quantifies the difference between development dynamics of the region and Croatia, and is calculated according to the formula (adapted to Kosfeld, 2018):

$$RF = \frac{r^{t+1}}{r^t} \div \frac{c^{t+1}}{c^t} \quad (1)$$

- where r^{t+1} is the number of employed/GVA in the region in a newer year, r^t is the number of employed/GVA in the region in the earlier year, C^t+1 is the number of employed/GVA in Croatia in the newer year, C^t is the number of employed/GVA in Croatia in the earlier year. If RF is >1 development in the region is above average.

Structural and local factors provide the answer to the question whether the difference in development happened due to exogenous (structural) or endogenous (local) conditions (Wenjuan, 2006). If SF is >1, fast-growing activities in the country are extremely represented in the region while LF>1 indicates that the region has competitive advantages. To calculate the structural factor the following formula was used (adapted from Farhauer & Kröll, 2013; Kosfeld, 2018):

$$SF = \frac{\sum_{i=1}^{I} \left(r_i^t \cdot C_i^{t+1} / C_i^t \right) / r^t}{C^{t+1} / C^t} \quad (2)$$

- where r_i^t is the number of employed/GVA in the activity *i* in the region in the earlier year, C_i^t is the number of employed/GVA in activity i in Croatia in the earlier year, C_i^{t+1} is the number of employed/GVA in the activity *i* in Croatia in the newer year.

Local factor, or better yet, local competitiveness factor was calculated the following way (Farhauer & Kröll, 2013; Kosfeld, 2018):

$$LF = \frac{r^{t+1}}{\sum_{i=1}^{I} r_i^t \cdot C_i^{t+1} / C_i^t} \quad (3)$$

In order to identify the competitive activities in the region, change in the number of employed/GVA in every activity was decomposed on several components – national, structural and local (Dawson, 1987; Heijman & Heide, 1998; Çelebi Deniz, 2014). The last of the listed components is especially important since the activities with higher positive value of this component can be considered competitive. The component of local competitiveness is the difference between the real change of employment/GVA in a certain activity in the region and the expected change of employment/GVA if the same happened according to national growth rate of that activity.

The relations between structural (Proportional Shift) and local (Differential Shift) factors enable the determination of the type of region, which is the essence of Boudeville's classification (Tab. 1). For every type of region Christofakis et al. (2019) suggest the basic means of regional policy, emphasizing that regional flaws can be removed by general improvements of the infrastructure or injecting growing sectors in the region.

Besides the listed quantity analysis, a short written structural interview with the representatives of Croatian Chamber of Economy (CCE) and its county organizations[1] was conducted. The goal was to additionally interpret the acquired results.

Table 1. Boudeville's classification of region types and means of regional policy

Type		RF	SF	LF		Means of regional policy
1	Regions grow faster than average	> 1	> 1	> 1	SF>LF	
2		> 1	> 1	> 1	SF<LF	
3		> 1	> 1	< 1		infrastructure strengthening
4		> 1	< 1	> 1		sectoral restructuring
5	Regions grow below average	< 1	< 1	> 1		sectoral restructuring
6		< 1	> 1	< 1		infrastructure strengthening
7		< 1	< 1	< 1	SF<LF	sectoral restructuring and infrastructure strengthening
8		< 1	< 1	< 1	SF>LF	infrastructure strengthening and sectoral restructuring

Source: modified according to Christofakis et al., 2018; Frey, 2004; Tamayo, 1999.

[1] Goran Šaravanja (chief economist of CCE), Renata Lohajner (CCE – Koprivnica), Dijana Krnjak (CCE – Čakovec) and Marina Kezić Mekota (CCE – Varaždin) participated in the creation of answers to the questions.

Results

Shift-share analysis of employment in the Varaždin-Koprivnica Region

Economic structure of the Varaždin-Koprivnica Region is significantly different from the structure of national economy. According to the data of the number of employed people in 2020 (CBS, 2021), manufacturing dominates in the economic structure of the region with the share of 40.5%. It is followed by retail (10.8%), education (9.5%), construction (7.3%) and health care (7.1%). While in the region the number of employed in the industry exceed many times over the number of those employed in retail, in Croatia those two activities have a similar number of the employed (Tab. 2). In spite of the national trend of tertiarization and deindustrialization of economy, the region was more successful in the transition period and continues to achieve a more dynamic industrial development.

The region represents one of the strongest industrial areas in Croatia which can legitimately be called the industrial region. In the literature it is known as the Upper-Drava and Međimurje industrial region which includes the industrial centres Varaždin, Čakovec, Koprivnica and Ludbreg (Feletar & Stiperski, 1992; Lončar & Stiperski, 2019). Counties in the North-West of Croatia are traditionally characterised with the highest level of industrialization in the country (Lončar & Braičić, 2016). The leading areas are the County of Varaždin and the County of Međimurje were the only counties in Croatia to have a degree of industrialization higher than 130 in 2020, which means there were more than 130 employees in manufacturing on

Table 2. Number and structure of the employed in the Varaždin-Koprivnica Region and Croatia according to economic activities

Activities*	Employment in 2020				Change 2009-2020 in %	
	Varaždin-Koprivnica Region		The Republic of Croatia		Varaždin-Koprivnica Region	The Republic of Croatia
	Number	%	Number	%		
A	1,148	1.0	22,108	1.9	-49.8	-10.7
B	625	0.6	4,190	0.4	-11.6	-51.1
C	44,285	40.5	207,303	17.5	8.3	-11.2
D	1,022	0.9	14,082	1.2	-35.4	-16.1
E	1,993	1.8	26,065	2.2	34.9	23.0
F	8,008	7.3	82,261	6.9	-18.0	-18.7
G	11,825	10.8	178,615	15.0	-6.3	-6.8
H	4,592	4.2	63,648	5.4	6.0	-0.9
I	2,436	2.2	56,548	4.8	49.0	48.2
J	1,559	1.4	39,540	3.3	69.1	29.7
K	1,972	1.8	35,147	3.0	-20.2	-6.5
L	173	0.2	7,279	0.6	35.2	42.1
M	2,899	2.7	50,148	4.2	11.8	4.5
N	1,235	1.1	39,395	3.3	-5.8	27.3
O	5,588	5.1	104,941	8.8	-7.1	-0.8
P	10,443	9.5	118,999	10.0	25.6	15.4
Q	7,767	7.1	99,865	8.4	27.2	25.2
R	1,057	1.0	23,550	2.0	40.6	19.3
S	728	0.7	14,040	1.2	7.1	18.5
Total	109,355	100.0	1,187,724	100.0	4.6	1.3

**A: Agriculture, forestry, and fishing; B: Mining and quarrying; C: Manufacturing; D: Electricity, gas, steam and air conditioning supply; E: Water supply; sewage, waste management activities; F: Construction; G: Wholesale and retail trade; H: Transportation and storage; I: Accommodation and food service; J: Information and communication; K: Financial and insurance; L: Real estate activities; M: Professional, scientific and technical activities; N: Administrative and support service activities; O: Public administration and defence; compulsory social security; P: Education; Q: Human health and social work; R: Arts, entertainment, and recreation; S: Other service activities.*

Source: CBS, 2010; 2021.

1000 inhabitants. The County of Koprivnica-Križevci also has a relatively high percentage of industrialization (83.2) (according to CBS, 2021, 2022).

This industrial region is characterised by the export orientated industry which is mostly work-intensive and low accumulative. Food, textile, leather and shoemaking industry and metal processing industry are the most represented (Savić et al., 2020, 2021). According to total income (2022) the leading industrial companies in Varaždin are *Vindija*, *Koka* (food factory), *Ytres* (footwear, textile), *Kostwein* (machine factory) etc. In Koprivnica *Podravka* (food factory) and *Belupo* (pharmaceutical company) stand out, while the leading companies in Čakovec are *Perutnina Ptuj Pipo* (food factory), *Tubla* (textile industry) and *Muraplast* (rubber and plastic) (Internet 1).

The results of shift-share analysis (Tab. 3) indicate that the Varaždin-Koprivnica Region achieved the above average employment growth compared to the entire area of Croatia in the observed period. The value of regional factor (1.032) indicates that the employment in the region rose by 3.2% more than on national level. Since the local factor is higher and the structural factor lower than 1, the growth in the region is the result of endogenous conditions, which means that the region possesses local competitive advantages. According to the local competitive factor (1.08) the employment growth is higher by 8% than expected based on the local economy structure. According to Boudeville's classification, the region is type 4.

According to the statement of the connoisseurs in Chamber of Economy of analysed counties, local advantages of the researched area are: the tradition of the industrial production, the vicinity of Austria, Slovenia and Hungary as well as the good overall traffic position and the connection with the capital city. Despite the development and high employment rates, competitive drawbacks of the region are emphasised. They are visible in low salaries (for example in textile industry, but in other activities as well) and the lack of work force which is becoming a limiting factor of further development. Along with the increasing necessity for the foreign workers, they indicate the need for a better coordination of educational system and economy in order to generate domestic work force and pass the knowledge to younger generations to preserve the industrial base.

In order to establish the competitive economic sectors using the shift-share analysis the entire change in the number of the employed is decompose into components (tab. 3). The most important component is local competitiveness which shows how many work places in a certain activity are attributed to the competitiveness of that activity (Çelebi Deniz, 2014). It can be noticed that 12 activities have a positive value of the local competitiveness component, manufacturing standing out. In the region, the number of employed in manufacturing has increased by 3,404, while at the same time manufacturing in Croatia loses work force which causes an extremely negative structural component (-5,114). Structural component is a hypothetical value which indicates the change in the number of employees in manufacturing in the region if the shifts occur according to the national rate of change. Therefore, manufacturing is the most competitive sector in the Varaždin-Koprivnica Region.

