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28. konferenca Združenih narodov o podnebnih spremembah (COP28) je potekala od 30. novembra do 12. decembra 2023 v Dubaju v Združenih arabskih emiratih. Glavne teme konference COP28 so bile: pregled globalnega stanja, blažitev in prilagoditev na ekološke izzive ter podnebno financiranje. Pri pregledu stanja je bilo poudarjeno, da morajo emisije toplogrednih plinov vrhunec doseči do leta 2025 ter da je te emisije treba zmanjšati za 43 % do leta 2030 in za 60 % do leta 2035 v primerjavi z ravnmi iz leta 2019, da bi globalno segrevanje omejili na 1,5 °C. Poleg tega je bilo ugotovljeno, da nekatere države niso uspešne pri izpolnjevanju ciljev Pariškega sporazuma. Konference COP potekajo neprekinjeno od leta 1995, takrat je potekala prva konferenca v Berlinu.

V zadnjem času so se ekološki problemi še povečali, še posebno problemi, kot so naraščanje gladine morja, trend naraščanja globalne svetovne temperature, taljenje ledenikov … Zato upamo na še bolj konkretne in akcijsko usmerjene cilje na naslednjih konferencah COP.

V Azerbajdžanu bo novembra potekala 29. Konferenca Združenih narodov o podnebnih spremembah (COP29). Upajmo na uspešen in čim bolj konkreten dogovor o rešitvi parečih ekoloških problemov.

Jurij AVSEC
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Dear Readers of the Journal of Energy Technology (JET)

The 28th United Nations Conference on Climate Change (COP28) took place from 30 November to 12 December 2023 in Dubai, United Arab Emirates. The main themes of COP28 were: global stocktaking, mitigation and adaptation to environmental challenges and climate finance. The stocktaking highlighted that greenhouse gas emissions need to peak by 2025, and that these emissions need to be reduced by 43% by 2030 and by 60% by 2035 compared to 2019 levels, in order to limit global warming to 1.5°C. It also noted that some countries are not on track to meet the goals of the Paris Agreement. COP conferences have been held continuously since 1995, when the first conference was held in Berlin.

Recently, ecological problems have increased, especially problems such as rising sea levels, the trend of increasing global temperatures, melting glaciers... Therefore, we hope for even more concrete and action-oriented goals at the next COP conferences.

The 29th United Nations Conference on Climate Change (COP29) will be held in Azerbaijan in November. Let's hope for a successful and as concrete an agreement as possible on solving the burning ecological problems.

Jurij AVSEC
Editor-in-chief of JET

Table of Contents
Kazalo

JET Volume 17 (2024) p.p. 11-25
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ENERGY MANAGEMENT IN MICROPROCESSOR-DRIVEN CIRCUIT DESIGN USING SLEEP MODES

UPRAVLJANJE PORABE ENERGIJE MIKROPROCESORSKEGA VEZJA Z UPORABO NAČINOV PROCESORSKEGA MIROVANJA

Dalibor Igrec[1ℜ], Jože Hebar[2], Amor Chowdhury[1]

Keywords: Energy Management, Sleep Mode, Microprocessor, Electronic Circuit Design, Efficiency

Abstract

The article explores the important significance of sleep mode in the design of microprocessor-centric electronic devices, emphasising energy efficiency, device longevity and environmental sustainability. Sleep mode enables devices to enter low-power states during periods of inactivity, conserving energy and extending battery life. Various levels of sleep modes are examined, ranging from light to deep sleep, each with unique power savings and system responsiveness advantages.[1]

The article also presents a case study involving an electronic circuit controlling sensors, actuators, LTE, WiFi and a geolocation module, where sleep mode is utilised to optimise power consumption. The system operates at varying activity levels, and the employment of sleep modes such as light sleep, deep sleep and hibernation, results in energy savings exceeding 70%. Light Sleep offers rapid responsiveness with moderate power savings, while Deep Sleep and Hibernate Mode maximise energy efficiency but require longer wake-up times. The design approach emphasises the importance of managing the system components carefully, and transitioning

ℜ Corresponding author: Dalibor Igrec, University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, 8270 Krško, Slovenia, E-mail address: dalibor.igrec@um.si

1 University of Maribor, Faculty of Energy Technology, Hočevarjev trg 1, 8270 Krško, Slovenia

2 Energetika Maribor d. o. o., Jadranska cesta 28, 2000 Maribor, Slovenia

between different power modes to ensure an optimal balance between energy conservation and performance.

Finally, the article discusses the broader environmental impact of sleep mode, noting its contribution to reducing devices' energy demands and carbon footprints. By integrating effective sleep mode strategies, designers can create energy-efficient systems that meet both consumer expectations and environmental responsibilities, supporting sustainability efforts in electronic device design.

Povzetek

Članek opisuje pomen uporabe procesorskega mirovanja Sleep Mode pri načrtovanju elektronskih naprav, osredotočenih na mikroprocesor, s poudarkom na energetski učinkovitosti, daljši življenjski dobi naprav in okoljski trajnosti. Način procesorskega mirovanja omogoča napravam, da med nedejavnostjo preklopijo v nizkoenergijska stanja, kar pripomore k varčevanju z energijo in podaljšanju življenjske dobe baterije. Raziskane so različne stopnje načinov procesorskega mirovanja, od lahkega do globokega procesorskega mirovanja, pri čemer ima vsaka svoje prednosti glede na prihranke energije in odzivnost sistema.

V članku je predstavljena tudi študija primera elektronske naprave s procesorjem, ki nadzoruje senzorje, aktuatorje, LTE, WiFi in geolokacijski modul. Z uporabo načinov procesorskega mirovanja je sistem optimiziral porabo energije, saj deluje na različnih ravneh dejavnosti. Uporaba lahkega procesorskega mirovanja, globokega procesorskega mirovanja in hibernacije omogoča več kot 70 % prihranka energije. Lahko procesorsko mirovanje zagotavlja hitro odzivnost z zmernim varčevanjem energije, medtem ko globoko procesorsko mirovanje in hibernacija maksimirata energetsko učinkovitost, vendar zahtevata daljši čas za prebujanje. Pristop k načrtovanju strojne in programske opreme poudarja pomen natančnega upravljanja sistemskih komponent in preklapljanja med različnimi načini varčevanja z energijo, da se doseže optimalno ravnovesje med varčevanjem in zmogljivostjo.

V zaključku članek obravnava tudi širši okoljski vpliv načinov procesorskega mirovanja, pri čemer poudarja njihov prispevek k zmanjšanju porabe energije naprav in ogljičnega odtisa. Z vključitvijo učinkovitih strategij za uporabo načinov procesorskega mirovanja lahko načrtovalci dosežejo energetsko učinkovite sisteme, ki izpolnjujejo tako pričakovanja uporabnikov kot okoljsko odgovornost ter prispevajo k trajnostnemu razvoju elektronskih naprav.

1 INTRODUCTION

In today's technology-driven world, the proliferation of electronic devices has become ubiquitous, with an ever-increasing number of gadgets and appliances permeating our daily lives. While these devices provide convenience, connectivity and entertainment, they contribute significantly to our energy consumption.

One often overlooked aspect of this energy usage is the power consumption of devices in standby mode, commonly referred to as the "vampire power" or "phantom power" phenomenon. When electronic devices are not in active use they often consume a small, but persistent amount of electricity, even when seemingly turned off or dormant. Although seemingly insignificant on an individual level, this standby power consumption can impact global energy usage and carbon emissions substantially when aggregated across millions of devices.

Research has shown that the energy consumed by devices in standby mode can account for a significant portion of a household's or workplace's total electricity usage. [1][2][3]

For example, a study in California found that the energy used to run appliances in low-power modes totalled about 13% of the state's total residential electricity consumption. [3]

The importance of efficient energy management in modern electronic devices cannot be overstated. With the advancement of technology, microprocessor-based devices have become widespread, being used in everything from simple household appliances to complex industrial systems. These devices, however, are often limited by the capacity of their power sources, making energy efficiency a critical aspect of their design and functionality. Efficient energy management ensures longer battery life and improves the device's reliability and performance.

A key component in achieving this energy efficiency is the use of sleep mode, or low-power mode, which allows the device to reduce its power consumption during periods of inactivity. [4][5]

Sleep mode is an essential strategy for improving energy efficiency in microprocessor-centric circuits, as it reduces a device's power consumption significantly when not in active use. Sleep mode conserves energy without fully turning off the device by effectively shutting down parts of the device while keeping others minimally active for basic operations. This feature is particularly important in portable and battery-operated devices, where power conservation is crucial. [6] [7]

The relevance of sleep mode extends beyond simple power conservation. In today's digital age, where the environmental impact of technology is a growing concern, reducing power consumption through methods like sleep mode aligns with broader sustainability goals. However, the benefits of sleep mode go beyond environmental considerations. It also enhances device usability by extending battery life, improving user satisfaction significantly, and reducing recharge frequency and urgency.

The ability to wake from sleep mode allows devices to offer immediate functionality when needed, matching convenience with energy efficiency. This balance is not just important; it's vital in maintaining a positive user experience, as modern consumers expect both high performance and responsible energy usage from their electronic devices. Thus, sleep mode is important in energy management and electronic products' overall design and consumer appeal. As we continue to push the boundaries of what electronic devices can do, integrating and optimising sleep mode will remain a cornerstone of innovative electronic circuit design.

1.1 Environmental Impact and Sustainability

Sleep mode reduces the energy consumption of electronic devices by powering down non-essential components when they are not in active use. This reduction in energy demand translates directly into lower electricity usage, which is particularly significant given the scale of global electronic device proliferation. For instance, the cumulative energy savings can be substantial if millions of devices enter sleep mode when inactive. This widespread reduction in energy consumption decreases the overall demand from power plants, which often burn fossil fuels, thereby reducing the amount of carbon dioxide and other greenhouse gases released into the atmosphere. [8]

Moreover, sleep mode extends the lifespan of devices by reducing the wear and tear on their components. This longer operational life means fewer devices are discarded, leading to a decrease in electronic waste. Electronic waste contributes to accumulating hazardous materials in landfills and involves energy-intensive recycling processes. By extending the life of electronic devices through reduced operational stress, sleep mode, indirectly, lessens the environmental degradation associated with waste disposal and recycling.

Another important aspect of sleep mode's contribution to sustainability is its role in complying with international energy efficiency Standards. Many countries have implemented regulations that require electronic devices to incorporate low-power modes to curb excessive energy use. Sleep mode enables manufacturers to meet these Standards, designed to reduce energy consumption at the individual device level, and contribute to national and global efforts to decrease overall energy demand.

The energy savings achieved through sleep mode can be significant when scaled across the numerous devices used in corporate and industrial settings. For example, Data Centres, which consume considerable energy to maintain data integrity and server responsiveness, can benefit immensely from servers and storage systems equipped with advanced sleep mode functionalities. These facilities can reduce operational energy costs and carbon footprint dramatically by allowing inactive servers to enter sleep mode.

1.2 Regulatory Compliance and Market Implications

One of the key regulations that govern energy consumption in 'off' and various 'standby' modes is the Ecodesign Regulation 1275/2008. [9] This regulation was designed as a horizontal legislation covering various relevant electronic and electrical products. It ensures that devices do not consume excessive power, particularly during inactivity, influencing market access and product design significantly across the electronics industry.

Compliance with Ecodesign Regulation 1275/2008 is essential for manufacturers seeking to distribute their products within the European Union and other regions that have adopted similar Standards. By incorporating sleep mode and optimising energy consumption in accordance with these Regulations, manufacturers can access a broader market and align their products with sustainable and energy-efficient consumer trends.

Globally, energy efficiency Standards, such as the Energy Star programme in the United States, the European Union's Ecodesign Directive, and similar regulations in countries like Japan and Australia, mandate specific requirements for electronic devices. [10], [11] These Standards typically specify maximum allowable power consumption levels for various states of device operation, including active, idle and sleep modes. The rationale behind these Regulations is to reduce the environmental impact of electronic devices by minimising their energy consumption, and, by extension, the associated carbon emissions from power generation.

Furthermore, including advanced sleep mode functionalities can be a competitive advantage in the electronics market. Consumers are prioritising energy efficiency and sustainable practices increasingly when making purchasing decisions. Products that adhere to Regulatory Standards and offer enhanced energy-saving features are likely to enjoy stronger market appeal and consumer trust, leading to potential business growth and brand differentiation. Overall, understanding and adhering to Regulatory Standards regarding energy consumption in 'off' and 'standby' modes ensures market access ,and positions electronic devices as environmentally friendly and sustainable, contributing to the global effort to decrease overall energy demand and mitigate environmental impact. Consequently, the ability to implement effective sleep mode functionalities has become a crucial factor in the design and development of new electronic devices. Manufacturers must now ensure that their products can meet the current technological demands and adapt to stringent energy-saving requirements. [12]

The impact of these Regulations extends beyond simple compliance. They drive innovation in product design, encouraging manufacturers to develop more advanced power management technologies. These include sophisticated sleep mode algorithms that adjust energy use dynamically based on the device's operation, user behaviour and even ambient conditions. The evolution of such technologies enhances product functionality, and positions companies as leaders in energy-efficient technology.

2 FUNDAMENTALS OF SLEEP MODE

The effectiveness of sleep mode lies in its ability to decrease the microprocessor's clock speed, or halt certain circuits entirely while maintaining minimal functionality in others. This selective suspension of activities helps maintain the device's state, enabling a fast return to full operation when required. In microprocessors, sleep mode is achieved by reducing the power supplied to various components, such as the CPU, memory and peripheral interfaces, thereby reducing the overall power consumption of the device significantly.

Sleep mode can be implemented at various levels, each offering a different balance between power savings and operational readiness.

2.1 Light Sleep Mode or Idle Mode

Light sleep mode, also known as Idle mode, is the least aggressive form of sleep mode.

In this state, the microprocessor's clock speed is reduced, but the processor and memory remain powered and ready to resume full operation quickly.

Light sleep mode is suitable for brief pauses in device activity, as it allows the system to respond rapidly to user input or other events, maintaining a high level of responsiveness.

The power savings in light sleep mode are moderate, as the device is still partially active, but it offers a good balance between energy efficiency and the immediacy of response.

2.2 Deep Sleep Mode

Deep sleep mode, on the other hand, is a more aggressive power-saving state.

In this mode, the microprocessor and memory are powered down, and the device enters a low-power state that reduces its energy consumption significantly.

However, the trade-off is a longer wake-up time, as the device must power up fully and restore its operational state before responding to user inputs or other events. Deep Sleep Mode itself can be divided in a little more detail into;

2.2.1 Standby Mode

A deeper sleep state, in which the CPU and most peripherals are turned off, except for a few essential components required for basic device monitoring. This mode provides substantial power savings while allowing relatively quick wake-up times.

2.2.2 Hibernate Mode

It is one of the deepest sleep states, where the content of the memory is saved to non-volatile storage, and the power to the CPU and most of the system components is cut off completely. Hibernate mode offers the most significant energy savings, and is ideal for extended periods of inactivity. However, the wake-up time is longer, as the system needs to reload the memory state from the non-volatile storage.

2.2.3 Power-Down Mode

In the most extreme sleep mode, the device turns off all functions except for a few critical monitoring capabilities, such as the real-time clock. This mode is used when no immediate use of the device is expected, and it maximises energy conservation at the cost of longer recovery times when the device is reactivated.

Deep sleep mode is suitable for longer periods of inactivity, where the device can afford a slightly longer wake-up time in exchange for substantial power savings.

2.3 Hybrid Sleep Mode

Some microcontrollers and microprocessors offer a hybrid sleep mode, which combines elements of both light and deep sleep modes.

In this approach, certain components, such as the CPU, are powered down, while other essential peripherals, such as real-time clocks or interrupt controllers, remain active.

This hybrid sleep mode balances power savings and responsiveness, allowing the device to wake up more quickly than deep sleep mode while conserving significant energy.

The specific implementation of hybrid sleep mode can vary across different microcontroller architectures and product lines, offering designers flexibility in optimising energy efficiency for their particular applications.

2.4 Strategy for using Sleep Mode

Electronic devices commonly incorporate multiple sleep modes, each engineered to strike a balance between power conservation and preparedness for reactivation. The specific functions and energy-saving advantages of these sleep modes may differ, but they all share the common objective of diminishing energy requirements during periods of inactivity.

The implementation of various sleep modes necessitates a meticulous analysis of the device's usage patterns and user expectations. The determination of which sleep mode to employ and when to activate it is contingent upon finding the optimal equilibrium between the need for expeditious responsiveness and the imperative of energy conservation. This analysis involves evaluating the device's typical usage scenarios, user preferences, and the trade-offs between power savings and responsiveness. By considering these factors carefully, device designers can select the most appropriate sleep mode configurations to meet the specific needs of the target user base.

3 DESIGN CONSIDERATIONS FOR SLEEP MODE INTEGRATION

One of the primary technical requirements for integrating sleep mode is the ability to deactivate and reactivate components selectively. [13] It requires detailed control over the power supply to individual components, which can be complex given the integrated nature of modern electronics. Designers must ensure that power management circuits can handle multiple power states, and can switch between these states seamlessly without disrupting the device's overall functionality.

Additionally, integrating sleep mode involves challenges related to timing and synchronisation. Components must enter and exit sleep mode coordinated to avoid data loss or corruption. It necessitates robust firmware that can manage the state transitions effectively. It is also essential to consider the wake-up latency, the time it takes for a device to return to full operational status from sleep mode. Optimising this latency is important for user satisfaction, particularly in devices that require immediate responsiveness, such as smartphones and medical devices.

From a design strategy perspective, one practical approach to optimising sleep mode functionality is implementing hierarchical sleep states. By designing multiple levels of sleep mode - from light sleep, where only the display and non-essential services are turned off, to deep sleep, where almost all processing is suspended - designers can tailor the power consumption to the exact needs of the device based on its operational context. This multi-tier strategy allows devices to conserve more power, while still being able to respond quickly if required.

Another strategy involves using intelligent sensors and context-aware algorithms that adjust the sleep mode settings dynamically based on the environment and usage patterns. For example, a device might enter a deeper sleep mode when it detects that it has been inactive for a prolonged period, or in a particularly low-power environment, such as at night when the user is likely asleep.

It is also essential to ensure that the integration of sleep mode does not compromise the device's security. As devices wake from sleep mode, they must re-establish secure connections and protect all data. It requires encryption mechanisms and secure authentication protocols to be maintained across sleep transitions, adding another layer of complexity to the design.

3.1 User Experience and Responsiveness

From a user experience perspective, the primary concern with sleep mode is the wake-up time - the delay between the user initiating an action and the device's response. If a device takes too long to wake up, users may perceive it as unresponsive or slow, affecting their overall satisfaction negatively and potentially deterring future use. Therefore, optimising this aspect involves minimising the wake-up time while ensuring the device remains sufficiently responsive, even when coming out of deeper sleep states.

For example, modern smartphones are adept at managing sleep mode to optimise energy efficiency and user experience [14][15]. When a user turns off the smartphone screen, the device enters a light sleep mode where non-essential processes are paused, but it can resume full functionality as soon as the screen is touched. Deeper sleep modes are used during prolonged periods of inactivity, such as overnight. Here, more extensive parts of the system are shut down. Still, critical functions like clock updates and incoming notifications are maintained, allowing for a balance between energy savings and readiness for use.

Another illustrative case is that of wearable devices, such as fitness trackers and smartwatches. These devices use advanced algorithms to determine when to enter different levels of sleep mode based on user activity patterns. For instance, during periods of intense physical activity, the device may avoid entering sleep mode entirely to ensure real-time tracking and feedback. Conversely, during periods of inactivity, such as sleeping or sitting at a desk, the device can enter deeper sleep modes safely without affecting user experience, as immediate responsiveness is less critical.

Smart home devices like thermostats and security cameras also employ sleep mode, to enhance energy efficiency without compromising their primary functions. Smart thermostats, for instance, reduce their sampling rate of environmental data during times when less frequent adjustments are necessary. However, they remain responsive to significant changes in temperature or user inputs. Security cameras might power down non-essential components when no motion is detected, but can activate quickly to record when motion sensors are triggered.

Designers achieve these balances by combining hardware optimisations, such as low-power processors and memory, and software strategies, like predictive algorithms, anticipating user needs. This integration ensures that devices conserve energy and provide a seamless and responsive experience aligned with user expectations.

To enhance user satisfaction and energy conservation further, it is crucial to consider how sleep mode impacts the overall user experience. While optimising wake-up time is essential, it is equally important to ensure that the transition in and out of sleep mode is seamless and non-disruptive. [16]

Modern electronic devices can achieve a harmonious blend of energy efficiency and user satisfaction by refining the integration of sleep mode continually and considering user experience as a top priority. This approach aligns with the growing demand for sustainable and user-friendly technology solutions in today's market.

4 AN EXAMPLE OF DESIGNING AN ELECTRONIC CIRCUIT WITH MULTIPLE SLEEP MODES

The following example demonstrates how to design an electronic circuit with multiple sleep modes, highlighting the role of the microcontroller and its components, along with strategies for transitioning between modes based on real-world usage patterns. The approach shown in Figure 1 conserves energy and enhances the device's efficiency and operational longevity.

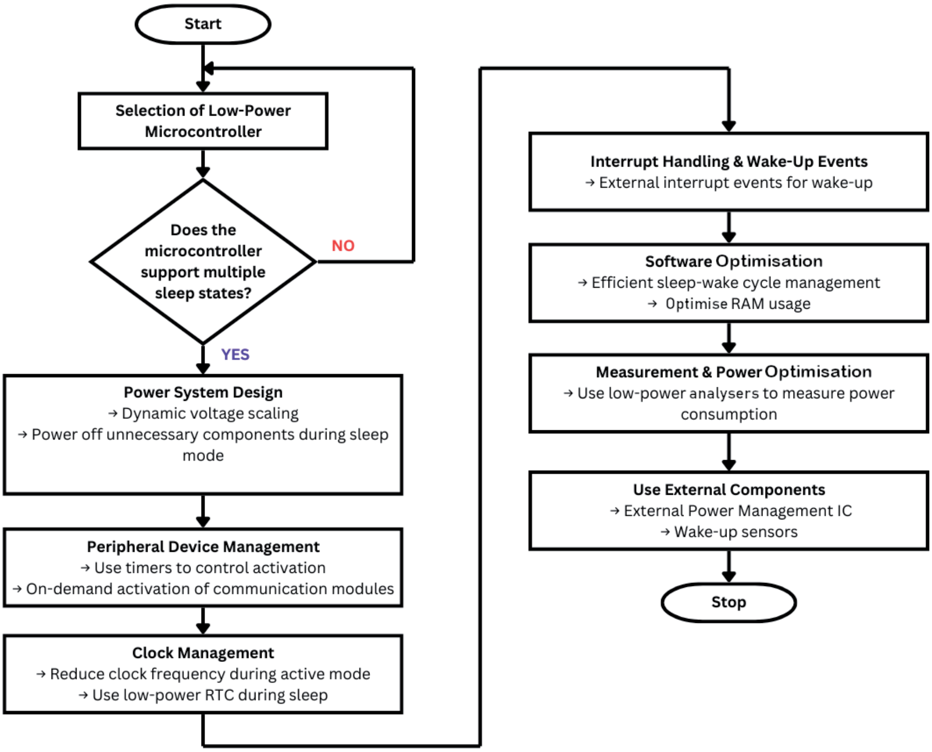

***Figure 1:** The process of designing an electronic circuit with a microprocessor and implementing different levels of Sleep Mode*

Consider the electronic circuit shown in Figure 2 with a microprocessor, abbreviated as P, that controls 5 sensor inputs (S1, S2, S3, S4, and S5), 3 actuator outputs (A1, A2, and A3), a WiFi telecommunications module (abbreviated as WiFi), an LTE telecommunications module (abbreviated as LTE), and a geolocation module (abbreviated as GPS). The electronic circuit with the microprocessor P is battery-powered.

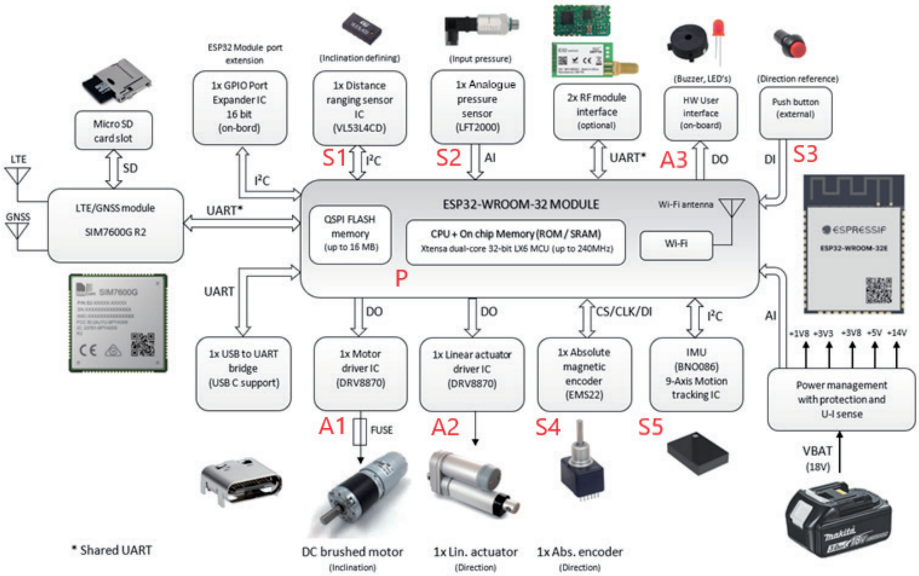

Figure 2: *Case study electronic circuit with microprocessor*

Developing an electronic circuit that incorporates sleep modes necessitates a strategic approach, balancing functionality and power efficiency carefully. Initially, conducting a comprehensive analysis of all system components, including the microprocessor, sensors, actuators, communication modules and the geolocation unit, is crucial. Each of these elements plays a distinct role in the overall operation, yet they exhibit varying power consumption and activity levels. Understanding these differences is essential for formulating an efficient energy management plan.

The next step involves defining various operational modes that the system can enter based on real-time requirements. The system operates at full capacity in active mode, with the microprocessor and all peripherals functioning optimally. However, a more efficient approach is needed for periods of inactivity, and sleep modes come into play. One such state is light sleep mode, or idle mode, where the microprocessor's clock speed is reduced, but remains partially active, allowing for quick resumption of operations. This mode is especially useful for brief pauses in activity, where the system needs to maintain responsiveness with moderate energy savings.

On the other hand, deep sleep mode is a more aggressive energy-saving strategy, where the microprocessor and memory are powered down significantly. This mode is ideal for longer periods of inactivity, as it reduces energy consumption drastically, though it requires a longer wake-up time. Within deep sleep mode, further subdivisions can be made, such as standby mode, where only essential components for basic monitoring remain active, allowing faster wake-up, and hibernate mode, where the system saves its state to non-volatile memory, cutting off power to most components for maximal energy savings. The deepest level is power-down mode, where only critical monitoring capabilities, such as a real-time clock, remain powered. This mode is used for long-term inactivity, offering the most energy savings at the cost of slower recovery times when reactivating the device.

Once these operational modes are established, the selection of an appropriate microcontroller becomes critical. Opting for a processor that supports multiple low-power states, including light and deep sleep modes, ensures the system's ability to adjust its energy consumption dynamically. Furthermore, software control can enhance this process by managing the transitions between power modes based on real-time system activity. For instance, when no inputs are detected for a specified duration, the system can transition smoothly from active to sleep mode. Additionally, the incorporation of interrupt-driven wake-up mechanisms allows the device to maintain responsiveness while conserving power.

Moreover, implementing Dynamic Voltage and Frequency Scaling can optimise energy use during less demanding tasks, by adjusting the processor's clock speed and voltage per the workload.

The potential for power savings from using these sleep modes is substantial. For instance, light sleep mode can reduce overall energy consumption by 20-40%, while deep sleep mode can yield energy savings of up to 80-90% during prolonged periods of inactivity. The power-down mode offers the most dramatic reduction, conserving nearly all the energy during non-use. By designing the circuit strategically and managing these power modes effectively, the system can achieve significant improvements in battery life and overall efficiency, meeting both operational demands and energy-saving goals.

4.1 The Starting Point

The device operates under the following conditions:

- 40% of the time the device is in complete idle mode.
- 3% of the time, all components (GPS, LTE, WiFi, S1, S2, S3, S4, S5, A1, A2, and A3) are active simultaneously.
- 5% of the time, only LTE and GPS are active together.
- 2% of the time, only GPS and WiFi are active together.
- 30% of the time, GPS, all 5 sensors (S1, S2, S3, S4, S5), and all 3 actuators (A1, A2, A3) are active together.
- 10% of the time, GPS, 3 sensors (S1, S2, S3), and 2 actuators (A1 and A2) are active together.
- 10% of the time, GPS, 2 sensors (S1 and S2), and 1 actuator (A1) are active together.

The microcontroller has four operational modes:

- Full Activity Mode: All components and communication modules are fully operational.
- Full Activity without Communication: The device functions normally, but disables communication modules like WiFi and LTE.
- Active Sleep Mode: The system is in a low-power mode, with selected components like sensors or actuators active while the rest of the system remains in standby.
- Complete Sleep Mode: The system enters a low-power state, with minimal functions operating, conserving the most energy.

4.2 Proposed Model for Sleep Mode Management

Based on the described device operation, the strategy should leverage various sleep modes, including Light Sleep Mode, Standby Sleep Mode, Hibernate Mode and Power-Down Mode:

- Full Activity Mode (3% of the time): Used when all components (GPS, LTE, WiFi, sensors, and actuators) are active simultaneously. This is the highest power consumption mode, and is only necessary when full functionality is required.
- Idle Mode or Light Sleep (7% of the time): Applied during periods when only the GPS and either LTE or WiFi are active. Idle Mode reduces energy consumption by allowing the microcontroller to keep essential functions running while the rest of the system operates at lower power. This can reduce power consumption by about 50-60%.
- Standby Mode (50% of the time): This mode is used when GPS, sensors and actuators are active, but the communication modules (LTE/WiFi) are not. Standby Mode allows the microcontroller to keep key peripherals operational while powering down less critical components, leading to energy savings of about 70% compared to full activity.
- Hibernate Mode (40% of the time): Hibernate Mode can be activated during periods of complete idle. This deep sleep mode reduces power consumption by up to 90%, as most of the system shuts down, leaving only minimal functionality to preserve the system state.

4.3 Energy Savings Analysis

When all sleep modes are used effectively, the overall energy savings can be substantial:

- Idle Mode for 7% of the time results in 50-60% power savings.
- Standby Mode for 50% of the time saves up to 70% in energy.
- Hibernate Mode for 40% of the time saves 90% of power, as most components are powered down.

Given this usage profile, the total estimated energy savings would be around 60-75%, depending on how often each mode is applied and the specific power characteristics of the components. This strategy extends battery life significantly, reducing the need for frequent recharging or battery replacement.

With fewer sleep modes, the device's ability to optimise power consumption becomes limited, leading to higher overall energy consumption. Let's consider a scenario where only Idle Mode and Hibernate Mode are available, and Standby Mode is not an option:

- Idle Mode would still save 50-60% during light activity periods (GPS with LTE or WiFi), covering 7% of the operational time.
- Hibernate Mode would still save 90% of energy during the 40% idle time.
- However, without Standby Mode, during the 50% of the time when GPS, sensors and actuators are active together, the device would have to operate in Full Activity Mode, consuming much more energy.

In this case, energy savings would drop to around 40-50% as the device consumes more power during moderate activity periods (when Standby Mode would otherwise have been used). This would lead to higher energy consumption overall, reducing battery life compared to a scenario with full sleep mode

Without any sleep modes, the device would operate at maximum power continuously, resulting in the worst-case scenario, providing no energy savings.

4.4 Comparison of Energy Consumption Scenarios

- Full Sleep Mode Management (best case):
  - Estimated energy savings: 60-75%.
  - Battery life extended significantly due to strategic use of Idle, Standby, and Hibernate modes.
- Limited Sleep Modes (only Idle and Hibernate available):
  - Estimated energy savings: 40-50%.
  - Battery life is shorter than with full sleep mode management, but still more efficient than without sleep modes.
- No Sleep Modes (worst case):
  - Energy savings: 0%.
  - The device consumes full power constantly, leading to the shortest battery life.

When all sleep modes are available, the system can achieve significant energy savings of up to 75%, and those extend the battery life significantly. However, with fewer sleep modes, energy savings are reduced to 40-50%, and, if no sleep modes are available, the device consumes maximum power, depleting the battery rapidly.

Introducing multiple sleep modes into electronic devices presents challenges related primarily to increased complexity. Both hardware and software design become more sophisticated, as managing the transitions between sleep modes requires precise control, which extends development time and increases the potential for errors. Longer wake-up times, especially from deeper sleep modes, can impact system responsiveness negatively, which is problematic for applications that demand quick activation.

Frequent transitions between modes can introduce additional energy consumption, reducing overall savings, and certain components may experience issues during re-initialisation. Deeper sleep modes also risk data loss or inconsistency if the system is not configured properly to preserve the state.

Developing and maintaining these systems require more resources, due to the need for extensive testing and optimisation, driving up costs. In some cases, the benefits of multiple sleep modes are limited, as not all modes result in significant energy savings relative to the complexity involved in managing them. Thus, a robust sleep mode strategy is essential for maximising the performance and longevity of battery-powered systems.

5 FUTURE TRENDS AND INNOVATIONS

As technology advances, the role of sleep mode in electronic circuit design is also evolving, with emerging trends and potential innovations poised to enhance its effectiveness further. The future of sleep mode technology holds promising developments, that aim to achieve even greater energy efficiencies and more seamless integration into everyday devices. [17]

One emerging trend is the development of more intelligent, context-aware sleep modes, that can adjust dynamically based on user behaviour, environmental conditions and device status. It involves using machine learning algorithms to predict periods of device inactivity and adjust power consumption more accurately. For instance, future devices could learn a user's daily patterns, and anticipate automatically when to enter more profound levels of sleep mode, thereby conserving more energy without user input. [18]

The integration of ultra-low-power microcontrollers and IoT devices has spurred innovations in sleep mode technology. These components are designed to operate on minimal power, and can maintain device functionality while consuming very little energy. Future enhancements may focus on developing microprocessors and other elements optimised explicitly for various sleep mode levels, allowing devices to perform essential tasks like updates and data synchronisation without waking fully from sleep mode.