Since the Varaždin-Koprivnica Region consists of three counties, the continuation of analysis had to research possible intra-regional disparities. As shown on figure 2, Counties of Varaždin and Međimurje have RF>1 which indicates the above average employment growth in comparison to the entire area of Croatia. The above average growth in these counties was achieved due to a favourable local competitiveness factor (LF>1) despite the 'unfavourable' structural characteristics of their economy (SF<1). Therefore, these two counties are also type 4 regions according to Boudenville's classification. Structural characteristics are conditionally unfavourable since the economic structures of these counties are significantly represented by the activities which stagnate or register regression on national level. The County of Koprivnica-Križevci has unfavourable trends because the change in the number of employed is below average. That means that the employment rate is decreasing. The below average development of employment in the County of Koprivnica-Križevci is the result of mutual activity of unfavourable structural (exogenous) and local (endogenous) circumstances, so this county belongs to type 7 regions. The unfavourable local competitiveness factor (LF<1) indicates a lower level of local economy's competitiveness in the County of Koprivnica-Križevci.

According to data in table 4, only four economic activities in County of Varaždin have a negative component of local competitiveness while manufacturing leads in positive values. However, in the County of Međimurje ten activities have negative local competitiveness. None the less, that loss is successfully compensated through manufacturing which has an extremely positive indicator of local competitiveness in that area as well, which makes the total component of local competitiveness of the County of Međimurje a positive one. On the other hand, manufacturing in the County of Koprivnica-Križevci as well as the other 11 activities have a negative indicator of local competitiveness. In the interview, the leading people of the County chamber in Koprivnica emphasise the fact that there are efforts to increase local competitiveness. They are also mentioning the upcoming completion of a number of large infrastructural projects like communal infrastructure of the leading city centres, as well as the sectors of traffic, sanitation departments and manufacturing, which, according to their opinion, should influence the economic growth of the County of Koprivnica-Križevci. The modernization of railway in-

Table 3. Shift-share analysis of employment development in the Varaždin-Koprivnica Region, 2009-2020

Activity*	Total change	„Share-Effect“	„Shift-Effect“		
		National growth component	Regional component (Total Shift)	Structural component (Proportionality Shift)	Local competitiveness component (Differential Shift)
A	-1,138	30	-1,168	-276	-893
B	-82	9	-91	-371	279
C	3,404	540	2,864	-5,114	7,978
D	-559	21	-580	-276	-304
E	516	20	496	320	176
F	-1,753	129	-1,882	-1,951	69
G	-795	167	-962	-1,022	61
H	258	57	201	-97	298
I	801	22	779	767	12
J	637	12	625	262	363
K	-499	33	-532	-192	-340
L	45	2	43	52	-9
M	306	34	272	83	189
N	-76	17	-93	340	-433
O	-428	79	-507	-125	-382
P	2,126	110	2,016	1,169	847
Q	1,662	81	1,581	1,455	126
R	305	10	295	135	160
S	48	9	39	117	-78
Total	4,778	1,381	3,397	-4,723	8,120
			Regional factor (RF) = 1.032		
			Structural factor (SF) = 0.955		
			Local competitiveness factor (LF) = 1.080		

**reading of letters for activities the same as in table 1*

Source: Author's calculation based on data from CBS, 2010; 2021.

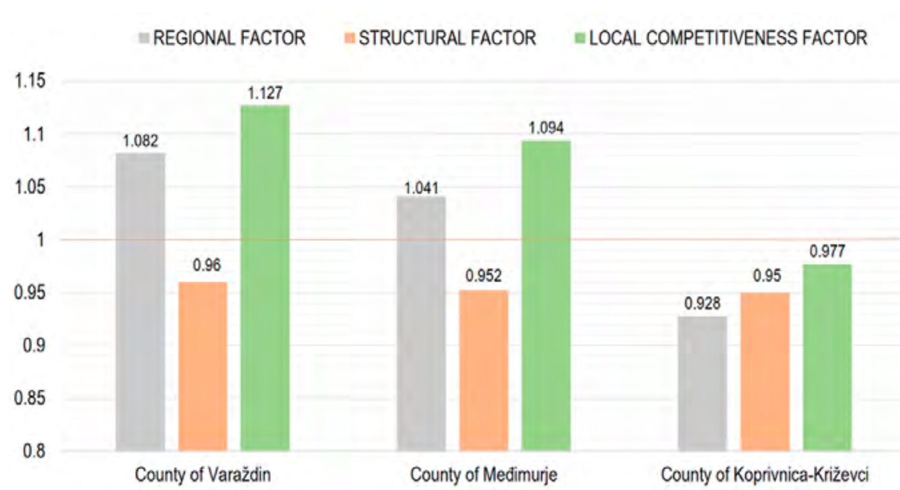

Figure 2. Regional, structural and local employment factor in the counties of the Varaždin-Koprivnica Region, 2009-2020.
Source: Author's calculation based on data from CBS, 2010; 2021.

Table 4. Shift analysis of employment development in the counties of the Varaždin-Koprivnica Region, 2009-2020.

Activity*	Total change in the number of employed			Local competitiveness component (Differential Shift)		
	County of Varaždin	County of Međimurje	County of Koprivnica-Križevci	County of Varaždin	County of Međimurje	County of Koprivnica-Križevci
A	-645	-283	-210	-553	-232	-108
B	-31	2	-53	95	4	181
C	2,792	1,888	-1,276	4,923	3,246	-192
D	-53	-35	-471	36	17	-357
E	79	72	365	-132	-14	323
F	-571	-749	-433	208	-75	-63
G	-17	-776	-2	386	-527	201
H	469	79	-290	489	87	-278
I	460	245	96	169	-71	-86
J	478	99	60	337	7	19
K	-44	-220	-235	24	-179	-185
L	41	8	-4	14	-13	-10
M	280	52	-26	230	14	-55
N	151	-139	-88	4	-253	-184
O	-194	-202	-32	-171	-192	-20
P	947	624	555	382	249	217
Q	419	802	441	-452	508	70
R	93	170	42	15	142	3
S	46	1	1	7	-37	-48
Total	4,700	1,638	-1,560	6,012	2,681	-573

**reading of letters for activities the same as in table 1*

Source: Author's calculation based on data from CBS, 2010; 2021.

frastructure in the corridor stretching from the Hungarian border, across Koprivnica and Zagreb to Rijeka is one of the most important projects.

Shift-share analysis of Gross Value Added (GVA) in the Varaždin-Koprivnica Region[2]

The Varaždin-Koprivnica Region effectuated 3.5 billion euros of GVA in 2020. The highest GVA was effectuated in manufacturing and it made 35.7% of total GVA in the region (tab. 5). The same year manufacturing in Croatia made only 14.4% of total GVA in the country (CBS, 2023). The development of the Varaždin-Koprivnica Region can be characterised as above average due to a stronger GVA growth than that on national level. Even though a growth of GVA was recorded in most activities in the period between 2009 and 2020, the most prominent was the one in manufacturing activity. Gross Value Added made in manufacturing in the region grew many times compared to Croatia.

According to regional factor value (1.049) GVA in the Varaždin-Koprivnica Region rose by 4.9% more than on national level (tab. 6). Just like with shift-share analysis of the employment development, the local factor is higher and the structural lower than 1. That indicates that the above average growth of GVA in the region is the result of endogenous factor, and proves that the region has local competitive advantages. According to local competitiveness factor (1.072) the growth of GVA is higher by 7.2% than expected based on the structure of local economy. The weaknesses of branch structure have been successfully compensated by local forces – the region is type 4 according to Boudeville.

The enclosed table presents the total change in GVA decomposed to components and groups of activities. Man-

[2] CBS does not publish data on Gross Value Added based on activities on county levels, but on groups of activities. Therefore, this part of shift-share analysis was conducted using the available data for 11 groups of activities instead for the 20 areas of activities (according to NKD 2007).

Table 5. Structure of Gross Value Added (GVA) in the Varaždin-Koprivnica Region and Croatia according to economic activities (current prices)

Activity*	GVA in 2020				Change 2009-2020 in %	
	Varaždin-Koprivnica Region		The Republic of Croatia		Varaždin-Koprivnica Region	The Republlic of Croatia
	in thous. euros	%	in thous. euros	%		
A	242,782	7.0	1,555,672	3.7	-15.4	-12.4
B, D, E	130,288	3.8	1,825,307	4.3	-1.6	23.7
C	1,233,960	35.7	6,086,541	14.4	51.7	3.6
F	194,827	5.6	2,536,736	6.0	4.0	-6.4
G, H, I	428,748	12.4	8,385,600	19.9	-5.1	9.5
J	77,641	2.2	2,529,075	6.0	7.0	35.6
K	101,265	2.9	2,176,323	5.2	-26.7	-10.9
L	279,506	8.1	4,157,864	9.9	9.2	18.6
M, N	131,728	3.8	3,192,672	7.6	1.5	5.4
O, P, Q	552,416	16.0	8,239,842	19.5	24.9	25.8
R, S, T, U	79,521	2.3	1,509,970	3.6	46.6	34.6
Total	3,452,682	100.0	42,195,602	100.0	16.5	11.0

**reading of letters for activities the same as in table 1*

Source: CBS, 2023.

ufacturing is standing out with the highest values of regional and local components; manufacturing is the most competitive activity in the Varaždin-Koprivnica Region according to GVA. However, unlike manufacturing, it should be noted that a substantial number of activities has a negative regional component or the component of regional competitiveness. Activities of retail, transport and storage of furniture and food preparation (G, H, I) as well

Table 6. Shift-share analysis of Gross Value Added (GVA) in the Varaždin-Koprivnica Region, 2009-2020. (in current prices in thous. euros)

Activity	Total change	„Share-Effect"	„Shift-Effect"		
		National growth component	Regional component (Total Shift)	Structural component (Proportionality Shift)	Local competitiveness component (Differential Shift)
A	-44,278	31,651	-75,929	-67,097	-8,832
B, D, E	-2,148	14,602	-16,750	16,770	-33,520
C	420,679	89,672	331,007	-60,429	391,436
F	7,417	20,664	-13,247	-32,565	19,318
G, H, I	-23,015	49,811	-72,826	-6,847	-65,980
J	5,110	7,997	-2,887	17,798	-20,685
K	-36,825	15,226	-52,051	-30,215	-21,836
L	23,452	28,232	-4,780	19,367	-24,148
M, N	1,983	14,306	-12,323	-7,318	-5,005
O, P, Q	110,253	48,753	61,500	65,393	-3,893
R, S, T, U	25,284	5,980	19,304	12,802	6,501
Total	487,912	326,894	161,018	-72,339	233,357
			Regional factor (RF) = 1.049		
			Structural factor (SF) = 0.978		
			Local competitiveness factor (LF) = 1.072		

Source: Author's calculation based on data from CBS, 2023.

as mining and extraction, and activities of electric power distribution, water and gas distribution (B, D, E), real estate business (L), financial activities (K), information and communications (J) etc. stand out due to negative value of local competitiveness. Despite that, total component of local competitiveness is positive because the competitive drawbacks and weaknesses noticed in these activities, are successfully compensated with the competitive advantages in manufacturing.

Data on GVA has also indicated the existence of intra-regional disparities in the Varaždin-Koprivnica Region (Fig. 3). In Counties of Varaždin and Međimurje, RF>1, which indicates the above average growth of GVA in comparison to Croatia. The same as with the growth of employed, the above average growth of GVA in those Counties was achieved due to a favourable local competitiveness factor (LF>1) in spite of less favourable structural characteristics of their economy (SF<1). Therefore County of Varaždin and County of Međimurje belong to type 4 regions. According to this indicator County of Koprivnica-Križevci also shows unfavourable shifts. Below average growth of GVA in County of Koprivnica-Križevci is the result of unfavourable structural and local conditions (according to Boudeville regional type 8). Local competitiveness factor is low

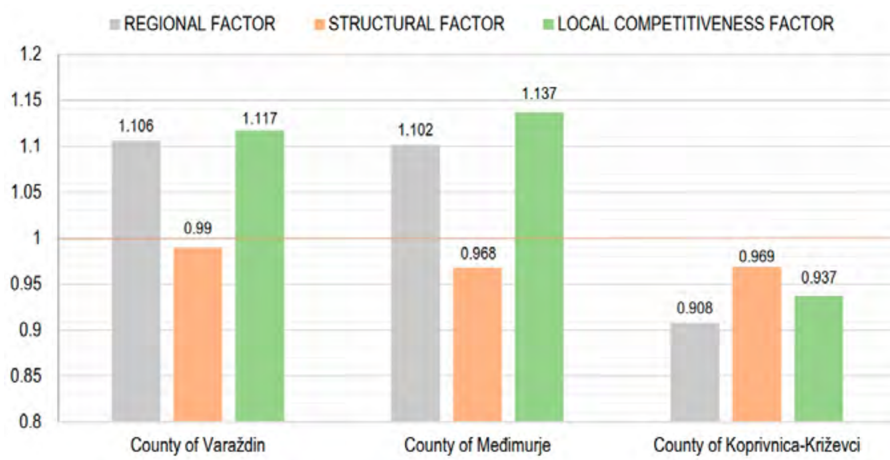

Figure 3. Regional, structural and local factor of Gross Value Added in the counties of the Varaždin-Koprivnica Region, 2009-2020.
Source: Author's calculation based on data from CBS, 2023.

Table 7. Shift analysis of Gross Value Added (GVA) development in counties of the Varaždin-Koprivnica Region, 2009-2020. (in current prices in thous. euros)

Activity*	Total GVA change			Local competitiveness component (Differential Shift)		
	County of Varaždin	County of Međimurje	County of Koprivnica-Križevci	County of Varaždin	County of Međimurje	County of Koprivnica-Križevci
A	-28,033	-10,474	-5,771	-18,262	-120	9,549
B, D, E	15,174	14,477	-31,799	3,838	8,703	-46,061
C	241,200	155,601	23,878	228,207	146,780	16,449
F	22,653	-3,924	-11,312	27,201	25	-7,907
G, H, I	-13,975	-14,628	5,588	-35,273	-26,024	-4,683
J	15,813	-2,261	-8,442	3,010	-9,513	-14,183
K	-7,527	-14,571	-14,727	-1,236	-10,556	-10,045
L	10,221	13,646	-415	-9,244	-435	-14,469
M, N	-8,288	4,698	5,573	-12,093	2,781	4,307
O, P, Q	36,152	36,011	38,090	-23,010	9,554	9,563
R, S, T, U	14,796	4,089	6,399	5,647	-166	1,021
Total	298,186	182,664	7,062	168,786	121,030	-56,459

**reading of letters for activities the same as in table 1*

Source: Author's calculation based on data from CBS, 2023.

(0.937) which indicates a lower level of economy's competitiveness in this County.

Despite the fact that Counties of Varaždin and Međimurje have a favourable local competitiveness factor, the analysis of activities reveals that in all three counties there are activities with negative indicators of local competitiveness (tab. 7). In Counties of Varaždin and Međimurje this shortfall is compensated through manufacturing which generates an extremely positive indicator of local competitiveness which results in positive total component of local competitiveness. In County of Koprivnica-Križevci the compensation effect of manufacturing is absent, which makes its overall local competitiveness negative.

Discussion and conclusion

The Varaždin-Koprivnica Region is one of the main industrial cores in Croatia. Shift-share analysis has shown similar results regardless of the use of number of employed or Gross Value Added as indicators. In comparison with the Republic of Croatia this region registered the above average development which is the result of endogenous or local conditions. Therefore, it can be concluded that the region possesses competitive advantages. Geographical location in the vicinity of Hungary, Slovenia and Austria, good traffic connections with the capital city and tradition of manufacturing had a positive effect on its development and competitiveness.

Results similar to those presented in this case study can be noticed in other research papers, such as the already mentioned *Regional competitiveness index of Croatia* (NCC, 2014). Analysing *Regional competitiveness index*, Čučković et al. (2013) conclude that the counties in the North-West of Croatia have good performances regarding the development of infrastructure, entrepreneurship and investments, with somewhat lower educational indicators. Čavrak (2012) conducted a shift-share analysis of Croatian counties for the earlier period (1997-2008) and claimed that Counties of Zagreb and Varaždin have the highest growth of local competitiveness in the country. The County of Međimurje was also amongst the few counties with the growth in competitiveness, while the competitiveness of the County of Koprivnica-Križevci was already decreasing.

Besides its enormous importance in the economic structure of the area, manufacturing is the most competitive economic activity of the analysed region. It is mainly true for Counties of Varaždin and Međimurje. In the County Koprivnica-Križevci manufacturing is slightly less competitive but it is still one of the most industrialised in Croatia. The analysis indicated the presence of intra-regional disparities where Counties Varaždin and Međimurje note an above average growth compared to Croatia, whilst the development of the County of Koprivnica-Križevci has a below average development rate. Since nationally stagnating activities are significantly represented in the economic structure of Counties of Varaždin and Međimurje, their above average development is first and foremost the result of a favourable local competitiveness factor. The economic structure of County of Koprivnica-Križevci is also dominated by nationally stagnating activities but with the lower level of local competitiveness.

The obtained results can serve as a basis for rethinking economic policies. Although the region has local competitive advantages, due to its less favourable structural economic characteristics, the strengthening of nationally growing sectors is recommended (sectoral restructuring). For the County of Koprivnica-Križevci, along with the already mentioned restructuring, general improvement of the infrastructure is suggested, which should contribute to the competitiveness growth of its economy. Problems with the work force are one of the limiting factors in the further development of the region. It is suggested to work on a better coordination between education system and economy in order to generate a domestic work force with the skills necessary for the work market and adaptable to technological and other changes.

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GIS-based Multi-criteria Assessment of Areas Suitable for the Construction of a Repository for Low and Intermediate Kevel Radioactive Waste in Slovenia

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KEYWORDS

spatial planning
nuclear waste
geographical information systems
OWA
TOPSIS
MCE

ABSTRACT

This study evaluates the site selection for a new repository for low and intermediate level radioactive waste in Slovenia. The ordered weighted average method is used in combination with the TOPSIS method to evaluate the current site and its alternatives considering eight criteria and five constraints. The results show that 52.37% of the country's area falls into five suitability classes for the two decision alternatives, while others do not fulfil the criteria at all. In both cases, the most suitable areas are located in the north-eastern part of Slovenia. The current site tends to be less suitable (categorised as moderately suitable and very unsuitable) and should be reassessed by the relevant stakeholders.