Another promising area of innovation lies in developing energy-harvesting technologies that complement sleep mode functionalities. Devices could be designed to harness ambient energy sources - such as solar, thermal, or kinetic energy - while in sleep mode, to recharge batteries or power low-energy tasks. It would extend the intervals between charging and reduce dependency on traditional power sources, making devices even more energy-efficient and environmentally friendly.

Moreover, advancements in semiconductor technology could lead to the creation of chips that are more effective at entering and exiting sleep modes with virtually no latency. Such improvements could reduce the wake-up time for devices drastically, enhancing user experience by providing immediate responsiveness upon activation, which is critical for devices like smartphones and medical alert systems.

There is a growing trend towards standardising sleep mode protocols across different devices and platforms, which could lead to a more uniform and efficient implementation of sleep mode technologies. Standardisation would simplify manufacturers' design processes, and ensure that all devices contribute to energy savings at a larger scale.

The future of sleep mode in electronic devices looks to leverage advancements in machine learning, energy harvesting and semiconductor technologies, to reduce power consumption further and enhance electronic device functionality. As these innovations continue to unfold, sleep mode will become even more integral to the design and operation of energy-efficient devices, aligning with global efforts towards sustainability and conservation.

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ADDRESSING THE CHALLENGES TO THE INTRODUCTION OF BATTERY ENERGY STORAGE SYSTEMS IN RENEWABLE ENERGY UTILISATION SYSTEMS

OBRAVNAVANJE IZZIVOV PRI UVEDBI SISTEMOV ZA SHRANJEVANJE ENERGIJE IZ OBNOVLJIVIH VIROV V SISTEME ZA IZKORIŠČANJE ENERGIJE

Eleonora Jovanovikj[1], Nikola Manev[2ℜ], Dame Dimitrovski[1]

Keywords: grid stability, electricity generation intermittency, green transition, environmental resilience, widespread deployment

Abstract

The transition to sustainable energy sources is integral to addressing climate change and ensuring long-term environmental resilience. Battery Energy Storage Systems (BESS) play a pivotal role in this transition, by mitigating the intermittency of renewable energy sources such as wind and solar power. However, the widespread deployment of BESS faces significant challenges, including high implementation costs, environmental impacts, grid stability concerns and battery lifecycle management issues. This paper investigates these challenges systematically through a comprehensive literature review methodology, synthesising insights from peer-reviewed articles, conference proceedings and technical reports. Common themes and recurring challenges related to BESS implementation are identified and categorised, encompassing technical, economic, regulatory and environmental factors. Furthermore, the effective mitigation strategies and solutions proposed in the literature are analysed and evaluated for their

ℜ Corresponding author: Ass. Prof. Nikola Manev, PhD, University "Goce Delcev" - Stip, Military academy "General Mihailo Apostolski" - Skopje, Vasko Karangeleski, bb, Skopje, E-mail address: nikola.manev@ugd.edu.mk

1 University of "Ss. Cyril and Methodius" in Skopje, Faculty of Mechanical Engineering, Rugjer Boskovic 18, P.O. Box 574 1000 Skopje, R. N. Macedonia

2 University "Goce Delcev" Stip, Military academy "General Mihailo Apostolski" - Skopje, Vasko Karangeleski, bb, R. N. Macedonia

feasibility and applicability. The findings underscore the importance of innovative approaches, such as second-hand battery modules, sustainable production practices, the implementation of advanced operational strategies, and predictive maintenance algorithms, in enhancing the feasibility and efficacy of BESS integration. Additionally, policy incentives and collaborative efforts with utilities and grid operators are highlighted as crucial for promoting grid resilience and reliability. This research contributes to a nuanced understanding of the complexities inherent in advancing sustainable energy infrastructures, and provides valuable insights for policymakers, industry stakeholders, and researchers seeking to address the challenges of BESS deployment in renewable energy utilisation systems.

Povzetek

Prehod na trajnostne vire energije je sestavni del obravnave podnebnih sprememb in zagotavljanja dolgoročne okoljske odpornosti. Sistemi za shranjevanje energije iz baterij (BESS) igrajo ključno vlogo pri tem prehodu, saj zmanjšujejo prekinitve obnovljivih virov energije, kot sta vetrna in sončna energija. Vendar pa se široka uvedba BESS sooča s precejšnjimi izzivi, vključno z visokimi stroški izvajanja, vplivi na okolje, pomisleki glede stabilnosti omrežja in vprašanji upravljanja življenjskega cikla baterije. Ta članek sistematično raziskuje te izzive s pomočjo obsežne metodologije pregleda literature, ki združuje vpoglede iz strokovno pregledanih člankov, zbornikov konferenc in tehničnih poročil. Skupne teme in ponavljajoči se izzivi, povezani z izvajanjem BESS, so opredeljeni in kategorizirani, kar vključuje tehnične, ekonomske, regulativne in okoljske dejavnike. Poleg tega so učinkovite strategije za ublažitev in rešitve, predlagane v literaturi, analizirane in ovrednotene glede na njihovo izvedljivost in uporabnost. Ugotovitve poudarjajo pomen inovativnih pristopov, kot so rabljeni baterijski moduli, trajnostne proizvodne prakse, izvajanje naprednih operativnih strategij in algoritmov za napovedno vzdrževanje, pri izboljšanju izvedljivosti in učinkovitosti integracije BESS. Poleg tega so politične spodbude in sodelovanje z javnimi podjetji in upravljavci omrežij poudarjeni kot ključni za spodbujanje odpornosti in zanesljivosti omrežja. Ta raziskava prispeva k natančnemu razumevanju zapletenosti, ki je neločljivo povezana z napredovanjem trajnostnih energetskih infrastruktur, in zagotavlja dragocene vpoglede za oblikovalce politik, zainteresirane strani v industriji in raziskovalce, ki želijo obravnavati izzive uvajanja BESS v sistemih za uporabo obnovljive energije.

1 INTRODUCTION

The increasing global demand for electricity, coupled with the growing penetration of renewable energy sources like solar and wind, has led to a growing interest in energy storage solutions to address intermittency and variability in power generation. Battery energy storage systems (BESS) have emerged as one of the most promising technologies for storing excess energy during periods of high generation, and discharging it during times of high demand or low generation. BESS offer various advantages, including fast response times, scalability, modularity, and the ability to provide ancillary services such as frequency regulation and voltage support. Despite their benefits, however, the widespread adoption of BESS in energy systems faces a multitude of challenges, including high initial costs, the associated negative impact on the environment, adjustment to the intermittent nature of the renewable energy sources, and managing the lifespan and performance of the components of the system. Additionally, integrating BESS into the existing energy infrastructure requires addressing technical issues such as compatibility with grid systems, optimal siting, control and management strategies, and grid stability considerations.

Understanding and mitigating these challenges are crucial for maximising the effectiveness and economic viability of battery energy storage systems in modern energy systems and achieving broader energy transition goals.

With that said, the primary aim of this research paper is to examine prominent impediments and drawbacks associated with the deployment of BESS within renewable energy utilization infrastructures systematically. Additionally, this paper seeks to analyse prospective resolutions to these challenges comprehensively, encompassing diverse methodologies for their amelioration. Finally, it aims to explicate varying strategies and approaches aimed at mitigating the identified negative aspects, thereby fostering a nuanced understanding of BESS integration, and facilitating informed decision-making in energy system optimisation endeavours.

2 METHODS

Energy storage systems form somewhat of an emerging field in the Electricity sector, which, despite being under the spotlight for the better part of the last decade, were only given the research and development emphasis required sporadically. To address this issue, this article employs a methodology based on a comprehensive literature review, to identify and investigate the challenges associated with the implementation of BESS to propose effective mitigation strategies to these challenges, and facilitate a more knowledgeable and well-informed approach to their adoption and introduction.

This includes an extensive research conducted across multiple reputable academic databases and a detailed analysis of different peer-reviewed articles, conference proceedings, feasibility studies, technical reports and legislation published between 2012 and 2023. Keywords such as "battery energy storage systems," "energy storage challenges," and "mitigation strategies" were utilised in various combinations, to ensure extensive coverage of the literature. The inclusion criteria comprised relevance to the research topic, publication in peer-reviewed journals or reputable conference proceedings, and alignment with the scope and objectives of the present study.

Common themes, patterns, and recurring challenges related to BESS implementation in energy systems are identified by reviewing and synthesising the selected literature. This is followed by applying thematic analysis techniques to categorise the identified challenges into distinct domains, such as technical, economic, regulatory and environmental factors. To address the identified challenges, the proposed mitigation strategies and solutions presented in the literature are analysed and evaluated systematically based on their feasibility, effectiveness and applicability. Ultimately, a comparative analysis was conducted to identify the consensus among the different studies, and to highlight the variations in perspectives and approaches across the various analysed sources.

3 MATERIALS

In contemporary society, the transition towards sustainable energy sources, such as wind and solar power, has emerged as an imperative strategy to mitigate the adverse impacts of climate change and ensure the long-term viability of environmental ecosystems. Concurrently, the development of effective energy storage solutions has become paramount to facilitate peak shaving and accommodate dynamic consumption patterns, thereby harmonising the adoption of renewable energy with the prevailing societal lifestyles and consumption habits, while fortifying energy resilience for future contingencies. Furthermore, it is essential to understand the impact of energy storage systems on electricity production in wind and solar power generation systems. Fig. 1 illustrates the electricity production dynamics in systems reliant on wind and solar power, elucidating the effects of omitting energy storage systems on overall production stability and efficiency.

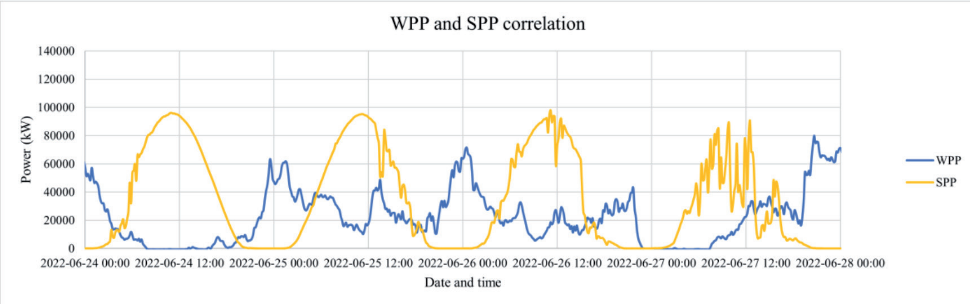

Figure 1: *Wind power plant [WPP] and solar power plant [SPP] production for a sample time period [1]*

Real-world applications demonstrate that regions with different renewable energy profiles face distinct challenges. For instance, areas with high solar irradiance, such as the state of California in the United States of America, tend to have surplus energy during the day, while regions known to utilise wind energy, like the United Kingdom, face different, almost unpredictable fluctuations when using this renewable source, due to variable wind patterns.

The US state of California is a leader in combining solar energy with BESS. In fact, battery storage is the fastest-growing resource in the California Independent System Operator (CAISO) balancing area (Fig. 2) [2], and batteries accounted for approximately 8.3% of load from hours-ending 10 to 13 in 2023, reducing the need to curtail or export surplus solar energy at very low prices.

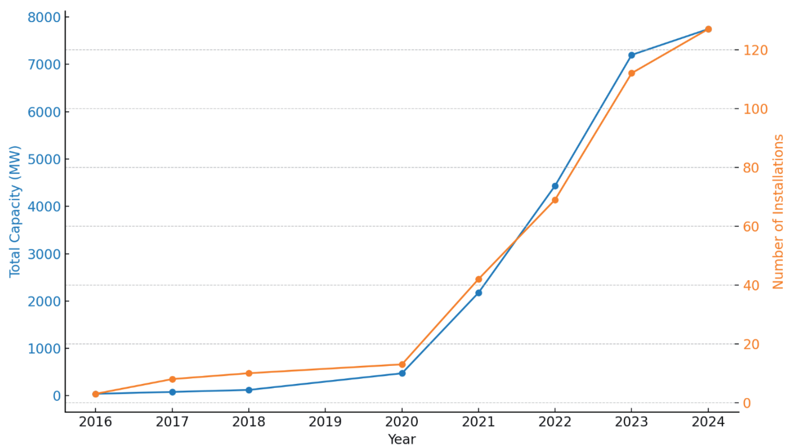

Figure 2: *Installed utility BESS for the 2016-2024 timeframe, in the CAISO balancing area*

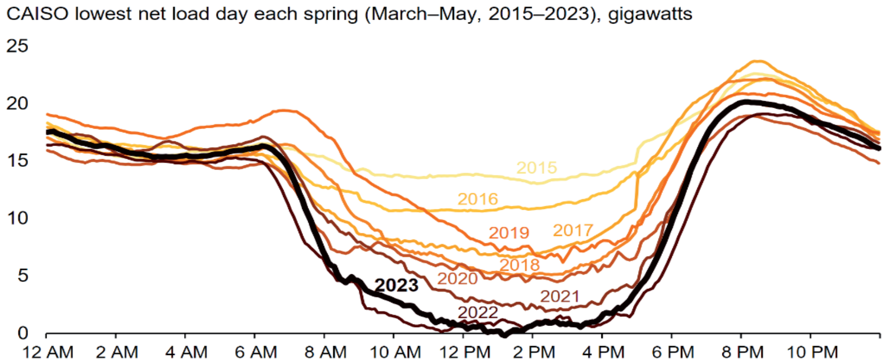

***Figure 3:** CAISO lowest net load day, each spring for the March-May timeframe of 2015-2023, in gigawatts, representing the so-called California's duck curve [3]*

The intermittency of the solar energy, however, reveals a pronounced daily generation pattern characterised by peak energy production during midday, followed by a steep decline in output as the sun sets. This results in significant overgeneration during sunny days, often leading to curtailment or negative pricing, as the excess solar energy surpasses demand, while simultaneously creating challenges for grid stability, due to the rapid ramp-up required from alternative energy sources, such as batteries, to meet the evening demand [3]. California is projected to require around 50 GW of battery energy storage to meet its 2045 greenhouse gas reduction goals [4], which would also help in managing the duck curve phenomenon.

On the other hand, wind energy patterns generally show that higher wind speeds can often be expected during nighttime and early morning hours, typically aligning with lower electricity demand. Conversely, wind speeds can be lower during the afternoon, when electricity demand is often higher. In such cases, it is crucial to understand the demand pattern that the remaining local or regional power stations will have to meet, in case energy storage is not available. Fig. 4 shows a correlation of electricity demand and wind generation in the British and Irish markets, as part of the United Kingdom (UK), showing substantial space for improvement. Total wind generation in the UK increased by 18% to a record 75.4 TWh between 2019 and 2020; within it, offshore wind generation rose by over 27% to 40.7 TWh, surpassing onshore wind at 34.7 TWh (Table 1).

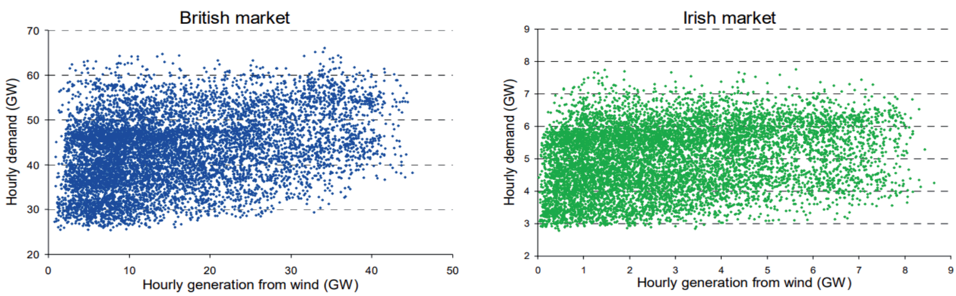

***Figure 4:** Correlation between hourly wind generation and hourly electricity demand, on the British market (left) and Irish market (right) [5]*

Table 1: *UK's electricity generation from renewable sources since the year of 2020 [6]*

Type of renewable energy	2000	2010	2018	2019	2020
Onshore wind (TWh)	0.9	7.2	30.4	31.8	34.7
Offshore wind (TWh)	-	3.1	26.5	32.0	40.7
Solar PV (TWh)	-	0.0	12.7	12.6	13.2
Hydro (TWh)	5.1	3.6	5.5	5.9	6.8
Landfill Gas (TWh)	2.2	5.2	3.9	3.6	3.5
Other Bioenergy (TWh)	1.7	7.0	31.1	33.7	35.8
Total (TWh)	9.9	26.2	110.0	119.5	134.6

Given that renewable electricity accounted for a record 43.1% of electricity generated in the UK during 2020, it is important to note that large grid energy storage can help in stabilising the integration of renewable energy sources, by removing the variability and intermittency associated with wind farm plants, too [7]. Although the UK Government has stated that grid-scale BESS enable the UK to use electricity more flexibly and decarbonise the energy system in a cost-effective way, in 2023 the electricity output from battery storage on the grid scale was equivalent to only 1,018 GWh (Table 2).