Introduction

Krško Nuclear Power Plant (KNPP) is the only nuclear power plant in Slovenia that has been in commercial operation since 1983 (NEK, 2023). It is located in the south-eastern part of the country near the town of Krško. Low and intermediate level radioactive waste generated during electricity production is currently stored on the site of the nuclear power plant or in the central radioactive waste storage facility in the village of Brinje. Radioactive waste from medical, scientific, and other industrial projects is also disposed of there. As the amount of waste is constantly increasing, the Republic of Slovenia has decided to build a new repository. It took more than a decade to finalise the selection of the area suitable for construction, which is located next to the current nuclear power plant in the village of Vrbina (RS, 2009).

The final selection of the site was the subject of much public and expert debate because of the potential risks of radioactive waste to humans and the environment, such as contamination of groundwater and soil and displacement of radioactive materials, and because the selected site is located in one of the most earthquake-prone areas in Slovenia (SEA, 2021a). Due to these risks, great caution is required when selecting a site for the final disposal of radioactive waste. Although new repositories for low and intermediate level radioactive waste are already under construction, a reassessment of the site selection is necessary based on the remaining conflicting opinions.

When selecting a site for the disposal of nuclear waste, many important spatial variables should be considered that are similar to those relevant to the selection of the site for a nuclear power plant, such as land use, population density, lithology, groundwater discharge rate, slope gradient, landslide potential, precipitation, seismicity, soils,

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protected areas, freshwater areas, distance from agglomerations and possible others (Abudeif et al, 2015; Bilgilioğlu, 2022; Lim & Afifah Basri, 2022; Susiati et al., 2022). Since the number of important factors can and should be high, complex spatial multi-criteria methods are required to consider all factors and constraints in the final site selection. Geographic information systems (GIS) offer many spatial quantitative multi-criteria evaluation (MCE) methods to overcome this challenge. One of these methods is the ordered weighted average (OWA), which was used in this study.

OWA was introduced by Yager (Yager, 1988). It is a multi-criteria aggregation technique that considers two types of weights, namely criteria and order weights, and allows the generalisation of weighted linear combination (WLC) and Boolean AND and OR logic in a methodological framework (Valente & Vettorazzi, 2008). A criterion weight is assigned to a given criterion, which is usually standardised using fuzzy functions for the entire study area and indicates its relative importance, while the ordinal weight for a given criterion varies from site to site. The ordinal weights are associated with the trade-off measure of compensation between the criteria, which leads to a certain risk that the final decision will be wrong (Drobne & Lisec, 2009). To determine the criteria weights, the analytical hierarchy process (AHP) method is often used in various MCE approaches (Cunden et al., 2020; Khazaee Fadafan et al., 2022; Kocabaldır & Yücel, 2023). The weights are assigned by the pairwise comparison of the importance of the criteria. The weights of the order are determined based on a selected decision risk taking approach and the degree of trade-off between the criteria (Drobne & Lisec, 2009).

The TOPSIS (Technique for Order Preference Similarity to Ideal Solution) method is another MCE method that can be used to rank location alternatives based on the shortest distance to the ideal solution (Makwakwa et al., 2023). It is useful for ranking spatial results derived from GIS MCE analyses (Foroozesh et al., 2022; Rane et al., 2023).

The aim of this study is to identify which locations in Slovenia as a whole are most suitable for construction when selected criteria are taken into account. The two main research questions are:

Q1: Which other potential sites could be suitable for construction if a GIS-based MCE assessment is performed?

Q2: Is the current site selection acceptable based on the selected criteria?

The objectives of this study are as follows:

G1: Identification of relevant evaluation criteria based on a literature review.

G2: Creation of GIS layers for the selected evaluation criteria and constraints.

G3: Assessment of different suitability classes for the placement of a repository for low and intermediate level radioactive waste in Slovenia with maximum trade-off between the criteria and the moderate risk of the selected site using OWA.

G4: Assessment of different suitability classes for the placement of a repository for low and intermediate level waste in Slovenia with moderate trade-off between the criteria and low risk of the selected site using the OWA.

G5: Evaluation of the current site selection for the repository for low and intermediate level radioactive waste near the village of Vrbina based on the results of the third and fourth objectives.

G6: Identification of the most suitable site for a repository for low and intermediate level waste using the TOPSIS method based on the results of the third and fourth objectives.

Study area

The analysis was carried out for the entire territory of Slovenia (Figure 1), which is located in Central Europe between 46° 52' 37.52" and 45° 25' 18.34" latitude and 16° 36' 07.69" and 13° 23' 47.81" longitude (SORS, 2004). The country has around 2,117,000 inhabitants and a total area of 20,271 km2 (SORS, 2023). It is bordered to the north by Austria, to the north-east by Hungary, to the east and south by Croatia and to the west by Italy. The Alpine region forms the highest part of the country in the north-east and north. Approximately half of the country's relief is karst (Stepišnik, 2024). The KNPP and the site selected for the repository for low and intermediate level radioactive waste are located in the Pannonian region, which forms the western edge of the Pannonian Basin.

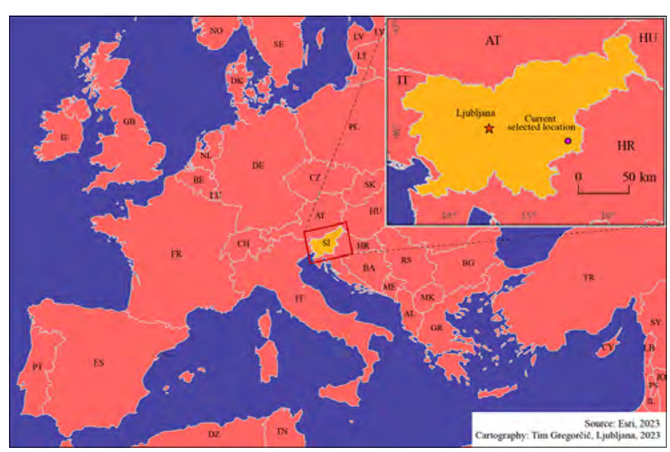

Figure 1. Study area with marked location of the capital city and currently selected location of the repository

Methodology

The processes of the study consisted of seven main steps, which are shown in Figure 2. All spatial analyses were carried out using ArcGIS Pro 3.1.0 and TerrSet 2020, a spatial monitoring and modelling software.

Literature review

Based on a review of the relevant literature, we identified the criteria and constraints that should have been used in our study to achieve its objectives. As mentioned above, the factors relevant to the siting of a nuclear waste repository are similar to the factors relevant to the siting of a nuclear power plant. The biggest difference is the lack of a freshwater source in the case of nuclear waste storage. We have therefore analysed the MCE studies in both areas.

Table 1 shows the results of this review. The final selection of criteria and constraints is shown in Figure 2.

Input data preparation

This phase of the study was divided into two parts. In the first part, criteria raster layers with a cell size of 100 m and constraints raster layers were created. In the second part, they were standardised using fuzzy logic.

GIS layers creation

All layers used for the analyses were created in raster format. A vector layer of the Slovenian landslide areas at a scale of 1:250,000 was used for the landslide potential (SWA, 2020b). A seismic intensity layer was created using maximum ground acceleration data at a scale of 1:500,000 with a return period of 475 years (SEA, 2021a). The original ground acceleration values were used in the conversion from vector to raster format. To obtain the rock permeability layer, we transformed the classes of the hydrogeo-

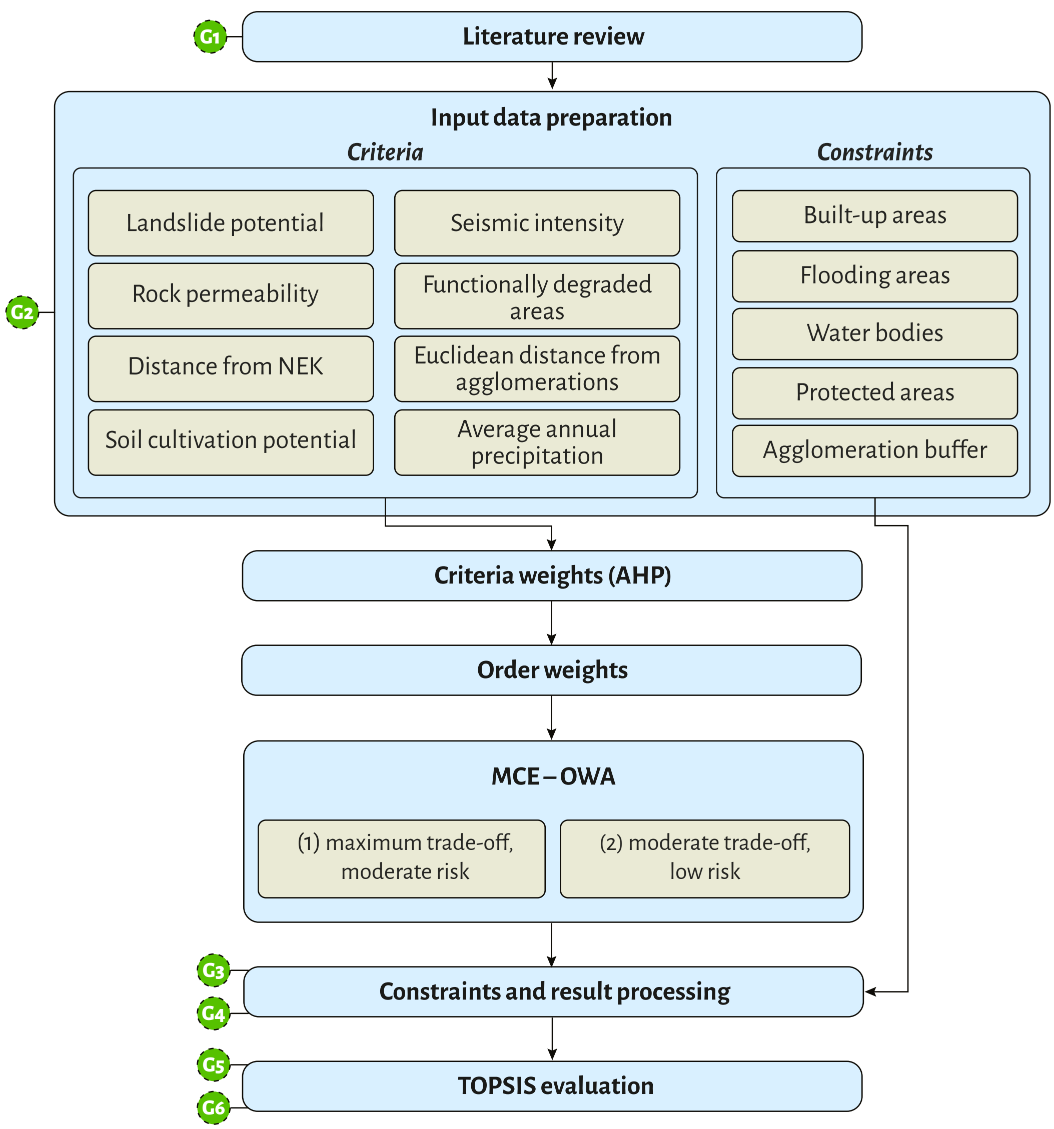

Figure 2. Methodological flowchart

Table 1. Literature review results

Paper	Criteria	Constraints
Lim & Afifah Basri, 2022	Land use, population density, lithology, lineament density, groundwater discharge rate, slope, landslide potential, rainfall, seismicity intensity, elevation	Flooding area, river area, protection area
Bilgilioğlu, 2022	Elevation, slope, aspect, lithology, soil map, land use, lineament density	Land use, protected areas, proximity to faults, roads, rivers, settlements, water surfaces
Susiati et al., 2022	Elevation, slope, groundwater, soils, rainfall, climate, land use & land cover, land system, distance from settlements, accessibility, central business district, vital and dangerous infrastructure, geological structures, disaster risk	/
Baskurt & Aydin, 2018	Proximity to national borders, hazardous facilities, transport infrastructure and electrical grid	Capable faults, seismicity, existence and sufficiency of cooling water, population, elevation and flood level, topography and slope, environmental sensitivity

logical vector map layer at a scale of 1:250,000, which was created using the LAWA method (DSS, 2008), according to the method of Lampič et al. (2021). Twelve LAWA classes were summarised into five new classes, with class 1 representing the parent rock with the lowest permeability and class 5 the parent rock with the highest permeability. The details of the grouping are listed in Table 2.

Table 2. Reclassification of LAWA classes.

Class	Hydrogeological class
1	Intergranular silicate aquifers Fissured silicate aquifers Fissured silicate/carbonate aquifers Special cases: strata reach with organic material
2	Fissured carbonate aquifers
3	Poorly karstified carbonate cavern aquifers Other special cases
4	Moderately karstified carbonate cavern aquifers Moderately karstified organic/carbonate cavern aquifers
5	Intergranular carbonate/silicate aquifers Intergranular carbonate aquifers Very karstified carbonate cavern aquifers

We created the Functionally Degraded Areas (FDA) layer (Lampič et al., 2020) according to the status of the polygons (FDA or non-FDA). The distance to the KNPP was calculated using the Make Service Area Analysis Layer tool based on the transport network created by Esri. The transport network was not limited to Slovenia, so the method was able to determine the shortest route to a given location, partly via Croatia. We calculated the distance from KNPP in kilometres and in one-kilometre increments. The layer representing the Euclidean distance from the agglomerations (SEA, 2019) was created using the Euclidean Distance tool. The soil quality vector layer (Rupreht, 1991) at a scale of 1:25,000 (MAFF, 2008), which was used to consider the yield potential of the soil, was initially merged with the FDA layer. The FDA was assigned a non-agricultural category. For the average annual precipitation layer, adjusted mean annual precipitation data for 1981-2010 were used (SEA, 2022b).

The land use dataset (MAFF, 2022) was used for the constraint layers for built-up areas and water areas. The floodplain layer was created using the Q500 flood risk area (SWA, 2022). Missing data was replaced by an older layer with very rare floodplains from the flood warning map (SWA, 2020a). The protected areas layer consisted of three different vector layers: Nature 2000, protected areas at national level and protected areas at local level (SEA, 2022a, 2022c, 2022d). The agglomeration layer (SEA, 2019) was used again to create agglomeration buffers with a radius of 500 metres. This decision was influenced by the examples of existing repositories for low and intermediate level waste in Europe, including those at Drigg, Lakenheath and Morsleben.

GIS layers standardisation

The values in the raster criteria layers were standardised using the fuzzy tool of the TerrSet software. Increasing linear, decreasing linear and decreasing J-shaped membership functions were used. In the case of the linear membership functions, all values were arranged in the interval from 0 to 1, while the interval for the J-shaped function ranged from 1 to near 0 (infinity). Information on the standardisation of the criterion levels can be found in Table 3, while the standardised levels are shown in Figure 3.

Table 3. Standardisation of criteria layers

Layer	Fuzzy function	Limit A	Limit B	Unit
Landslide potential	Decreasing linear	1	6	Unit of landslide potential
Seismic intensity	Decreasing linear	0.1	0.325	PGA
Rock permeability	Decreasing J-shaped	1	3	Unit of rock permeability
Functionally degraded areas	Increasing linear	0	1	Unit of FDA
Distance from KNPP	Decreasing linear	0	237	km
Euclidean distance from agglomerations	Increasing linear	750	13,261	m
Soil cultivation potential	Decreasing linear	1	80	Unit of soil cultivation potential
Average annual precipitation rate	Decreasing linear	900	4000	mm