Table 2: *Electricity output from energy storage facilities [8]*

Storage type	2017	2018	2019	2020	2021	2022	2023
Pumped storage (GWh)	2,872	2,498	1,838	1,567	1,893	1,991	1,823
Battery storage – grid scale* (GWh)	0	36	82	113	94	195	1,018
Other energy storage (GWh)	0	0	0	0	0	0	0
Total (GWh)	2,873	2,534	1,920	1,680	1,987	2,185	2,841
*Data include grid-scale battery storage, excluding small "behind the meter" batteries, such as those in domestic or commercial properties.							

The burgeoning demand for energy storage systems (ESS) mirrors the escalating adoption of sustainable energy technologies [1]. However, the utilisation of an ESS necessitates a surplus of generated power to ensure its practical functionality. Forecasts indicate a significant upscaling in the deployment of BESS [9] in the forthcoming years, underscoring the growing significance of these technologies in the energy landscape.

Critical to the effective integration of energy storage systems into existing infrastructures are the challenges inherent in their implementation. An understanding of these challenges is pivotal for achieving optimal efficiency and cost-effectiveness, while upholding the stringent environmental and social imperatives associated with climate change mitigation and sustainability endeavours.

4 RESULTS

Based on the performed research, the results section delineates four common challenges encountered in the implementation of BESS:

4.1 Cost of implementation

The initial capital outlay required for implementing battery energy storage systems often represents a substantial financial commitment, depending mainly on the power capacity of the system. This upfront investment encompasses various elements, such as the cost of battery modules, inverters, control systems, installation and site preparation. As the main component of a BESS, the cost of battery modules can vary significantly in price, depending on factors such as technology type, energy capacity and performance characteristics. When compared with technologies for energy storage with a similar level of popularity in the industry, battery energy storage systems are shown to be unprofitable in multiple studied scenarios, but they are still considered a valuable addition to the energy system [1].

4.2 Environmental Impact

Addressing environmental concerns related to battery production, disposal and recycling is increasingly important for sustainable BESS deployment, which should also involve managing the impacts. Production of batteries entails resource extraction and manufacturing processes that contribute to habitat destruction, pollution and emissions [10]. Furthermore, improper disposal of batteries at the end of their life cycle can release hazardous substances into the environment, causing harm [11].

4.3 Tailoring BESS to the intermittent nature of the energy source and stability of the grid

The general incorporation of renewable energy sources into the power grid, such as integrating wind and solar power plants, and simultaneous maintenance of constant and reliable power delivery despite fluctuations in supply and demand, presents challenges, owing to their intermittent characteristics. Moreover, managing the produced surplus electrical energy by using BESS poses additional challenges in power electronics integration and storage-system technology for investors, given the considerable impact of their variable output [12,13]. Additionally, differences in the scale of implementation influence the challenges associated with integrating BESS significantly. In a micro-grid setting, the challenges are related to managing local generation and consumption dynamics, as well as ensuring grid stability on a smaller scale. In large-scale integration, challenges arise from coordinating the interactions between multiple energy sources and addressing grid-level stability concerns across a broader geographical area.

4.4 Lifecycle Management

Managing the lifespan and performance degradation of batteries over time, including monitoring and maintenance, is essential for maximising BESS efficiency, but can be arduous. Battery degradation impacts the profitability of grid-level energy storage systems significantly, with a reduction in revenue of 12-46%, depending on the degradation model and end-of-life criteria [14].

5 DISCUSSION OF PROPOSED MITIGATION STRATEGIES

Following a better and more comprehensive understanding of the complexities inherent in advancing sustainable energy infrastructures and the most common challenges associated with the introduction of BESS in renewable energy utilisation systems, the proposed mitigation strategies to these challenges are as follow:

5.1 Cost of implementation

When assessing the profitability and feasibility of investing in BESS, investors should duly account for the ancillary financial benefits inherent to such systems. Beyond direct revenue streams, the financial viability of BESS investments is augmented by the multifaceted economic advantages they afford. BESS deployment contributes to optimising energy asset utilisation, enhancing grid reliability, and facilitating the integration of renewable energy sources, thus fostering a more resilient and sustainable energy infrastructure. Acknowledging and quantifying these ancillary financial benefits are imperative for evaluating the investment potential and overall profitability of BESS implementation in renewable energy utilisation systems comprehensively. These benefits encompass, but are not limited to, arbitrage, revenue increase of central generation capacity, revenue increase of ancillary services, transmission and distribution deferral, peaking plant capital saving, increased revenue from renewable energy sources, and reduced reliability-related and power quality-related financial losses [15].

Certain solutions, such as using second-hand battery modules, can help mitigate upfront costs and improve the financial feasibility of BESS projects. Second-hand battery modules, sourced from electric vehicles, consumer electronics, or decommissioned stationary storage systems, offer a practical alternative to purchasing new batteries for BESS applications. Investors can find suitable used batteries through various channels, including battery recycling facilities, online marketplaces, or partnerships with manufacturers and suppliers. Repurposing electric vehicle batteries in secondary applications can reduce initial costs, with government support being the most important trigger for battery reuse [16]. By giving these batteries a second life in BESS applications, investors could also contribute to environmental conservation and the promotion of a circular economy [17].

5.2 Environmental Impact

Sustainable practices throughout the battery life cycle, including responsible mining, clean production methods, and circular economy initiatives, are crucial considerations for environmental sustainability in BESS deployment. Prioritising the use of environmentally sustainable materials, investing in research and development of recycling technologies to recover valuable materials from spent batteries, and promoting circular economy principles in battery manufacturing and disposal processes, are potential approaches to mitigating the negative impact on the environment.

While the recycling of Li-ion batteries helps prevent the shortage of critical minerals from a mass flow perspective, from an environmental perspective, the currently available technologies lead to significant consumption of energy and higher air emissions than the primary production [18]. The most obvious environmental benefit of BESS is lengthening the battery's lifespan by postponing recycling (or, even worse, landfill), and ensuring the most efficient use of individual components. At some point, the batteries should still be recycled, however, reusing is preferable, since it exhausts the currently available resources. When discussing the environmental benefits, the fact that repurposing batteries reduces the need for new batteries in BESS goes without saying, but, additionally, it saves on raw materials. Compared to the effective use of original materials and manufacturing, repurposed batteries add a separate life cycle to the manufactured battery, by extending the effective useful lifespan of a battery pack by a decade when repurposed for stationary use [19].

5.3 Tailoring BESS to the intermittent nature of the energy source and stability of the grid

Implementing advanced forecasting and predictive modelling techniques can help in anticipating renewable energy generation patterns, allowing BESS to store excess energy effectively during periods of high generation and discharge during times of low generation. Namely, the intermittency can be addressed through programming of advanced management systems and incorporating balancing algorithms, enabled by specific regulatory components within the storage system, such as a controller and a scheduler [1]. This entails crafting a meticulously designed operational strategy that is not only efficient, but also finely attuned to the unique characteristics and requirements of the individual system in question, which can be achieved through astute task definition, resulting in optimisation of the system's performance as a cohesive unit. In a BESS with such an operational strategy, a scheduler determines actions for the upcoming hour, based on factors such as market prices, energy storage status, and anticipated power production over the next two hours. Upon calculating the optimal power allocations for fuel cells and grid interactions at the beginning of each hour, these Directives are conveyed to a controller. The controller's role is to maintain the prescribed values provided by the scheduler to the best of its ability, while ensuring that the system`s components operate within their specified parameters. While the scheduler relies on informed projections, should the demands exceed feasibility, the controller intervenes to safeguard the system`s integrity. In essence, the scheduler and the controller operate on different time scales, to facilitate the optimal technical and economic performance of the BESS.

The technologies and operational principles vary widely for different cases of implementation, leading to a significant diversification in the range of energy storage products available. Specifically, whereas one method may excel in evening out annual fluctuations, another might be better suited for meeting brief periods of high power demand. Therefore, it becomes crucial to have a fundamental understanding of the available technology, but also take into consideration the specifications of the renewable energy utilisation system.

Prior to modelling the operational strategy and the system's forecast model, a comprehensive evaluation of the integration scale is of great importance, considering variables such as local demand profiles and grid infrastructure. Moreover, a meticulous assessment of technical prerequisites and grid specifications is imperative, to facilitate the seamless and efficacious implementation of the BESS within the energy framework. The implementation of a deep learning-based peak forecasting model can outperform state-of-the-art techniques by 11-32%, yielding annual savings of $496,320 for a 4 MWh battery in certain microgrids [20]. At the same time, battery technologies are shown to be exceptionally good for grid-level large-scale electrical energy storage, due to their modularisation, rapid response, flexible installation and short construction cycles [21].

As an additional measure, focusing policy incentives on innovation in energy storage and grid management can tackle the issue of electricity grid management of the intermittent renewable energy sources [22]. Furthermore, participation in demand response programmes to provide grid stability services, and collaboration with utilities and grid operators to enhance grid resilience and reliability, is of great essence.

5.4 Lifecycle Management

To address this obstacle, one approach is to create predictive maintenance algorithms and monitoring systems. These tools can monitor battery performance, devise strategies to optimise battery usage and prolong the lifespan, and establish plans for environmentally compliant recycling and disposal at the end of the battery's life. By implementing a battery degradation model and a rolling look-ahead operational optimisation strategy, battery cycle life can be extended effectively and profits can be enhanced within the real-time electricity market [23]. Taking into consideration that reducing frequent charge-discharge cycles and high discharge currents can extend battery life [24], an effectively designed operational model has the potential to enhance battery life cycle management and optimise utilisation by timing the accumulation and release of energy strategically.

6 CONCLUSION

The analysis reveals that, while BESS offer significant potential for mitigating intermittency in power generation and facilitating the integration of renewable energy sources, several key hurdles must be overcome to realise their full benefits. The high initial costs of implementing BESS pose a substantial barrier to widespread adoption. However, innovative solutions, such as utilising second-hand battery modules, can help mitigate these upfront expenses and improve the financial feasibility of BESS projects. Furthermore, addressing the environmental impacts of battery production, disposal and recycling, is paramount for BESS' sustainable deployment. Additionally, tailoring BESS to the intermittent nature of renewable energy sources and grid stability considerations is essential for effective integration. Implementing advanced forecasting and operational strategies, along with focusing on grid management innovations, can help address these challenges and optimise BESS performance. Finally, effective lifecycle management of batteries is crucial for maximising BESS efficiency and longevity. Developing predictive maintenance algorithms and monitoring systems can help optimise battery usage and extend the lifespan, thereby enhancing profitability within the real-time electricity market.

While this study provides a comprehensive review of existing literature and research papers, it is important to acknowledge certain limitations. Firstly, reliance on secondary sources may introduce biases or methodological limitations. Furthermore, the findings and conclusions drawn from the review are dependent on the quality and reliability of the sources reviewed, which may vary across different studies. The scope of this review may not encompass all relevant research, and the inclusion of diverse examples from different markets introduces variability. Additionally, examining how other investors are addressing the challenges identified in this research, as well as identifying any new or more pressing challenges that may have emerged since the completion of this study, would contribute to a more comprehensive understanding of the topic.

Finally, this review does not include the policies and regulations segment required to support or incentivise the introduction of BESS on a larger scale. Being a somewhat new technology, many countries lack an overall proactive approach in the legislative segment, passing regulations only reactively, or once a challenge is exposed for the Energy sector. Some of the topics that the current legislation offers little to no answers to are the reliable physical integration of the new electricity generation infrastructure, and the overall system functioning, continuous improvement of the grid, but also plans for new investments and revitalisations of the distribution network and the implementation of advanced concepts like smart grids, vehicle-to-grid technologies and energy storage systems.

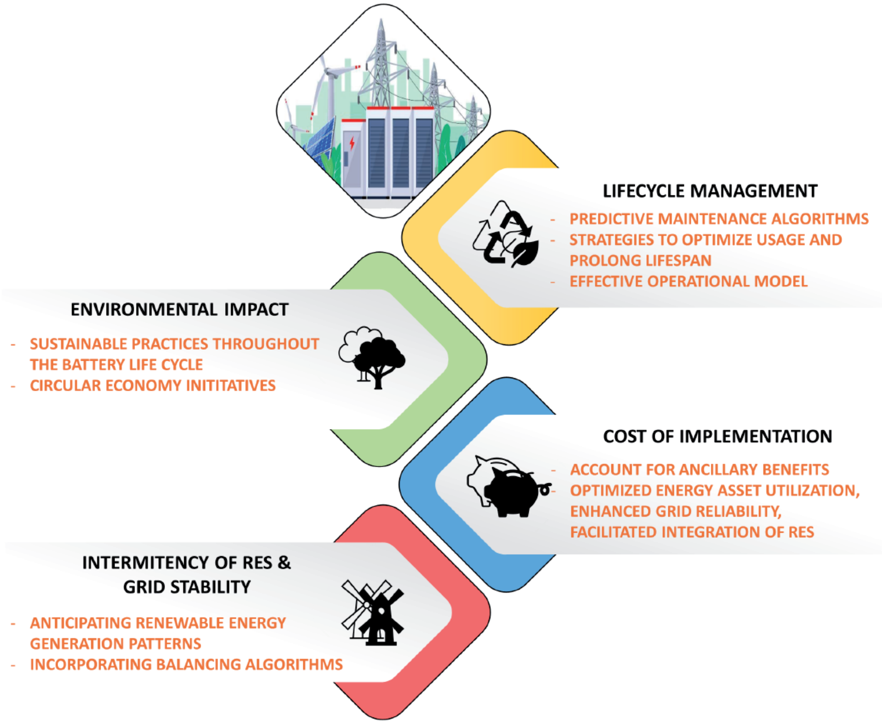

Figure 5: *Challenges and mitigation strategies to address the introduction of BESS*

As a point for future work, future endeavours that would cover any of the abovementioned remarks, would enhance the depth and breadth of knowledge in this field, thereby informing more effective strategies and solutions on the matter of the introduction of BESS.

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HEAVY METAL CONTENT IN SOILS OF SELECTED HOP PLANTATIONS IN RELATION TO THEIR NATURAL BACKGROUND

VSEBNOST TEŽKIH KOVIN V TLEH IZBRANIH HMELJIŠČ SPODNJE SAVINJSKE DOLINE

Katja Črnec[1], Lucija Božijak[1], Borut Vrščaj[ℜ,1,2]

Keywords: soil contamination, agriculture, food safety, beer, soil quality

Abstract

Heavy metals (HM) are present in soil naturally *[1]*, due to weathering of the element-rich parent rock and anthropogenic sources (industry, agriculture, traffic, energy production) *[2–4]*. The agricultural source of the increased HM concentrations in soil are HM-containing fertilisers and pesticides. Agricultural soils are often considered polluted, and are, therefore, subject to soil contamination monitoring for food safety reasons. Permanent crops are particularly at risk, due to the intensive and traditional (over)use of pesticides and fertilisers. Hop plantations are a special type of economically important permanent crop in the Lower Savinja region. The product, the dried hop cones, is mainly exported. The cultivation of hops requires intensive soil tillage, fertilisation, and, above all, constant protection of the hop plant by usage of pesticides. According to Slovenian legislation *[5]*, the HM concentration is considered elevated if the HM concentration in the soil is above the limit immission value (LIV), polluted if it is above the warning immission value (WIV), and critically polluted if it is above the critical immission value (CIV). The HM content was analysed in the soils of 10 hop plantations in the Lower Savinja region. The soil samples were

ℜ Corresponding author: Prof. Dr. Borut Vrščaj, Faculty of Environment Protection (FEP), Trg mladosti 7, 3320 Velenje, Slovenia, E-mail address: borut.vrscaj@fvo.si

[1] Faculty of Environment Protection (FEP), Trg mladosti 7, 3320 Velenje, Slovenia

[2] Agricultural Institute of Slovenia, Department of Agroecology and Natural Resources, Center for Soil and Environment

dried, ground and sieved in the FVO laboratory, and analysed by Bureau Veritas Commodities (Canada) using Aqua Regia extraction to determine the 'pseudo-total content' for 37 elements (Ag, Al, **As**, Au, B, Ba, Bi, Ca, **Cd**, **Co**, **Cr**, **Cu**, Fe, Ga, **Hg**, K, La, Mg, **Mn**, Mo, Na, **Ni**, P, **Pb**, S, Sb, Sc, Se, Sr, Te, Th, Ti, TI, U, V, W, and **Zn**), 10 of which (in the frames) are considered common HM soil contaminants. The HM concentrations in the soils of the hop plantations were within the natural background values *[1]* (below the LIV), with the exception of Cd, Cu and Zn, which were above the LIV in some cases. The Cd concentration was elevated in 90 % (it exceeded the LIV). The hop fields were not contaminated with Cd – as the concentration did not exceed the WIV. The Cu concentration was within the natural background values in 20 % of the hop plantations (well below the LIV), 30 % were elevated (exceeded the LIV), while 50 % were polluted with Cu (the Cu exceeded the WIV). The Zn concentration was below the LIV value in 80 % of the hop plantations, 10 % exceeded the LIV value, while 10 % of the hop plantations were considered to be polluted with Zn (the Zn exceeded the WIV value) *[6]*. As expected, we found that the soils of the hop plantations contained significantly increased, and, in some places, exceeded quantities of Cu and Zn, and in some cases also Cd. Elevated concentrations of HM may also be reflected in other parts of the environment, while the effects on food quality were not detected (i.e., elevated concentrations in beer).