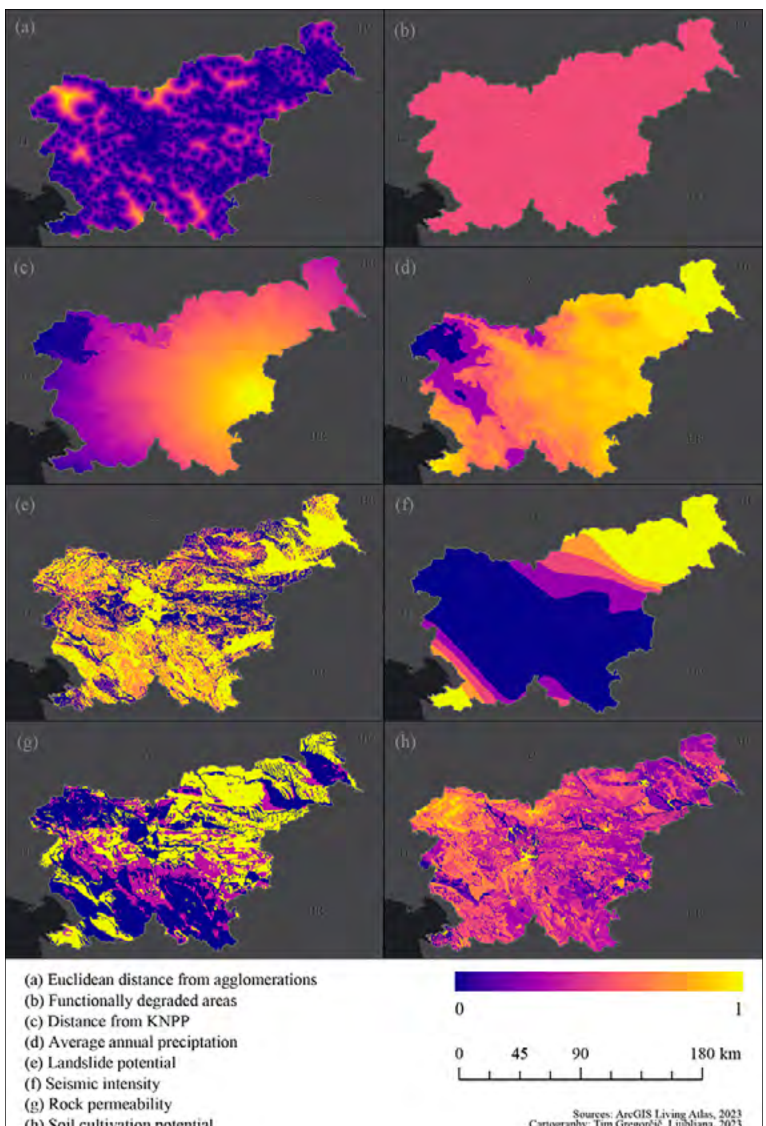

Figure 3. Standardised criteria layers

Weighting of the criteria

The weighting of the criteria was determined by the authors using the AHP method (Table 4). The factor with the greatest weighting was rock permeability, because in the event of an accident, the permeability of the geological structures determines how quickly radioactively contaminated groundwater spreads into the surrounding area and possibly into the aquifers used for drinking water supply. This risk was also emphasised in the environmental permit (SEA, 2021b: 21). This is followed by the factors of landslide potential and seismic intensity, which in the case of Slovenia were also emphasised by the French Institute for Radiological Protection and Nuclear Safety (IRSN) and the International Atomic Energy Agency (IAEA) (SEA, 2021b: 16). As landslides of a magnitude that can damage infrastructure occur more frequently than such earthquakes, they are weighted with a higher value. The fourth highest weighting was assigned to the productive potential of the soil. Although the difference between the third and fourth weights is relatively large (x = 0.0905), the fourth position is appropriate to protect the highest quality soils. Some factors, such as landslide potential, favour the lowlands, where the highest quality soils are also found, so the appropriateness of a high weighting is even higher. Distance to KNPP is the fifth most heavily weighted factor and ranks sixth in terms of Euclidean distance from agglomerations. This is due to the fact that when we standardised the Euclidean distance layer, we had already established that suitability increases from 750 m, limiting the risk of living near the landfill, but we had not yet addressed the risk of an accident during hazardous waste transport. In addition, during the public consultation on the landfill project, the public expressed concerns about the safe transport of waste (SEA, 2021b, p. 12). The average annual precipitation factor is the least weighted, as it is a factor in the leaching of radioactive materials in the event of an accident. Most of the other factors are aimed at preventing accidents involving the release of hazardous waste into the environment itself and are therefore weighted more heavily. Accordingly, the Euclidean distance from the agglomerations is also one of the less weighted factors.

Order weights

Table 5 shows the order weighting values based on the selected MCDE directions: maximum trade-off between the criteria values at a selected location and moderate risk of wrong choice and moderate trade-off between the criteria values at a selected location and low risk of wrong choice. After determining both types of weights, the OWA method was performed using the MCE module of the TerrSet software.

Applying constraints and processing of the results

After obtaining the raw OWA results, constraint layers were applied using ArcGIS Pro software. In the next step, the results were reclassified into five classes based on the values of the grid cells:

- Highly suitable area (0.801-1.000),
- Suitable area (0.601-0.800),
- Moderately suitable area (0.401-0.600),
- Unsuitable area (0.201-0.400),
- Highly unsuitable area (0.000-0.200).

Table 4. Criteria weights based on the AHP method

	AHP matrix								AHP weights	
	A	B	C	D	E	F	G	H	Weights (consistency = 0,06)	Rank
A	1								0,0680	6
B	1/2	1							0,0543	7
C	2	2	1						0,0932	5
D	1/3	1/4	1/5	1					0,0328	8
E	3	4	3	4	1				0,2206	2
F	2	3	2	4	1	1			0,1956	3
G	4	5	3	6	1	1/1	1		0,2302	1
H	3	3	2	2	1/4	1/4	1/3	1	0,1051	4

A – *Euclidean distance from agglomerations,* **B** – *FDA,* **C** – *Distance from KNPP,* **D** – *Average annual precipitation rate,* **E** – *Landslide potential,* **F** – *Seismic intensity,* **G** – *Rock permeability,* **H** – *Soil cultivation potential.*

Table 5. Order weights

Maximum trade-off, moderate risk	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6	Weight 7	Weight 8
	0,125	0,125	0,125	0,125	0,125	0,125	0,125	0,125
Moderate trade-off, low risk	Weight 1	Weight 2	Weight 3	Weight 4	Weight 5	Weight 6	Weight 7	Weight 8
	0,25	0,25	0,25	0,25	0	0	0	0

The classified results were converted into locally homogeneous regions using the Region Group tool. Based on information from the National Spatial Plan for the disposal site for low and intermediate level radioactive waste in Vrbina in the municipality of Krško, we obtained information on the coordinates of nine points delimiting the disposal area selected by the state. The points were imported into GIS and used to create a polygon representing the planned area. We calculated its area, which was 9.47 ha, and the areas of the polygons that were categorised as highly suitable. We identified areas in this suitability class that had an area equal to or greater than the area of 9.47 ha. As part of the selection process, we also identified the three sites with the highest average OWA value and the three sites with the highest average suitability value according to the OWA.

TOPSIS evaluation

The TOPSIS method was used to assess the suitability of sites for the disposal of low and intermediate level waste that met the final selection criteria described in the previous section. A detailed description of this method was provided by Zeng et al. (2021). First, we evaluated outcome sites with the highest average OWA values. Second, given that the method certainly does not account for all factors relevant to repository site placement, we scored the outcome sites with the largest area, as a larger area implies greater flexibility in the final decision, which may depend on further evaluation of the sites at the micro-spatial level, with additional factors and constraints not considered in this study.

Results

Suitability classes assessment

Figure 4 shows the final spatial results of the selected decision scenarios. 40.08% of the area of the country was available for evaluation (8124.66 km^2). The differences in suitability between the two scenarios are significant. In the case of the maximum trade-off between the criteria and the moderate risk, the north-east of the country (the Pomurska and Podravska statistical regions) tends to be the most suitable for placement, as most of the areas classified as highly suitable are found there. Nevertheless, only 1.37% of the areas were categorised as very suitable (Table 6). The largest proportion of areas (62.26%) was categorised as moderately suitable. In the second decision scenario, no area was categorised as very suitable, only 0.003% as suitable and more than a half (57.21%) as unsuitable. In addition, the "very unsuitable" class increased dramatically (by 30.00%).

The proportions of the two decision scenarios are shown in Figure 5. The figure also shows the relationship between the two. It can be seen that more than 80% of the highly suitable areas in the first scenario skipped a suitable class in the second scenario, where they were categorised as moderately suitable. A similar pattern was observed for the suitable areas, where more than a half (54.95%) were categorised as unsuitable in the case of the moderate trade-off and low risk scenarios. Very unsuitable areas in the second scenario were mostly categorised as moderately suitable or unsuitable in the first scenario.

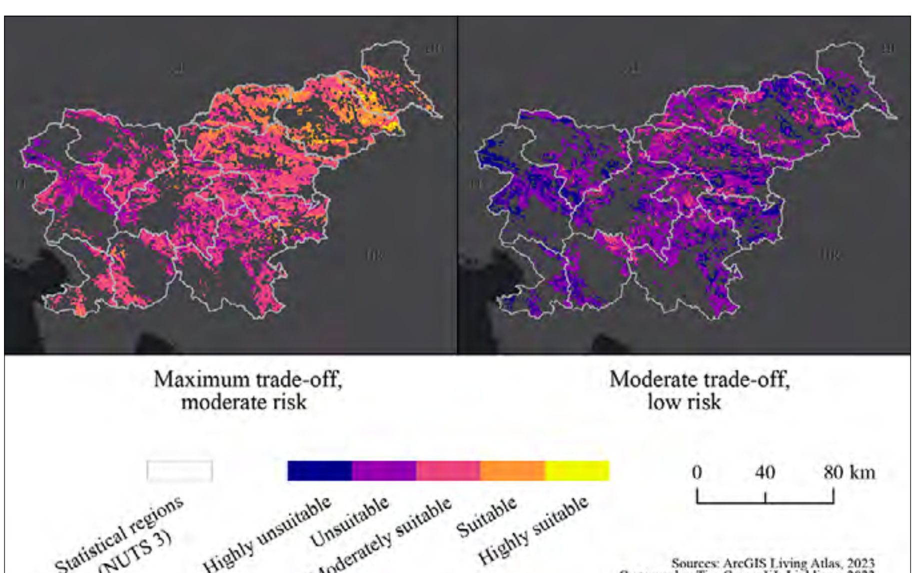

Figure 4. MCE results

Table 6. Areas of classified MCE classes

	Maximum trade-off, moderate risk		Moderate trade-off, low risk	
	km²	%	km²	%
Highly unsuitable	22.64	0.28	2459.71	30.27
Unsuitable	1765.93	21.74	4648.1	57.21
Moderately suitable	5058.6	62.26	1016.57	12.51
Suitable	1165.86	14.35	0.28	0.003
Highly suitable	111.63	1.37	0	0.00
Total	8,124.66	100.00	8,124.66	100.00

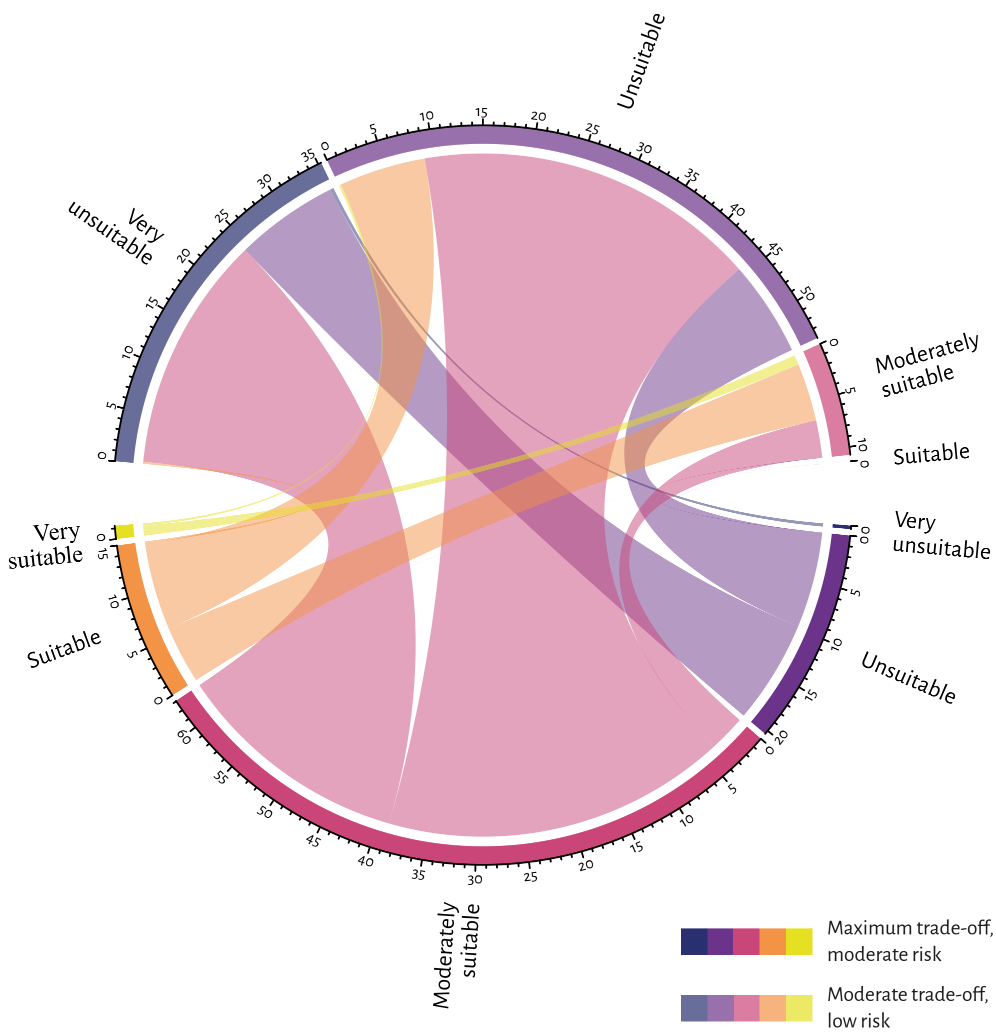

Figure 5. Class shares in both MCE alternatives and their relationships

Maximum trade-off, moderate risk

The results of the TOPSIS site suitability assessment are shown in Table 7. The results refer only to the scenario with the maximum trade-off between the criteria and the moderate risk of site selection, as there are no highly suitable and suitable sites with an area of at least 9.47 ha in the second scenario. Based on the TOPIS assessment of the sites with the highest average OWA value, the third most suitable site is located north of Slovenska Bistrica, the second most suitable site is located northwest of the village of Majšperk and the most suitable site is located south of Ptuj near Podlehnik with an area of 13 ha (Figure 6). The site had a soil cultivation potential of 34 and the rock permeability fell into class 1, which represents the lowest permeability and thus the highest suitability. The peak ground acceleration was 0.1, placing the site in the lowest seismic hazard class. In terms of landslide potential, the site fell into class 1, which represents the highest suitability. The

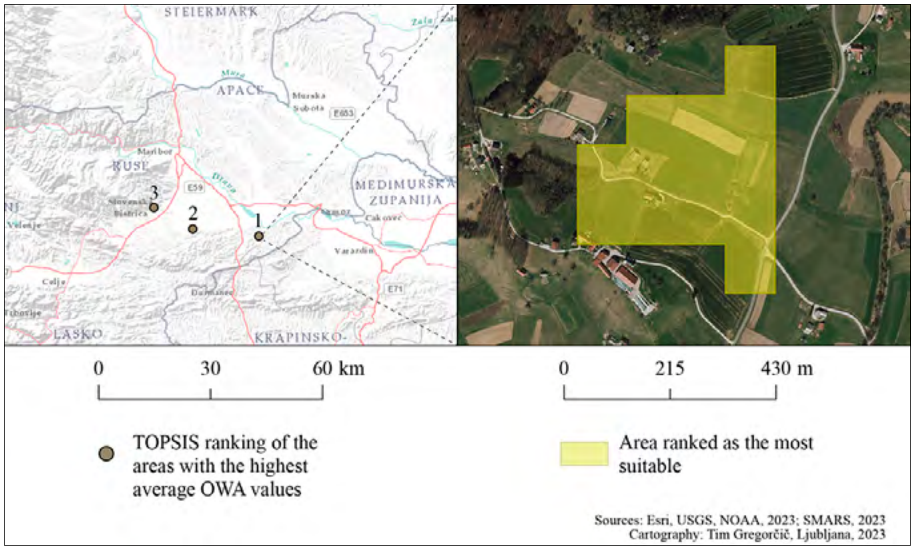

Figure 6. TOPSIS evaluation of the locations with the highest average OWA values

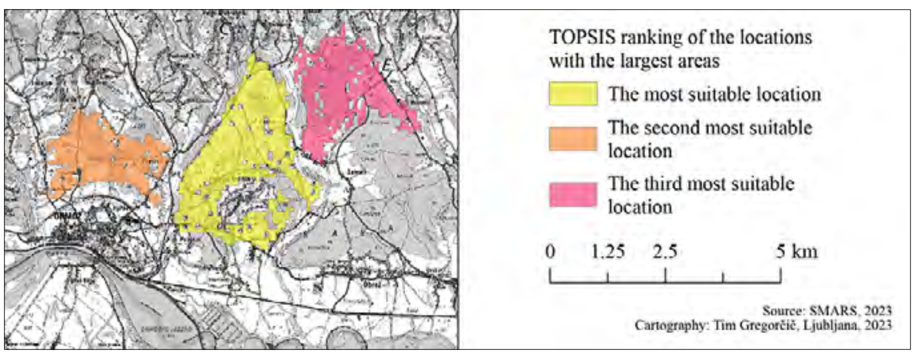

Figure 7. TOPSIS evaluation of the locations with the largest areas

average annual rainfall was 1100 mm (the 3rd lowest in the country). The average distance to the KNPP was 78.38 km and the average distance to agglomerations was 3.70 km. The area is not functionally degraded.

When analysing the locations with the largest areas, the three largest areas were in close proximity to each other. The seemingly uniform area was divided into lower suitability classes not only by constraints, but also by the categorisation of the areas in between. These areas are shown in Figure 7. In the most suitable area, which covers 668 ha, there are several areas with different soil cultivation potentials. The highest value was 56, the lowest was 40 and the average value was 45. The permeability of the rocks fell into class 1, which represents the highest suitability. The peak ground acceleration value was 0.1, placing the area in the lowest seismic hazard class. In terms of landslide potential, the area falls into class 1, which is the highest suitability. The average annual rainfall was 1053 mm. The average distance to the KNPP is 101.11 km and the average distance to agglomerations is 2.65 km. No part of the area was categorised as functionally degraded. Compared to the preferred area with the highest average OWA values, this area has a higher yield potential, is further away from the Krško Nuclear Power Plant and is less distant from agglomerations. The average annual precipitation is lower.

Table 7. Results of TOPSIS evaluation

Value [a]	Euclidean distance from the agglomerations	Functionally degraded areas	Distance from KNPP	Average annual precipitation	Landslide potential	Seismic intensity	Rock permeability	Soil cultivation potential	Si^+_i	Si^-_i	P_i	Rank
Evaluation of the locations with the highest average OWA values[a]												
0.831	0.008269	0.03135	0.054675	0.018712	0.127363	0.113045	0.132906	0.060727	0.090359	0.002862	0.030705	3
0.833	0.016255	0.03135	0.054882	0.085572	0.127363	0.113045	0.132906	0.060585	0.049348	0.067405	0.577329	2
0.843	0.065509	0.03135	0.051816	0.088627	0.127363	0.113045	0.132906	0.060727	0.003066	0.090358	0.967185	1
V^+_j	0.065509	0.03135	0.054882	0.088627	0.127363	0.113045	0.132906	0.060727				
V^-_j	0.008269	0.03135	0.051816	0.018712	0.127363	0.113045	0.132906	0.060585				
Evaluation of the locations with the largest areas[a]												
339 ha	0.011088	0.03135	0.054429	0.085167	0.127175	0.113045	0.132906	0.064927	0.045878	0.066261	0.590885	2
416 ha	0.056946	0.03135	0.052568	0.019265	0.127457	0.113045	0.132906	0.058587	0.067571	0.045859	0.404295	3
668 ha	0.035471	0.03135	0.05441	0.086512	0.127457	0.113045	0.132906	0.058293	0.022476	0.071555	0.760977	1
V^+_j	0.056946	0.03135	0.054429	0.086512	0.127457	0.113045	0.132906	0.064927				
V^-_j	0.011088	0.03135	0.052568	0.019265	0.127175	0.113045	0.132906	0.058293				

Moderate trade-off, low risk

As mentioned above, when assessing the suitability of the sites in terms of moderate trade-off and low risk, only one site was found to be suitable and none were found to be particularly suitable. Therefore, we did not perform a TOPSIS assessment in this scenario.

The suitable site was again located near Ormož (northeast Slovenia), as shown in Figure 8. Part of the site is located on soil unsuitable for agriculture and part of the site is located in an area with a soil cultivation potential value of 41. In terms of rock permeability, the site fell into class 1, which represents the highest suitability. The design acceleration value was 0.1, which also placed the site in the class of areas with the lowest seismic intensity. In terms of landslide potential, the site fell into class 1, which represents the highest suitability. The average annual rainfall is 1100 mm. The average distance to the KNPP is 100.36 km and the average distance to agglomerations is 956 m. Today, this area also has the status of a functionally degraded area.