Povzetek

Težke kovine (TK) so naravno prisotne v tleh *[1]* zaradi preperevanja matičnih kamnin, ki so bogate z elementi, ter zaradi antropogenih virov (industrija, kmetijstvo, promet, energijska proizvodnja) *[2-4]*. Kmetijski vir povišanih koncentracij TK v tleh so gnojila in pesticidi, ki vsebujejo TK. Kmetijska tla pogosto veljajo za onesnažena, zato so del monitoringa onesnaženosti tal zaradi zagotavljanja varne hrane. Trajni nasadi so še posebej ogroženi zaradi intenzivne in tradicionalne (prekomerne) uporabe pesticidov in gnojil. Hmeljarski nasadi so posebni ekonomsko pomembni trajni nasadi v Spodnji Savinjski dolini. Pridelek, posušeni hmeljni storžki, se večinoma izvaža. Pridelava hmelja zahteva intenzivno obdelavo tal, gnojenje in predvsem stalno zaščito rastlin. V skladu s slovensko zakonodajo [5] koncentracija TK velja za povišano, kadar koncentracija TK v tleh presega mejno imisijsko vrednost (MIV), za onesnaženo, kadar presega opozorilno imisijsko vrednost (OIV), in za kritično onesnaženo, kadar presega kritično imisijsko vrednost (KIV). Analizirana je bila vsebnost TK v tleh 10 hmeljišč v Spodnji Savinjski dolini. Talni vzorci so bili posušeni, zmleti in presejani v laboratoriju FVO ter analizirani s strani Bureau Veritas Commodities (Kanada) z uporabo ekstrakcijske metode Agua Regia za določanje navidezne skupne vsebnosti za 37 elementov (Ag, Al, **As**, Au, B, Ba, Bi, Ca, **Cd**, **Co**, **Cr**, **Cu**, Fe, Ga, **Hg**, K, La, Mg, **Mn**, Mo, Na, **Ni**, P, **Pb**, S, Sb, Sc, Se, Sr, Te, Th, Ti, TI, U, V, W in **Zn**), od katerih jih 10 (v okvirju) velja za TK, ki onesnažujejo tla. Koncentracije TK v tleh hmeljišč so znotraj vrednosti naravnega ozadnja [1] (pod MIV), z izjemo Cd, Cu in Zn, ki v nekaterih primerih presegajo MIV. Koncentracija Cd je povišana v 90 % (presega MIV). Hmeljišča pa niso onesnažena s Cd – koncentracija ne presega OIV. Koncentracija Cu je znotraj vrednosti naravnega ozadja pri 20 % hmeljišč (močno pod MIV), pri 30 % hmeljišč pa je povišana (presega MIV), medtem ko je 50 % hmeljišč onesnaženih s Cu (koncentracija Cu presega OIV). Koncentracija Zn je pod MIV pri 80 % hmeljišč, pri 10 % presega MIV, medtem ko 10 % hmeljišč velja za onesnažene z Zn (koncentracija Zn presega OIV) *[6]*. Po pričakovanjih smo ugotovili, da tla hmeljišč vsebujejo znatno povišane in v nekaterih primerih celo presežene koncentracije Cu in Zn, ponekod pa tudi Cd. Povišane koncentracije TK se lahko odražajo tudi v drugih komponentah okolja, medtem ko vplivi na kakovost hrane (tj. povišanih koncentracij v pivu) niso zaznani.

1 INTRODUCTION

Heavy metals (HM) are present in soils naturally through weathering of the parent rock, but their input can also be anthropogenic through industry, agriculture and transport. Agricultural sources of HM in soil are, among others, pesticides and fertilisers containing HM. HM such as Fe, B, Mn, Zn, Cu, Mo and Ni are important plant and animal micronutrients at low concentrations. However, when the concentrations of these metals increase in the soil they become pollutants, as they can have toxic effects on plants, for example, by inhibiting their growth. Metals that are not macro- or micronutrients are called absolute pollutants *[7]*.

The important Lower Savinja Valley crop is the hop (*Humulus lupulus*, L.), which has been cultivated in the area for a century and a half *[8]* and is used mainly in the brewing industry. Hop production is one of the most intensive forms of agriculture, as intensive plant protection measures are needed to control diseases and pests *[9].*

1.1 Hop growing in Slovenia

In Slovenia, the use of hops for brewing beer was first mentioned around 1160 in the area around Škofja Loka. However, hop production began to develop more intensively in the Savinja valley area after 1870 *[11]*. Hop was cultivated on 1, 625 ha in Slovenia in 2022. Slovenia exports up to 99 % of its hop harvest, which is used mainly for beer production, to foreign markets *[12].* In Slovenia, spraying against pests and diseases is carried out according to the forecast of the requirement for spraying issued by the Institute of Hops and Brewing of Slovenia, based on the tracking of the occurrence of diseases and pests *[10].* In the past, copper preparations were used commonly for the control of fungal diseases in hops, such as hop peronospora (*Pseudoperonospora humuli*), but now only a minimum use of active copper is allowed (3 kg/ha/year). The copper content of hops soils is elevated, due to the longterm use of copper-based fungicides in hops *[9].*

1.2 Basic agricultural soil quality parameters

Soil acidity, expressed as a pH value, influences the solubility of HM in soil more than any other factor, and thus affects their availability to plants *[2]*. The basic cations, especially Mg^{2+} and Ca^{2+}, found in the parent material, have an important influence on acidity of the soil. In the upper soil horizons, acidity is also influenced by the SOM content, which can have a slightly lower pH value. As the soil ages, the upper layers become acidified slowly, due to precipitation that leaches the base cations through the soil profile *[14]*. Other soil properties that depend on soil acidity are buffering capacity, texture, humus content, structure and moisture *[15].*

Soil organic matter (SOM) is made up of organic plant debris such and microbial biomass. In the process of mineralisation, nutrients and energy are released from the SOM, becoming available to plants *[13]*. The SOM content affects various soil properties, such as the water and air properties of the soil, reduction of soil compaction, erosion and soil rooting. It can also improve soil consistency, increase water retention and the absorption rate and drainage capacity of the soil. It affects soil acidity, increasing the soil's ability to bind and exchange nutrients *[13, 14]*.

1.3 Heavy metals in natural and agricultural soils

HM are a group of metals with a high relative density. Pb, Cd, Zn, Cu, Cr, Ni, As, Co and Mo belong to this group of metals and are classified as HMs *[14]*. The metals B, Mn, Zn, Cu, Mo and Ni are micronutrients in small, normal amounts. The concentration range of when a metal is a soil nutrient and when it is a soil contaminant is sometimes very narrow *[16]*.

1.3.1 Influence of anthropogenic factors on soil heavy metal content

Anthropogenic soil contamination is one of the biggest impacts of humans on the environment. The enrichment of soils with chemical elements, especially in industrial areas, is attributed to anthropogenic influences. Other anthropogenic influences on the increase of HM in soils are urban and industrial air emissions, hazardous and special wastes (municipal sludge, industrial effluents, radioactive wastes, etc.), contaminated irrigation or flood waters, mineral and organic fertilisers in agriculture, and FFS and silt from riverbeds and lakes *[1]*. When soils lose their self-cleaning capacity, their physical, chemical and biotic properties deteriorate, and soil fertility is reduced. Such soils are referred to as contaminated soils *[14]*.

1.3.2 Agricultural soil contamination

Agricultural soil contamination is divided into direct and indirect inputs of substances into agricultural soils resulting from agricultural activities. Excessive amounts and bad practice usage of fertilisers and FFS used for prevention and control of hops diseases and pests are the main anthropogenic pollutants on agricultural land *[14]*. The most common metals that pollute soil and, at elevated levels, inhibit plant growth and development, are Cd, Cu, Pb and Hg. Agricultural activity can be a source of pollution, due to the overuse and misapplication of poor-quality fertilisers if they contain HM *[7].* Depending on their composition, fertilisers provide a variety of necessary nutrients that improve plant growth and resistance, as well as increase yields. Organic fertilisers also increase the organic matter content of the soil and improve soil fertility *[16].* The most commonly used fertilisers are based on potassium and phosphorus. In Table 1 below, the classification of the soils is presented, based on soil content of K_2O and P_2O_5.

***Table 1**: Soil classification and limit values for phosphorus and potassium according to the AL method*

Nutrient content class	Phosphorous content (P_2O_5) (mg / 100 g)	Potassium content (K_2O) (mg / 100 g)
Class A – Poorly supplied	< 6	< 10
Class B – Medium supplied	6 – 12	10 – 19
Class C – Optimally supplied	13 – 25	20 – 30
Class D – Excessively supplied	26 – 40	31 – 40
Class E – Extremely oversupplied	> 40	> 40

1.4 Soil types in the Lower Savinja Valley

Lower Savinjska is a fertile valley, dominated mainly by young soils that have developed on alluvial deposits, predominantly limestone gravel. Part of the area is still under the influence of the watercourses of the River Savinja, which deposit new sedimentary material, mainly gravels and sands. These sediments have resulted in the development of eutric Cambisols or rendzic Leptosols *[1].* Figure 1 below shows the geological types in the reaserch area graphically.

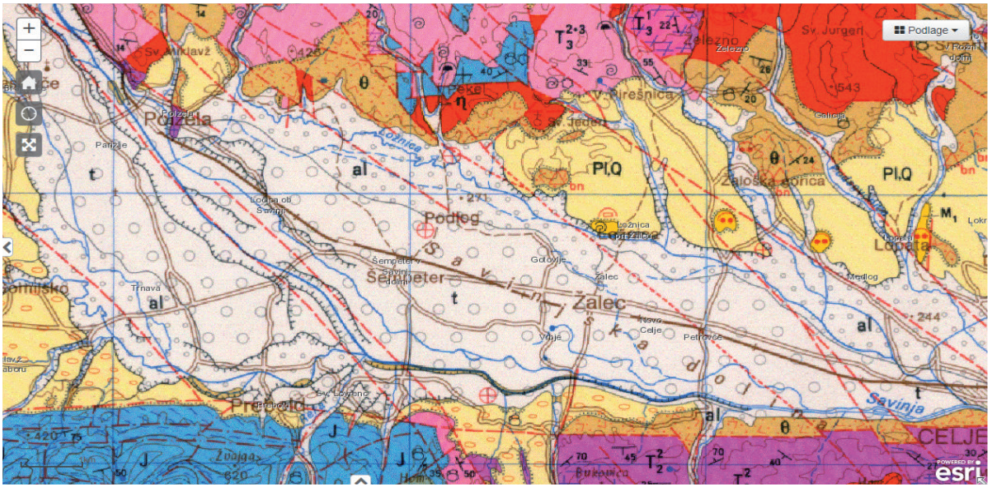

***Figure 1**: Basic geological map of the Lower Savinja Valley*

1.5 Slovenian soil contamination Legislation

Soils in Slovenia are protected by legislation and regulations:

- Regulation on the limit, warning and critical immission levels for dangerous substances in soil (Official Journal RS, nrs. 68/96, 41/04 – ZVO-1 and 44/22 – ZVO-2);
- Regulation on soil quality monitoring (Official Journal RS, nrs. 68/19 and 44/22 – ZVO-2);
- Regulation on operational soil monitoring (Official Journal RS, nrs. 157/22 and 7/23 – correct.);
- Agriculture Act (Official Journal RS, nrs. 45/08, 57/12, 90/12 – ZdZPVHVVR, 26/14, 32/15, 27/17, 22/18, 86/21 – odl. US, 123/21, 44/22, 130/22 – ZPOmK-2, 18/23 and 78/23);
- Environmental Protection Act (Official Journal RS, nrs. 44/22, 18/23 – ZDU-1O and 78/23 – ZUNPEOVE)

Soil contamination is determined according to the Regulation on the limit, alert and critical immission levels of substances in soil *[17]*:

"The limit immission value (LIV) is the level of a particular hazardous substance in soil at which the living conditions for plants and animals are ensured, and the soil fertility and groundwater quality are not impaired."

"The warning immission value (WIV) is a value at which certain land uses are likely to cause adverse effects or impacts on the environment and human health."

"The critical immission value (CIV) is the level at which contaminated soil is unsuitable for the production of plants for human and animal consumption, and for the retention and filtration of water because of adverse effects and impacts on humans and the environment."

2 MATERIALS AND METHODS

2.1 Description of the research area

The research area extends across the Lower Savinja Valley, from Drešinje village to Poljčane near Braslovče. In this area we selected ten hop plantations, from which soil samples were taken using the "zig-zag" method. The locations of the sampled hop plantations are shown in Figure 2, marked with numbers and circles. The plantations are separated spatially and are located on different soil types, either on brown eutric soils or on brown drift soils.

Figure 2: *Marked locations of the hop plantation [Hmeljišče] soil sample points*

2.2 Sampling, tools and field workflow

Field sampling took place in February and March 2023. The individual soil sample consisted of 20 collected sample units. The sampling locations were distributed evenly across the hopyard in a »zig-zag« pattern, avoiding the extreme edges of the field. A larger shovel was used to excavate a soil profile from 0 to 20 cm deep, and a smaller plastic shovel was used to remove a centimetre-deep strip that could be contaminated with HM from the excavation. The partial samples were pooled into one homogenised representative sample, which was stored in a PVC food bag free of HM.

2.3 Sample preparation for analysis

Sample preparation was carried out in the laboratory of FEP, Velenje. The samples were placed in a glass beaker and shaken carefully to settle, and thus remove any major air spaces. We marked the beakers accordingly with the sample codes. The dryer was set to 105 °C to obtain dry matter of the soil. After drying for 48 hours, the samples were stirred, small pebbles and larger roots were removed, and then sieved. The samples were stored in PVC »zip-lock« bags, labelled with the sample serial numbers. The package also needed a Canadian Import Declaration.

2.4 Laboratory analysis of the samples

The soil samples were analysed by inductively coupled plasma mass spectrometry (ICP-MS) after digestion with a modified *Aqua regia* process (15 g of the sample dissolved in a mixture of acids HCl : HNO3 : H2O = 1 : 1 : 1), resulting in a complete degradation of the soil and the breakdown of even less resistant minerals *[18]*. The laboratory analysis was carried out by a Bureau Veritas accredited laboratory in Vancouver according to ISO 11466:1995 (E) *[18]*. The metals analysed by this method were: Mo, Cu, Pb, Zn, Ag, Ni, Co, Mn, Fe, As, U, Au, Th, Sr, Cd, Sb, Bi, V, Ca, P, La, Cr, Mg, Ba, Ti, B, Al, Na, K, W, Sc, Tl, S, Hg, Se, Te and Ga.

Four basic soil parameters were analysed in the Agrochemical Laboratory of the Central Laboratory of the Slovenian Agricultural Institute using accredited methods:

- Soil acidity in $CaCl_2$ (ISO 10390:2021);
- Soil organic carbon content (SIST ISO 14235:1999 MOD);
- Content of plant-available P_2O_5 and K_2O (in-house method of the laboratory) *[20]*

3 RESULTS

3.1 Total HM content in soil samples from 10 hop plantations and comparison with the Limit Immission Values of the Slovenian regulation

For the 10 HM defined by the Regulation on limit, warning and critical immision levels for dangerous substances in soil (hereafter referred as the Regulation) (Cd, Cu, Ni, Pb, Zn, Cr, Hg, Co, Mo and As), we have presented the maximum and minimum levels and their median and mean values

3.1.1 Cadmium (Cd)

The Cd concentration in certain hop plantations exceeded the LIV according to the Regulation. The average Cd concentration in all ten soil samples was 1.2 mg/kg dry soil (in the continuation 'd.s.') and the median of the samples was 1.3 mg/kg d.s.. The lowest content was 0.7 mg/kg soil s.s., and the highest measured content was 1.5 mg/kg soil d.s.. The soils of the hop plantations were not contaminated with Cd, as no plantation exceeded the WIV.

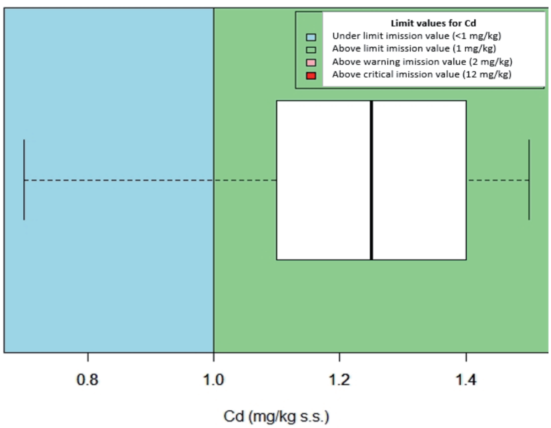

Figure 3: *Cd concentration in the selected hop plantations and immission values*

3.1.2 Copper (Cu)

The mean Cu value was 94.90 mg/kg soil d.s. and the median value was 102.70 mg/kg soil d.s. The highest measured Cu content was 131.5 mg/kg d.s., while the lowest Cu content was 52.9 mg/kg d.s.. In 3 out of the 10 hops, the LIV was exceeded, while, in the remaining 5 out of the 10 hops, the Cu content was above WIV, and, therefore, were contaminated.