Assessment of the current site selection for the construction of a repository for low and intermediate level radioactive waste near Vrbina

Most of the area selected for the construction of the KNPP nuclear power plant is located within 500 metres of agglomerations. Therefore, the selected restrictions make the site unsuitable for construction (Figure 9). If they were not a limiting factor, the selected area would be classified as moderately suitable for the repository in the case of a scenario with a maximised trade-off between the criteria and a moderate site selection risk. In the case of the as-

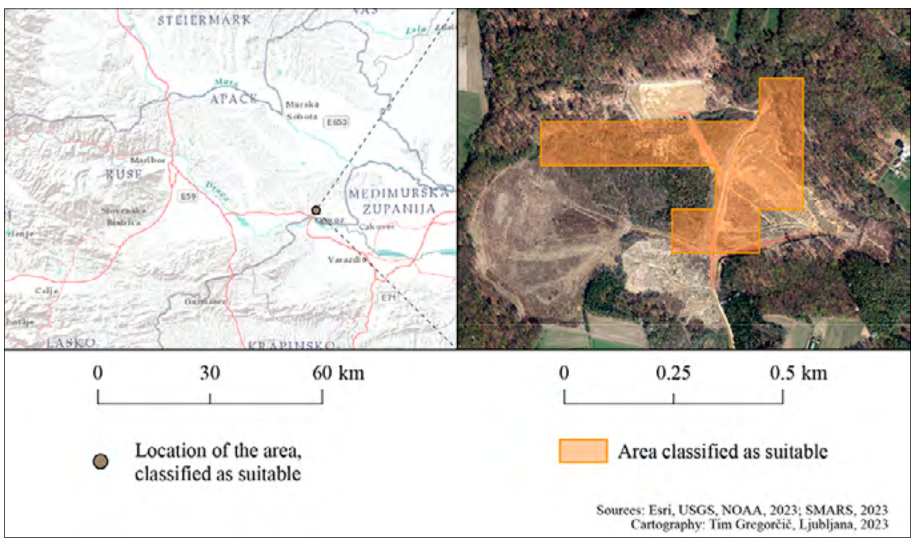

Figure 8. Location classified as suitable

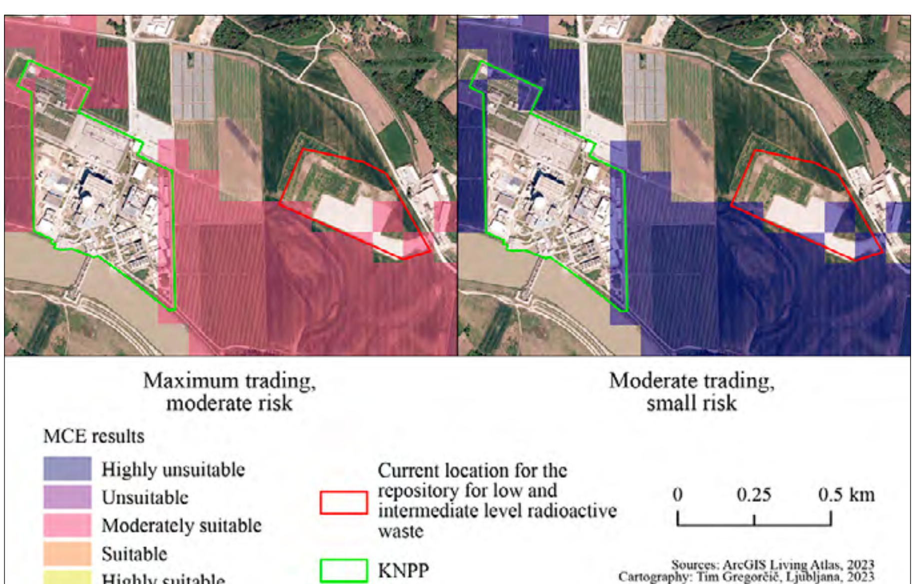

Figure 9. Evaluation of the current site selection

sessment variant with a moderate compromise and a low siting risk, the site of the facility would be classified as very unsuitable. The proposed landfill site has a soil cultivation potential score of 73 and the rock permeability falls into class 5, which is the highest permeability and consequently the least suitable. The peak ground acceleration value was 0.275, placing the site in the second class of the most seismically hazardous areas. In terms of landslide potential, the site falls into class 1, which represents the highest suitability. The average annual rainfall is 1200 mm, the distance to the KNPP is between 1 and 2 km and the average distance to the agglomerations is 483.99 m.

Discussion

The aim of this study was to identify the most suitable sites for the construction of a repository for low and intermediate level radioactive waste in Slovenia, taking into account certain criteria and constraints. The assessment was carried out using a GIS-based MCE approach and the TOPSIS method. The currently selected site is mostly located within the 500 metre agglomeration buffer and is therefore unsuitable. Apart from the constraints, the site is not located in a highly suitable or suitable zone, which justifies doubts about the current spatial planning decision. We have also proposed alternatives whose realisation poses a lower risk compared to the current site selection. The highest OWA values for both decision alternatives were observed in the north-eastern part of Slovenia.

As the Republic of Croatia is jointly responsible for the disposal of half of the radioactive waste produced in the KNPP, it is currently in the process of selecting a site for the construction of a repository for low- and intermediate-level radioactive waste. In contrast to the situation in Slovenia, the study by Perković et al. (2020), which considered a similar combination of constraints and criteria, showed that the results obtained with modern GIS research approaches are consistent with the assessment results of the old approaches and confirm that a large part of Trgovska gora (more precisely Čerkezovac) is suitable for the construction of the disposal site as originally planned. This suggests that the Croatian approach to site selection may have considered relevant constraints and criteria in a more meaningful or transparent way in previous decades, when advanced GIS evaluation capabilities were still limited. Nevertheless, Perković et al. (2020) used a simplified GIS-based multi-criteria methodology that is not directly comparable to the one used in our study. Their results also do not allow a comparison of suitability between alternative sites.

Compared to the studies by Bilgilioğlu (2018) and Lim & Afifah Basri (2022), the methodology used in this study provided the opportunity to assess the current site selection and propose alternative sites at a local spatial scale, while their methods only resulted in a regional overview. However, the alternatives proposed in this study require further assessment of environmental and social factors at the local level that have not yet been considered, such as water table, site accessibility, municipal spatial plans, public opinion, stakeholder consideration, etc. Public (non-) approval of site selection has already proven to be an important factor in the final decision on the site selection in Slovenia (Mele & Zeleznik, 1998). The weighting of the AHP criteria in this study was determined by the authors, while Bilgilioğlu (2018) conducted interdisciplinary expert interviews with nuclear safety experts to define them, making them more credible. No other study has attempted to assess the areas suitable for the construction of a repository for low and intermediate level radioactive waste in Slovenia using modern GIS methods. Therefore, it was not possible to compare the results directly. However, if we compare the results of this study with those of other countries, we can conclude that the alternative sites proposed in this study are generally consistent with the trend that the most suitable areas are located in flood-safe areas with low seismic intensity, low rock permeability, low annual precipitation rates and low landslide potential (Bilgilioğlu, 2022; Harun et al., 2016; Lim & Afifah Basri, 2022; Perković et al., 2020). In addition, our study has taken a step forward by using the OWA method instead of the WLC or other symmetric difference method, which leads to more complex alternative solutions to the identified problem based on a precautionary principle.

With possible methodological extensions, even higher quality results can be achieved. The OWA method offers even more risk and trade-off options than the two selected ones. This would make it possible to identify even more alternatives that would be even more useful from the decision-maker's point of view. The need for a better spatial resolution of some factor layers, such as seismic intensity and the very general 1:250,000 spatial scale rock permeability dataset, has already been mentioned. For the removal of agglomerations, the agglomeration layer representing the larger settlements of the country was used, but it would have been better for the quality of the results if it had also included data on smaller settlements that were not considered. The 2020 layer of functionally degraded areas is now partially outdated and an updated layer, which is not yet available, should be used for more up-to-date results. Figure 7 shows that many of the resulting areas are still covered by built-up areas. This is due to the relatively large size of the grid cells compared to the width of the polygons representing streets or individual buildings when these are scattered.

Conclusion

Slovenia's only nuclear power plant is the main source of low and intermediate level radioactive waste. Due to the accumulation of this waste, a new repository is needed. The aim of this study was to determine which sites in Slovenia as a whole are best suited for construction when selected criteria are taken into account. For this purpose, the GIS-based MCE method called OWA was used in combination with the TOPSIS method. The evaluation was based on eight criteria and five constraints. The weighting of the criteria was determined by the AHP. A total of 40.08% of the land area was divided into five suitability classes of two decision alternatives: maximised compromise between criteria with a moderate risk of a wrong decision and moderate compromise between criteria with a low risk of a wrong decision. In the first alternative, 1.37% of the evaluated areas were categorised as very suitable and 14.35% as suitable. The largest proportion was categorised as moderately suitable. In the second alternative, no areas were categorised as very suitable. Only 0.003% was classified as suitable, with an area smaller than 9.47 ha, i.e. insufficient. The largest proportion was categorised as unsuitable. Based on the criteria and constraints applied, the majority of the current development area is unsuitable, mainly due to its location within the 500 m agglomeration buffer. From this we can conclude that the current site selection is not an optimal choice in terms of human and environmental safety. Using the TOPSIS method, several sites with better characteristics were identified. They are located in the north-eastern part of Slovenia (in the northern foothills of Haloze and in the vicinity of Slovenska Bistrica, Slovenj Gradec and Ormož).

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