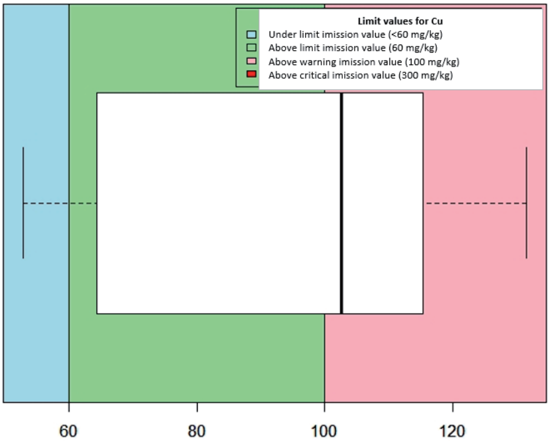

Figure 4: *Cu concentration in the selected hop plantations and immission values*

3.1.3 Zinc (Zn)

The median Zn content of the samples was 167.5 mg/kg d.s. and 147 mg/kg d.s.. The highest measured content was 303 mg/kg d.s. soil, while the lowest level was 94 mg/kg d.s.. The Zn concentration in 8 out of the 20 hops was under the LIV and were free from Zn contamination. In the one remaining hop sample, the Zn content was above LIV, meanwhile, in one hop sample the Zn content was above the WIV, resulting in Zn contamination.

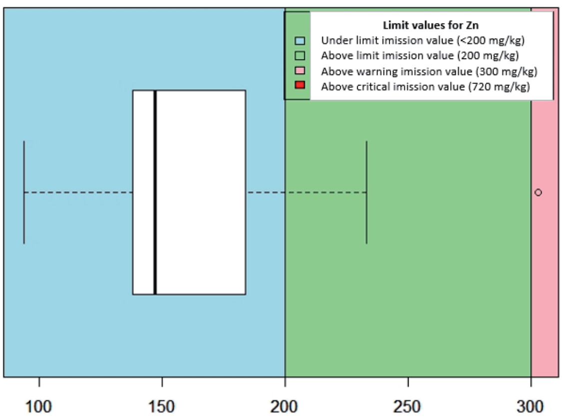

Figure 5: *Zn concentration in the selected hop plantations and immission values*

3.1.4 Other heavy metals included in the AQ251 analysis

The mean Nickel (Ni) value in the hops was 25.7 mg/kg d.s.. The lowest concentration was 15.7 mg/kg d.s. and the highest value was detected at 37 mg/kg d.s.. The LIV for Ni was not exceeded, thus confirming that the hop plantation soils were not contaminated with Ni.

The average Lead (Pb) content in the samples was 45.7 mg/kg d.s.. The highest level of lead was 82.6 mg/kg d.s. and the lowest level was 32.1 mg/kg d.s.. The Pb concentration in the samples did not exceed the LIV, therefore, the soils of the hop fields were not contaminated with Pb.

The mean value of Chromium (Cr) was 24.8 mg/kg d.s.. The highest level of Cr was 37 mg/kg d.s. and the lowest detected value was 16.0 mg/kg d.s.. The soils in the hop plantations analysed were uncontaminated with Cr, because the values did not exceed the LIV.

The mean Mercury (Hg) value in all 10 soil samples was 0.1 mg/kg d.s.. The Hg content in the samples was extremely low, and did not exceed the level of 0.2 mg/kg d.s.. The lowest measured level was 0.07 mg/kg d.s.. The Hg content did not exceed the LIV in the hop samples and therefore the soil was not Hg uncontaminated.

The mean Cobalt (Co) concentration in the samples was 11.60 mg/kg d.s.. The Co content ranged from 8.60 mg/kg d.s. to 14.70 mg/kg d.s.. The Co levels in the soil of all the sampled hop plantation areas were below the LIV, therefore, the soil of the hops was not contaminated with Co.

The mean concentration of Molybdenum (Mo) was 0.7 mg/kg d.s.. The Mo content of all the hop samples was extremely low and did not exceed 0.8 mg/kg d.s., while the lowest Mo content was 0.5 mg/kg d.s.. The Mo levels did not exceed the LIV, and the soils of the hops were free from Mo contamination.

The Arsenic (As) concentrations in all 10 samples did not exceed the LIV. The mean level in the samples was 9.4 mg/kg d.s. The highest measured As content was 12.30 mg/kg d.s., while the lowest As content was 7.5 mg/kg d.s.. The soil of the hops was not contaminated with As.

3.2 Standard soil analysis

Soil acidity is defined as the pH value, and it is measured in a $CaCl_2$ solution. The pH value varied depending on the hop plantations. The average pH value in the hop fields was pH 5.9. Hop 1 (pH 5.5), Hop 7 (pH 4.8) and Hop 8 (pH 4.5) had the lowest pH value among the 10 hop plantations. The highest pH value was pH 7.3.

The available phosphorus content varied between the hop plantations, with large differences between the lowest and highest levels. The average plant-available phosphorus (P_2O_5) content was 67.7 mg/100 g d.s.. The highest phosphorus content was 115 mg/100 g d.s., while the lowest content was 27 mg/100 g d.s.. The results revealed that 90% of the hop plantations fell into Class E (extreme phosphorus content), and none of the samples was in Class A (poor content) or Class B (medium content).

The average plant-available potassium (K_2O) content of hop-growing soils was 35.3 mg/100 g d.s.. The highest content was 59 mg/100 g d.s. and the lowest potassium content was 14 mg/100 g d.s.. In this case, 40% of the hops fell into Class E (extreme potassium content), and two out of the 10 hops sampled fell into Class B (medium content).

The median soil organic matter (SOM) content in the hops soil was 2%. The highest content was 3.6%, while the lowest content was 1.9%, which was detected in two out of the 10 sampled hops.

4 DISCUSSION

4.1 Comparison of the results of HM in the soils of the hop plantations with the study of the Geochemical background and upper limit of natural variability of 47 chemical elements in the topsoil of Slovenia

In the study of the Geochemical Background and threshold of 47 Chemical Elements in Slovenian topsoil *[1]* (hereafter referred to as the 'GB study'), systematic sampling was carried out in a 5 x 5 km mesh over the whole territory of Slovenia. A total of 817 samples were collected at depths ranging from 0 to 10 cm, for which the median and upper limits of natural variability were calculated. The results of our study were compared with the results for Slovenia as a total and for the spatial unit of the Interior Basins.

The comparison revealed that the metal contents of Hg, Tl, Bi, Mo, Th, Sc, Ga, Ag, Cr, K, Ti, Na, Al, Fe did not exceed the median values obtained in the GB study. The levels for the metals Cd, Au, Ba, Mn, Cu, Zn in the hops exceeded the values obtained in the GB study. The content values in hop plantation soils for the metals Co, Sr, La, Ni, Pb, Ca exceeded the values of the GB study for Slovenia as a whole, but not the values for the Interior Basins, while the values for the metals U and Mg exceeded the results of the GB study for the Interior Basins, but were lower compared to Slovenia as a whole. The causes of elevated concentrations of these metals vary. In the case of Cd, we assume that the cause was the fertilisation with low quality mineral fertilisers enriched with Cd. Ca and Fe are also added by the application of some fertilisers, but they are also present in the soil naturally, being important micro- and macro-nutrients necessary for optimal plant growth and development. The metals Th, Sc and Ga are also present naturally. As the eutric cambisols in the Lower Savinja Valley are formed on calcareous limestone gravel and sand, the agricultural soils may also have higher Mn, Cu and Zn contents. Soils on carbonate parent material also tend to have higher levels of the metal U *[1].* One of the reasons for the elevated levels is the use of Pb and Cu-based plant protection products in the past. In addition to all these possible agricultural soil pollutants, anthropogenic pollution from various industries, combustion and local pollution should not be neglected *[14].* It should also be considered that the proximity of Celje and the smelting industry, which is a well-known source of atmospheric Cd and Zn deposition in the area, also contributes to the higher HM content in the hops. Despite the higher Cu content in the hop plantation soils, according to a study *[23],* the Cu content of the spring hop crop is low, at only 2.3 mg/kg fresh weight. It can be concluded that hops do not absorb excessive amounts of either Cu or Zn *[23].* Research in Italy has shown that HM such as As, Cd and Pb may be present in beer, but do not pose a threat to consumers' health as the levels are so low *[19].*

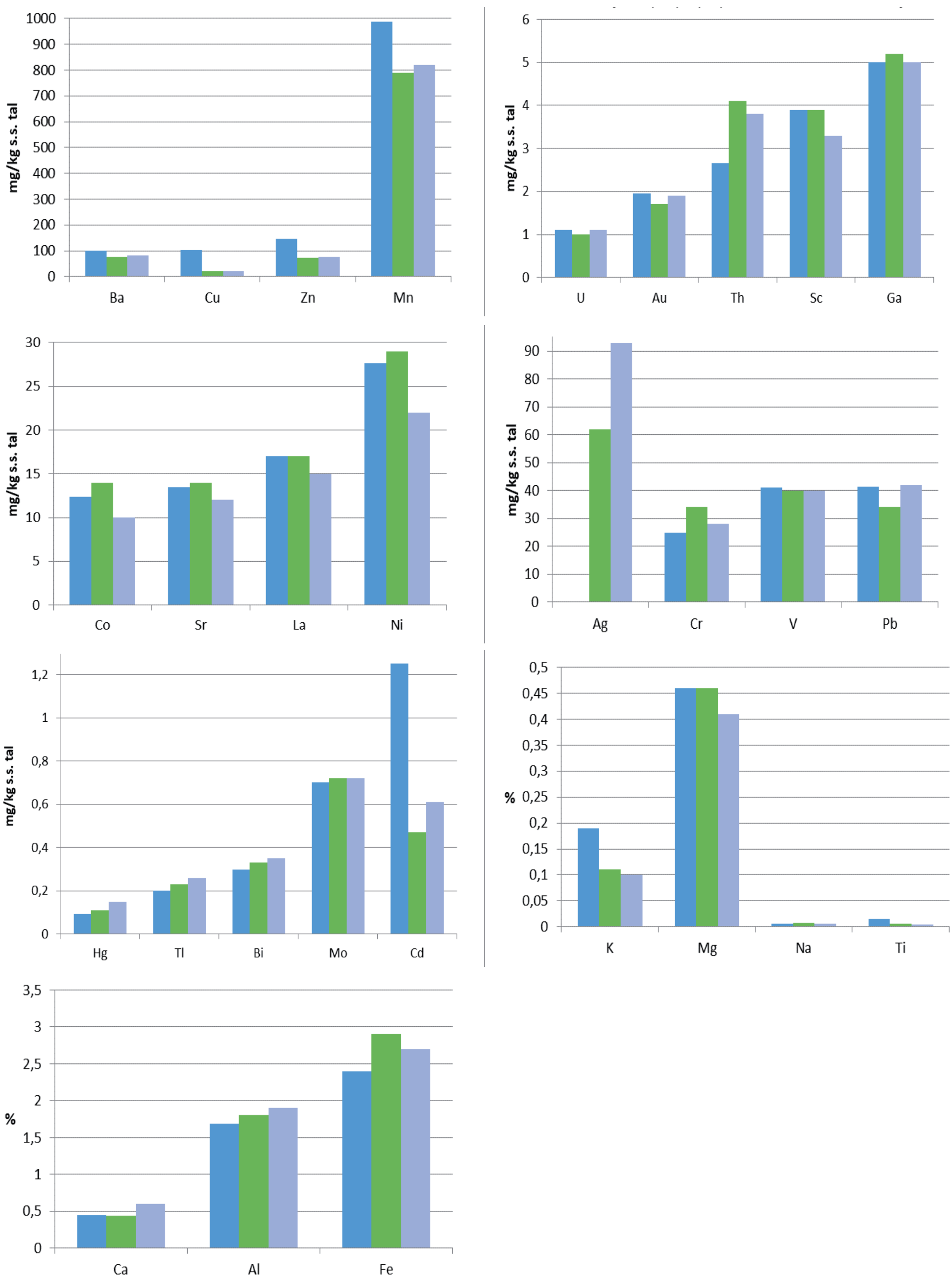

***Figure 6:** Combined results of the hop plantation soil HM content (blue column) compared to the study of the Geochemical Background for Slovenia as a total (grey column) and for the spatial unit of the Interior Basins (green column).*

5 CONCLUSIONS

Ten hop plantations were sampled for their agricultural soils. A sample from one hop plantation consists of 20 subsamples taken along the hop plantation at a depth of 0-20 cm. 37 metals (Mo, Cu, Pb, Zn, Ag, Ni, Co, Mn, Fe, As, U, Au, Th, Sr, Cd, Sb, Bi, V, Ca, P, La, Cr, Mg, Ba, Ti, B, Al, Na, K, W, Sc, TI, S, Hg, Se, Te, and Ga) were analysed at the Bureau Veritas accredited laboratory in Vancouver. Ten metals (Cd, Cu, Ni, Pb, Zn, Cr, Hg, Co, Mo and As) were compared with the Slovenian legislation on limit values . The results of the metal contents were also compared with the Geochemical background and upper limit of the nature of variability of 47 chemical elements in the topsoil of Slovenia in the Interior basins and Slovenia as a whole.

Based on a comparison of the median levels for ten metals (Cd, Cu, Ni, Pb, Zn, Cr, Hg, Co, Mo and As) with the limit values in the Regulation, we found that two metals, Cu and Zn, exceeded the WIV in several samples. Cu contaminated 50% of the tested hops, while only one hop plantation was contaminated with Zn. Only Cd exceeded the LIV according to the Regulation in 90% of the sampled hops. The other metals which are covered by the Regulation, did not exceed the LIV in any of the samples taken. The soil of the hop plantations is in agricultural use, which means that the elevated metal levels may also be due to the long-term use of mineral or organic fertilisers and FFS containing Cu, Cd and Zn. Metals used in the past still accumulate in the soil, reflecting the history of farming and the use of different chemical inputs in the hop fields, as they are not leached out, but accumulate in the soil over the years. However, elevated HM levels in soils can also be attributed to anthropogenic sources of pollution, as the soils of the hops in the Lower Savinja Valley have been exposed to various levels of HM pollution in the past. Among other sources, contamination of the soil by HM from various industries in the area of Žalec and Celje cannot be excluded. The possibility of soil contamination in the past, especially with Cd, can also be attributed to the burning of lignite and the proximity of the Zinc smelting industry in the nearby city of Celje. The urbanisation of the Lower Savinja Valley is also estimated to have contributed to the higher HM content in soil, while the possibility of soil contamination by traffic must also be considered in the soils of traffic corridors. In conclusion, higher HM levels in the soils of the hop plantations in the Lower Savinja Valley are estimated to be the result of a combination of industrial, agricultural, urban and other anthropogenic activities in the past and present.

The metals Cu and Zn, which were found at elevated levels in the hops soils, do not pose a risk to the consumer. From the study on the final products - beer, the contents of HM were extremely low and did not threaten the consumer. There were also no significant levels of these HM in the hop plant itself, through which they could pass from the soil to the hop cones and to the final product. The metals in question are bound to soil particles (clay minerals and soil organic matter) in the soil, and are therefore difficult to leach out of the soil. However, when soil properties change (reduced SOM content or increased soil acidity), the HM become mobile again and available to the plants.

The most ideal and optimal soils for growing hops are moderately acid soils in the pH range from 6 to 6.7 *[21]*. The conducted study showed that 60% of the hopgrowing areas are in the suitable class for growing hops in terms of soil acidity. The remaining 30% of hop soil sampled had pH values from 4.5 to 5.5, and 10% of the hop soil samples had a pH value above 7.2. There are several reasons for lower acidity in soils. These include leaching of cations out of the soil, acid precipitation and neutralisation during the growing season. Soil acidity is also influenced by cropping, which removes the base cations from the soil, especially Ca^+ and Mg^+. In addition, the use of acid-acting mineral fertilisers can also contribute to soil acidification *[15]*.

The analysed hop plantations are generally well supplied with plant-available K_2O and P_2O_5. According to the soil supply classification, the soil samples fell into the classes of medium to extreme soil content. In the case of phosphorus, out of the 10 hops analysed, 10% belonged to class D, with excessive content, and as much as 90% to class E, meaning extreme soil content. In the case of potassium, of the total of 10 hops analysed, 20% were in class B, medium soil content, 20% in class C, optimal content, 20% in class D, excessive soil content, and 40% in class E, meaning extreme content. The elevated levels are most likely due to the overuse of potassium- and phosphorus-based fertilisers. In agricultural lands where increased levels are measured, limited fertiliser application is recommended, and where values are extreme, complete restriction of fertiliser application is advised for the next 5 to 10 years *[22].*

For further research, it would be beneficial to identify additional hop plantations that contained higher levels of metals in the soil. At the same time, for food safety reasons, it would be recommended to check the mobility of HM in soil and their uptake by agricultural plants (hops), as well as the HM content in the produce (hop cones) and food (beer).

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Nomenclature

(Symbols)	(Symbol meaning)
HM	Heavy metals
FEP	Faculty of Environmental Protection
SOM	Soil organic matter
RS	Rebublic of Slovenia
ZVO	Environmental Protection Act
LIV	Limit immission value
WIV	Warning immission value
CIV	Critical immission value
d s.	Dry soil
Ag	Silver
Al	Aluminium
As	Arsenic
Au	Gold
B	Boron
Ba	Barium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Ga	Gallium
Hg	Mercury
K	Potassium
La	Lanthanum
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
Ni	Nickel
P	Phosphorus
Pb	Lead
S	Sulphur
Sb	Antimony
Sc	Scandium
Se	Selenium
Sr	Strontium
Te	Tellurium
Th	Thorium
Ti	Titanium
Tl	Thallium
U	Uranium
V	Vanadium
Zn	Zinc

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VERIFICATION AND VALIDATION OF STUDENT'S CFD TOOL ON THE VENTURI FLOW CASE

VERIFIKACIJA IN VALIDACIJA ŠTUDENTOVEGA CFD-ORODJA NA OHIŠJU VENTURIJEVEGA PRETOKA

Tihomir Mihalić[1ℜ], Ante Zaninović[1], Srđan Medić[2], Filip Krsnik[1]

Keywords: CFD, venturi, turbulence, mesh, student

Abstract

The main goal of this study is to investigate the usability of the CFD software ANSYS Student 2023 R1 for students` scientific research. To carry out this investigation, a comparison was carried out of the analytically calculated flow rates through a standard venturi tube with the results obtained by simulations of the flow in the specified program. Given that it is a student, free version of the program, which comes with certain limitations, proving its usability by performing verification and validation on known geometry would be of great benefit. To ensure comparability, a 3D model of the venturi tube was created in accordance with the ISO 5167 Standard. The flow rate was calculated on that selected geometry of the venturi tube, using the well-known equations of fluid mechanics. The selected geometry of the venturi tube was discretised in the ANSYS Student 2023 program, respecting all CFD rules. Comparison of these two sets of results showed a match within 5%.

ℜ Corresponding author: Zagreb University of Applied Sciences, Mechanical Engineering Department, Brozova 6A, 10000 Zagreb, Croatia

1 Zagreb University of Applied Sciences, Mechanical Engineering Department, 10000 Zagreb, Croatia

2 Karlovac University of Applied Sciences, Mechanical Engineering Department, I. Meštrovića 10, 47000 Karlovac

Povzetek

Glavni cilj te študije je raziskati uporabnost programske opreme CFD ANSYS Student 2023 R1 za znanstveno raziskovanje študentov. Za izvedbo te preiskave je bila izvedena primerjava analitično izračunanih pretokov skozi standardno venturijevo cev z rezultati, pridobljenimi s simulacijami pretoka v navedenem programu. Glede na to, da gre za študentsko, brezplačno različico programa, ki ima določene omejitve, bi bilo dokazovanje njegove uporabnosti s preverjanjem in validacijo na znani geometriji zelo koristno. Za zagotovitev primerljivosti je bil izdelan 3D-model venturijeve cevi v skladu s standardom ISO 5167. Hitrost pretoka je bila izračunana na izbrani geometriji venturijeve cevi z uporabo dobro znanih enačb mehanike tekočin. Izbrana geometrija venturijeve cevi je bila diskretizirana v programu ANSYS Student 2023 ob upoštevanju vseh pravil CFD. Primerjava teh dveh rezultatov je pokazala ujemanje znotraj 5 %.

1 INTRODUCTION

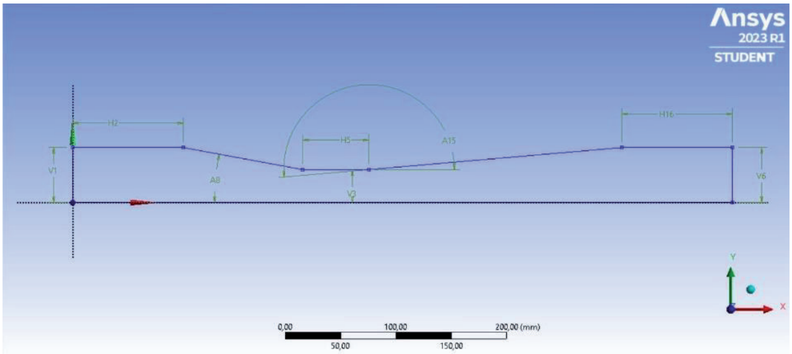
The EU's desire to popularise science leads to the need for students to get involved in scientific research as early as possible. In the past, scientific research was reserved for postdoctoral students. The approach that students get involved in the world of scientific research at the very beginning of their studies at undergraduate levels, or at least as part of their final theses, provides advantages to society, and to the Faculties themselves, because they get a better overview of which of these students have the research affinity *[1]*. Furthermore, it is the opinion of the authors of this paper that involving students in scientific researchs contributes to the development of civil society.

It has been shown with this approach that some students already have a hidden potential to produce scientific articles of the highest level *[2]*. The tendency to involve students in research is demonstrated by the example of some Faculties in Croatia, which give additional points for published scientific articles when they apply in graduate studies.

In order for students to be involved in scientific research, it is necessary to provide them with tools that they could use in their work *[3]*. In the field of CFD, these tools are various computer programs, some of which are commercial and some of which are open source. Considering the high price of commercial CFD tools, the idea appeared to test students` free versions of them, which the manufactures of these software packages themselves say that students may use in their research only with prior registration.

2 GEOMETRY GENERATION

The geometry and dimensions of the Venturi tube used for the purposes of this research were determined according to the ISO 5167-4:2003 Standard, *[4]*. According to the guidelines of the specified Standard, the geometry of the model was created in the ANSYS Student Design Modeler (Fig. 1).



Details View	
Dimensions: 8	
A15	185 °
A8	10,5 °
H16	100 mm
H2	100 mm
H5	60 mm
V1	50 mm
V3	30 mm
V6	50 mm

Figure 1: *Venturi geometry according the ISO 5167-4:2003 Standard [3]*

The angle φ = 10° was chosen for the divergent conical part. The ratio of the diameter of the inlet part and the throat of the Venturi tube is:

$$\beta = \frac{d}{D} = \frac{60\ \mathrm{mm}}{100\ \mathrm{mm}} = 0.6 \qquad 2.1$$

After all the dimensions of the test venturi tube were determined, a 3D model was created, shown in (Fig. 2).

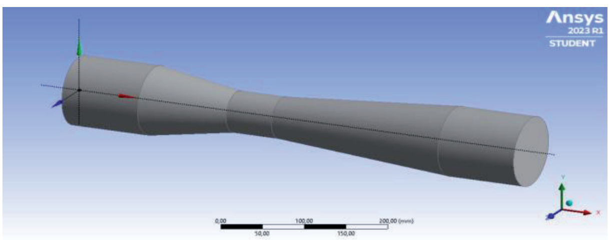


Figure 2*: 3D model of the Venturi pipe*

2 DISCRETISATION AND MESH GENERATION

The first step of creating a mesh of control vulumes is defining the boundary conditions, (Fig. 3). It is necessary to determine the fluid inlet and outlet from the venturi tube, and set the limits necessary for numerical calculations.

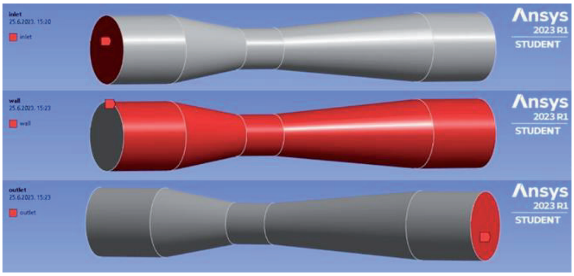


***Figure 3**: Definition of boundary conditions*

The next step is to set inflation conditions on the boundary region of the pipe wall. Inflation in a CFD simulation is a technique used to create mesh layers near the walls, to model the boundary zone between the fluid and the wall better. This technique is particularly useful in flow simulations, where it is important to model the fluid layer adjacent to the wall accurately [5]. Inflation is achieved by adding additional mesh layers near the wall. These layers have a higher density of nodes than the rest of the mesh, and extend within the fluid boundary layer. The goal of inflation is to create enough nodes within the boundary layer to capture and model the turbulent effects occurring at the wall`s surface. Inflation is usually applied in combination with turbulence models, in order to model turbulent flows near the wall more accurately, and in order to satisfy the value of the dimensionless parameter *y+*, the required value of which depends on the selected turbulence model. This technique enables a better resolution of the boundary conditions, and reduces the need for a very fine mesh of the entire computaional model, which would require large computing resources. The venturi wall is set as the inflation boundary, the number of inflation layers is set to 8, and the layer growth rate is set to 1.2 towards the centre of the pipe, (Fig. 4).

The discretisation itself was performed using tetrahedral control volumes. The tetrahedral mesh is flexible, and adapts well to geometries with curved surfaces, which is why they are one of the most commonly used elements in the analysis of turbulent flows, *[5].*

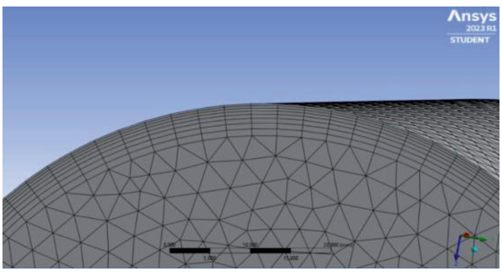


***Figure 4**: Inflation boundary layers*

For the purposes of this work, ANSYS Student was used, which limits the number of control volumes to 512000. Due to this fact and the addition of additional layers of inflation, the size of the elements was set to 3.5 mm, so that the number of elements was less than the allowed 512000, (Fig. 5).

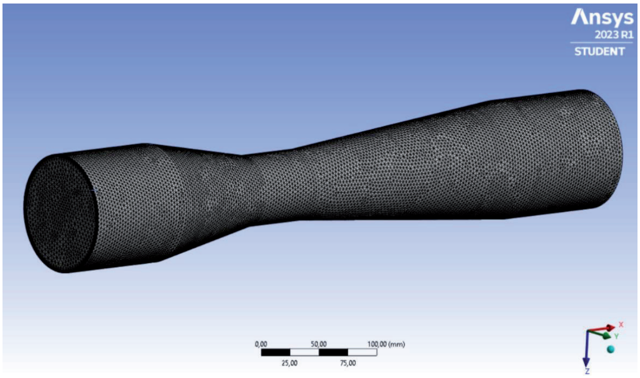


Figure 5: *Generated mesh*

3 PREPARATION AND SIMULATION RUN

The $k - \varepsilon$ model of tubulation was chosen, due to the limitations of the computing power of the computer used to create the simulation and the limitations of student licences. For the purposes of this work, water in liquid form was chosen as the working fluid. The inlet was defined as a velocity inlet (Velocity Inlet), with an initial velocity value of 2 m/s. The turbulence parameters were also defined: The turbulence intensity was set to 5%, and the hydraulic diameter was set to the pipe inlet diameter D = 100 mm. Atmospheric pressure was set at the outlet of venturi pipe.

Furthermore, a coupled (Fully Coupled Method) was used. This method uses fully implicit resolution of pressure and velocity, and allows full coupling between velocity and pressure at each iteration step, which is great for capturing small fluctuations due to turbulence, [6]. In this work, the convergence limit for all iteration parameters was set to the value 10^{-6}. This value brings sufficiently precise results considering the density of the mesh, the chosen discretisation method, and the mathematical and turbulence models.

4 MODEL VERIFICATION

Comparison of images obtained in known experimental flows through a standard venturi pipe with images of CFD simulated flows was used, to conduct verification of the built model and used student version of CFD software. The comparison was flow visualisation of the 2D contours of the pressure through the central plane of the Venturi tube in the axial direction (in the x-y plane), (Fig. 6).

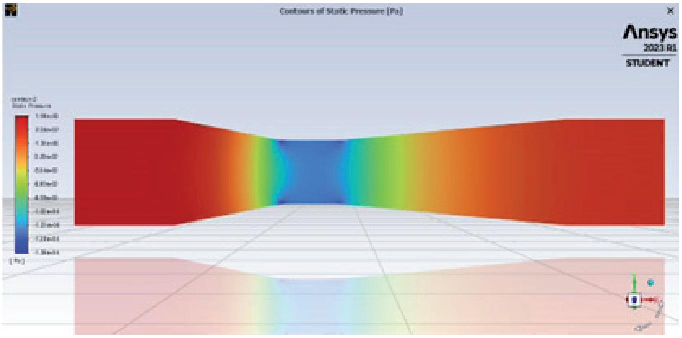


Figure 6*: Pressure distribution along the axial plane*

The pressure contours obtained by the CFD student package showed good agreement with the experimental images of flow through a standard venturi tube. This experimental images are well known and are in every book of fluid mechanics, so they are not presented here.

Furthermore, a comparison was made of the velocity distribution contours and flow velocity vectors with known experimental flow images, (Fig. 7 and 8).

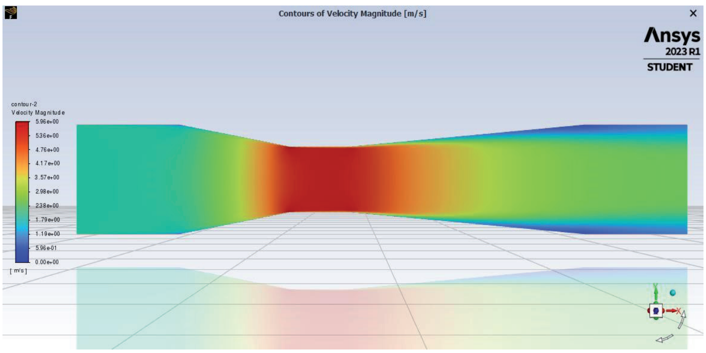


Figure 7 *Contures of velocity magnitude*

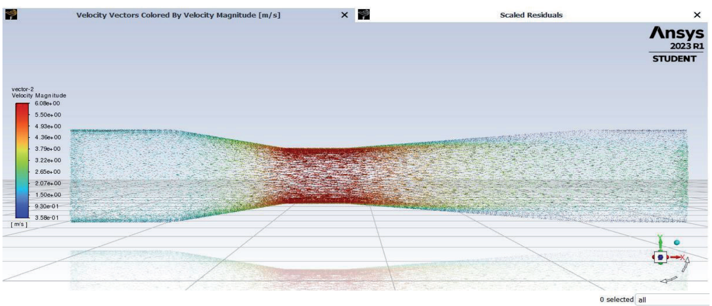


Figure 8 *Velocity vectors colored by velocity magnitude*

A comparison of the velocity field and velocity vectors obtained by the student CFD package with the existing experimental ones showed a good match. This proved that the student CFD package simulates well the physics of the flow itself and the phenomena in it. This proved the verification of the student CFD package.

5 RESULTS COMPARISON

The values obtained from the CFD simulation have a certain deviation with respect to the values obtained by analytical calculation, as shown in Table 1.

	Analytical calculation results	**CFD results**	**Relative deviation r [%]**
Δp [Pa]	13411.434	13977	4.22
q_v [m^3/s]	0.01571	0.01604	2.11
q_m [m^3/s]	15.6817	16.0111	2.11

Table 1: *Comparison of results gained with the analytical calculation and CFD*

The values obtained from the CFD simulation have a certain deviation with respect to the values obtained by the analytical calculation. It can be seen that this deviation was less then 5%.

6 CONCLUSION

From this work it can be concluded that the student's version of Ansys Fluent can be used for students` researches and projects with satisfactory reliability.

Future work suggests finding a numerical correlation between the accuracy of the results of student's cfd Ansys Fluent with geometry complexity.

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Nomenclature

(Symbols)	(Symbol meaning)
CFD	Computational fluid dynamics

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HEAVY METAL CONTENT IN VEGETABLE GARDEN SOILS IN RELATION TO THEIR NATURAL BACKGROUND

VSEBNOST TEŽKIH KOVIN V TLEH IZBRANIH KMETIJSKIH POVRŠIN V POVEZAVI Z NJIHOVIM NARAVNIM OZADJEM

Katja Črnec[1], Ana Strmčnik[1], Borut Vrščaj[1,2,ℜ]

Keywords: *soil contamination, soil degradation, food safety, allotment gardens, soil pollution*

Abstract

Heavy metals (HM) are present in soil naturally *[1]*, due to the weathering of the element-rich parent rock and by anthropogenic sources (industry, energy production, agriculture, traffic) *[2–4]*. The agricultural sources of increased HM concentrations in soil are HM-containing fertilizers and pesticides. Agricultural soils are often considered polluted, and are therefore subject to soil contamination monitoring for food safety reasons. Allotments are particularly at risk from intensive gardening, the general overuse of fertilizers, soil conditioners, often seen as a means of improving soil quality, in some cases the overuse or misuse of pesticides and, in the past, the use of coal ash. In some cases, landowners are also receiving untested and potentially polluted soils from elsewhere. Therefore, the soils of the vegetable/allotment gardens are generally considered to be 'highly anthropogenized'. According to Slovenian legislation *[5]*, the HM concentration is considered elevated if the HM concentration in the soil is above the limit immission value (LIV), polluted if it is above the warning immission value (WIV) and critically polluted if it is above the critical immission value (CIV). The HM content was analyzed in the soils of 20 allotment gardens

ℜ Corresponding author: Prof. Dr. Borut Vrščaj, Faculty of Environment Protection (FEP), Trg mladosti 7, 3320 Velenje, Slovenia, E-mail address: borut.vrscaj@fvo.si

1 Faculty of Environment Protection (FEP), Trg mladosti 7, 3320 Velenje, Slovenia

2 Agricultural Institute of Slovenia, Department of Agroecology and Natural Resources, Centre for Soil and Environment

in the village of Legen (Municipality of Slovenj Gradec, Carinthia, Slovenia). The soil samples were dried, ground and sieved in the FEP laboratory, and analyzed ‘by Bureau Veritas Commodities (Canada) using Aqua Regia extraction to determine the 'pseudo-total content' for 37 elements (Ag, Al, **As**, Au, B, Ba, Bi, Ca, **Cd**, **Co**, **Cr**, **Cu**, Fe, Ga, **Hg**, K, La, Mg, **Mn**, Mo, Na, **Ni**, P, **Pb**, S, Sb, Sc, Se, Sr, Te, Th, Ti, TI, U, V, W, and **Zn**), 10 of which (in the frames) are considered common HM soil contaminants. The comparison of the HM concentrations in the garden soils with the well-known rich natural geochemical background of the area showed that the values for all the compared metals, except Al, Fe, Ga, Sc, Th and Co, were higher than natural element backgrounds in the Eastern Alps and in Slovenia as a whole. The HM concentrations in the garden soils were within, or slightly above, the natural background values *[1]*, but below the LIV, with the exception of Pb and Zn in four gardens, where the concentrations exceeded the WIV *[6]*. The garden soils in the Legen village area have been enriched anthropogenically, most likely by the introduction of manure, and, in one case, untested and contaminated soils from elsewhere. Most of the gardens are characteristically oversupplied with the nutrients P and K; the soils are moderately enriched with soil organic matter and have an average acidity of pH 6.7, which means that the soil is neutral.

Povzetek

Težke kovine (TK) so v tleh naravno prisotne *[1]* predvsem zaradi preperevanja matičnih kamnin, bogatimi z elementi, in antropogenih virov (industrija, energijska proizvodnja, kmetijstvo in promet) *[2-4]*. Kmetijski vir povišanih koncentracij TK v tleh je uporaba raznih gnojil in pesticidov, ki vsebujejo TK. Kmetijska tla pogosto veljajo za onesnažena, ravno zato pa so zaradi varnosti hrane vključena v monitoring talne onesnaženosti. Vrtovi so še posebej ogroženi zaradi intenzivnega vrtnarjenja, splošne pretirane uporabe gnojil in drugih dodatkov, ki naj bi izboljšali kakovost tal, v nekaterih primerih prekomerne ali napačne uporabe pesticidov ter uporabe premogovega pepela v preteklosti. V določenih primerih lastniki zemljišč uporabljajo netestirana in potencialno onesnažena tla od drugod. Zato na splošno velja, da so tla vrtov »močno antropogena«. V skladu s slovensko zakonodajo *[5]* koncentracija TK velja za povišano, kadar koncentracija TK v tleh preseže mejno imisijsko vrednost (MIV), za onesnaženo, če preseže opozorilno imisijsko vrednost (OIV), in za kritično onesnaženo, kadar preseže kritično imisijsko vrednost (KIV). Analizirali smo vsebnost TK v tleh 20 vrtov v vasi Legen (občina Slovenj Gradec, Koroška). Talni vzorci so bili posušeni, zmleti in presejani v laboratoriju FVO ter analizirani v Bureau Veritas Commodities (Kanada) z uporabo ekstrakcijske metode Aqua Regia za določanje navidezne skupne vsebnosti 37 elementov (Ag, Al, **As**, Au, B, Ba, Bi, Ca, **Cd**, **Co**, **Cr**, **Cu**, Fe, Ga, **Hg**, K, La, Mg, **Mn**, Mo, Na, **Ni**, P, **Pb**, S, Sb, Sc, Se, Sr, Te, Th, Ti, TI, U, V, W in **Zn**), od katerih 10 (v okvirjih) spada med pogoste TK, ki onesnažujejo tla. Primerjava koncentracij TK v vrtnih tleh z dobro poznanim bogatim naravnim geokemičnem ozadjem območja je pokazala, da so vrednosti vseh primerjanih kovin, z izjemo Al, Fe, Ga, Sc, Th in Co, višje od elementov naravnega ozadja Vzhodnih Alp in celotne Slovenije. Koncentracije TK v tleh vrtov so znotraj ali tik nad vrednostmi naravnega ozadja *[1]*, vendar pod MIV, z izjemo Pb in Zn v štirih vrtovih, kjer koncentracije presegajo OIV *[6]*. Tla vrtov vasi Legen so bila antropogeno obogatena, najverjetneje z vnosom gnojil ter v enem primeru netestiranih in onesnaženih tal od drugod. Za večino vrtov velja, da so ekstremno preskrbljeni s hraniloma P in K; tla so zmerno obogatena z organsko snovjo in imajo povprečno kislost s pH vrednostjo 6.7, kar pomeni, da so tla nevtralna.

1 INTRODUCTION

1.1 Soil Structure

Soil is logically formed natural body composed of mineral particles and organic matter, soil water (i.e., the liquid phase) and air (soil atmosphere), microorganisms and nutrients. They are made up of soil horizons or layers, which are, according to Jenny *[17]*, formed by pedogenetic factors such as parent material, time, climate, topography, living organisms and mankind. A soil profile is defined by a sequence of horizons, more or less with the soil's surface, that differ in various morphological, chemical, physical and biotical properties such as soil structure, texture, acidity, porosity, nutrients and colour. Soil horizons are identified by the excavating a soil profile, a morphological description, chemical and physical measurements of the soil's parameters. *[7]*

1.2 Heavy metals and their sources in soil

Heavy metals (HM) are a persistent type of pollutant. HM not only degrade the quality of the air, water bodies, soils and food crops, but also threaten the health and well-being of animals and humans. Metals accumulate in the tissues of living organisms, because, unlike most organic compounds, they do not undergo metabolic degradation *[8].* HM are responsible for a wide range of human problems due to their toxic effects, including heart disease, cancer, mental health problems, chronic nausea, damage to the kidneys, nervous system and brain, and others. The most important aspect of the ecosystem is the soil which is contaminated heavily with HM. Compared to other pollutants, HM persist longer in soils because they bind to soil particles, from where they are released into the soil solution to become available to plant roots *[9].*

1.2.1 Parent Material

The parent material (PM) is a natural and primary source of HM in the soil. These occur naturally in low concentrations in soils, as their content depends on the parent rock, and its influence on the HM content becomes less pronounced with soil age due to weathering *[10].* In soils formed on PM rich in HM, the soil is, at least in the young development stage, logically rich in HM as well.

1.2.2 Anthropogenic immissions of HM

The main anthropogenic sources of HM are mine tailings, industrial sites, waste deposits with high metal content and leaded gasoline, which was used in the past to fuel vehicles. The combustion of leaded petrol in the engine produces toxic lead compounds which are released into the atmosphere and soil, where they accumulate. Excessive use of organic and mineral fertilizers can also be a source of HM in the soil *[10]*. Various pesticides, irrigation of soils with HM-rich wastewater, sewage sludge and petrochemical substances spillages, contribute to the increased HM content of soils. Heavy metals often enter the soil mainly through atmospheric depositions from various anthropogenic sources *[8].*

1.3 Garden Soils

Garden soils are classified as anthropogenic soils, meaning they have been altered fundamentally by tillage, and can be quite different from natural soils. Garden soils differ from natural or other agricultural soils in being supplied better with nutrients and soil organic matter (SOM), and often containing additives such as ash and/or compost. Their horizons also differ. The top horizon of garden soils is usually deeper and more nutrient-rich, and contains significantly more organic matter than comparable natural or modified soils intended for other agricultural uses. The top horizons are, therefore, deep, usually very loose and porous, as a result of frequent tillage. The pronounced use of organic fertilizers, the most common of which is compost, and sometimes farm manure, has contributed to the increase in SOM content. The addition of mineral fertilizers and occasional application of lime has the effect of reducing soil acidity, and, in the case of excessive doses of fertilizers, of increasing the amount of nutrients to a much greater extent than the plants need at all. The optimum garden soils are humic, loose and crumbly, with a lumpy texture, acidic and supplied adequately with nutrients. Good garden soils should contain approximately 20 mg of phosphorus (expressed as P_2O_5), between 20 and 25 mg of potassium (expressed as K_2O) per 100 g of dry soil, have the acidity of between pH 6 and pH 7 (mildly acidic), contain around 4 to 8% of SOM and be free from contaminants. If the nutrients in the soil are insufficient, they should be added by fertilization. *[11]*

Table 1: *Soil classification based on potassium and phosphorus soil content*

Nutrient content class	Phosphorous content (P_2O_5) (mg / 100 g)	Potassium content (K_2O) (mg / 100 g)
Class A – Poorly supplied	< 6	< 10
Class B – Medium supplied	6 – 12	10 – 19
Class C – Optimally supplied	13 – 25	20 – 30
Class D – Excessively supplied	26 – 40	31 – 40
Class E – Oversupplied	> 40	> 40

SOM also plays an important role in maintaining soil fertility, by retaining and providing nutrients and food for microorganisms, improving the soil's physical and chemical properties, improving soil porosity, and, thus, aeration, retaining soil moisture and binding nutrients to prevent leaching *[12].*

Table2: *Soil classification according to SOM content (%)*

Class	SOM content (%)
Mineral soil	< 1
Poorly humic soil	1 – 2
Medium humic soil	2 – 4
Humic soil	4 – 10
Extremely humic soil	> 10

1.4 Accessibility of HM and measures for safer vegetable production

The accessibility of HM is influenced by the clay and humus content and the acidity of the soil. If the soil is acidic (pH < 5.5), HM are more easily released into the soil solution, and thus become available to the roots. Therefore, care should be taken to maintain soil acidity above pH 6.5. This can be done by adding lime, fine limestone dust, or Ca-rich fertilizers. Clay and humus particles bind HM strongly, immobilizing them, and thus reducing their availability to roots. A good phosphorus supply in the soil helps to retain some forms of HM. Not all plants have the same capability to take up HM from the soil. HM are distributed differently in various parts of the plant. In general, more HM accumulate in leaves and roots than in fruits or seeds. Thus, eating leafy vegetables (spinach and lettuce) and root vegetables (carrots, potatoes and onions) grown in contaminated soil exposes us to more HM than fruit vegetables (tomatoes, peppers and beans). An important aspect of HM is urban composting, as dust particles rich in HM can settle on grass, leaves and green cuttings. Grasses and vegetables on contaminated soils consequently take up some HM from the soil. By composting such leafy materials, we concentrate the HM in the composts, and, later, by applying them, also in the soil of the gardens. *[11]*

1.5 Main features of the study area

The Municipality of Slovenj Gradec can be classified under the Eastern Alps region, as it lies on the border of the Eastern Karavanke mountains, the Pohorje mountains and the Strojna mountains *[1].* In Slovenj Gradec, districts are dominated by dystric cambisols, which make up about half of the Municipality. In the western part there are rendzic leptosols soils on dolomite/limestone and chromic cambisols on limestone. The eutric cambisols soils are found along the river that runs through the municipality. There is also a strip of luvisols *[13].*

1.6 Slovenian Legislation

The Government of the Republic of Slovenia has adopted the Environmental Protection Act (EPA; Official Journal RS, 32/93, followed by the Official Journals RS, 41/04 and 39/06), which contain general measures and basic methods for the protection of the environment and the use of natural resources. According to the EPA, Slovenia is obliged to carry out monitoring of the state of the environment (environmental monitoring) *[14].*

Various laws in the field of Soil Protection have been adopted on the basis of the EPA *[14]*:

- Regulation on the Limit, Warning and Critical Immission Values of Hazardous Substances in the Soil (Official Journal RS, nrs. 68/96, 41/04 – EPA-1 and 44/22 – EPA-2),
- Regulation on the soil pollution by the introduction of waste (Official Journal RS, nrs. 34/08, 61/11 and 44/22 – EPA-2); and
- Resolution on the National Environmental Protection Program for the period 2020-2030 (Official Journal RS, nrs. 31/20 and 44/22 – EPA-2).

Soil contamination is determined according to the Regulation on limit, alert and critical immission levels of substances in soil *[18]*:

"The limit immission value (LIV) is the level of a particular hazardous substance in soil at which the living conditions for plants and animals are ensured, and soil fertility and groundwater quality are not impaired."

"The warning immission value (WIV) is a value at which certain land uses are likely to cause adverse effects or impacts on the environment and human health."

"The critical immission value (CIV) is the level at which contaminated soil is unsuitable for the production of plants for human and animal consumption, and for the retention and filtration of water because of adverse effects and impacts on humans and the environment."

2 MATERIALS AND METHODS

2.1 Garden soil sampling procedure

For the sampling, we selected four small settlements (Legenska village, Krnice, Krnice - Šmartno and the surroundings of Bellevue) in the rural settlement of Legen. Five gardens were sampled in each of them. The sampling was permitted by the garden owners, who were also asked by a questionnaire how often and what kind of fertilizers they used in their gardens. The sampling took place at the end of March 2023. In each garden soil samples were taken over the entire area of the garden, taking five evenly distributed sample increments and homogenizing them into a representative soil sample of the garden. The depth of the sample was kept between 20 and 25 cm and the weight of each increment was approximately 0.5 kg. The soil sampling procedure involved the use of a shovel, which was first inserted perpendicularly into the soil. Another shovel was then inserted from the other end at an angle of 45° and a vertical section of the soil was removed. The homogenized samples were then packed in a plastic bag, which was labeled accordingly for further processing.

2.2 Analytical methods

2.2.1 Laboratory sample preparation

The samples were treated and prepared for further analysis in the laboratory at FEP, Velenje. The samples were placed in a 200 ml beaker, weighing approximately 110 g and shaken carefully to settle and thus remove any major air spaces. The sample beakers are weighed to determine the fresh volume and fresh weight of the samples, which weighed approximately 210 g. We marked the beakers accordingly with the sample codes. The dryer was set to 105 °C, as this temperature is used to obtain absolutely dry soil samples. The samples were placed in the oven for 48 hours. After drying, the samples were crushed and stirred, using a ceramic pestle. Small pebbles and larger roots were removed from the samples with gloved hands. After the pestling, the samples were sieved with a sieve (pore size 0,25 mm) and returned into the marked beakers. The samples were stored in PVC »zip-lock« bags, labeled with the sample serial number. The amount of each sample should be between 30 and 45 g. Before transporting, the samples must be labeled appropriately. The package also needed a Canadian Import Declaration.

2.2.2 Extraction method *Aqua Regia*

Part of the analysis of HM in soil was carried out by Bureau Veritas Commodities, Canada, according to the accredited method ISO 11466:1995 (E). The method used for the analysis was *Aqua Regia* (AQ251) - a solution which is a 3:1 mixture of concentrated HCl (hydrochloric acid) and HNO_3 (nitric (V) acid). In this method, all HM are first extracted from the soil sample by the addition of strong acid, including those that are bound to soil particles very strongly, and therefore unavailable to plants under normal soil conditions. The content of each HM in the extract is then measured using IPC-MS (Inductively Coupled Plasma Spectrometry) analytical equipment to determine the metal content of the soil *[11].*

2.2.3 Analyses at the Agrochemical Laboratory of the Agricultural Institute Slovenia

The other part of the sample analysis was performed in the Agrochemical Laboratory of the Agricultural Institute of Slovenia, located in Ljubljana. The accredited method was used to analyze the pH value of the soil sample in $CaCl_2$ (using ISO 10390:2021) and the content of organic carbon (using SIST ISO 14235:1999 mod.). The plant available phosphorus and potassium (P_2O_5 and K_2O) were analyzed according to the Agrochemical laboratory's internal method *[15].*

3 RESULTS

3.1 Results of the AQ251 analysis

This subsection shows the results of the analysis by the AQ251 method, which were compared with the Regulation on limit, warning and critical immission values for hazardous substances in soil (hereinafter referred to as the Regulation). The results of the comparison of the metals for which the limit and warning immission value was exceeded are additionally shown graphically with the "box-plot" chart.

3.1.1 Cadmium (Cd)

For Cd, the Regulation sets an LIV of ≥ 1 mg/kg, a WIV of ≥ 2 mg/kg and a CIV of ≥ 12 mg/kg. The highest Cd soil content measured was 1.6 mg/kg, while the lowest measured content was 0.3 mg/kg. In 4 out of the 20 sampled garden soils the Cd content was above the LIV, among which the highest measured value exceeded the LIV by 60%.

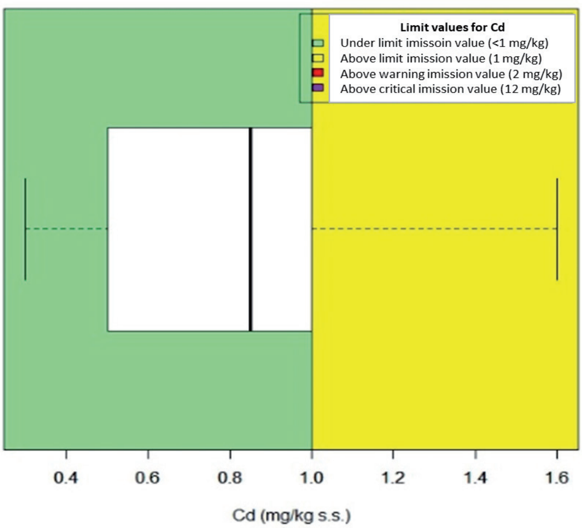


***Figure 1**: Cadmium content in the soil of the Legen gardens (mg/kg)*

3.1.2 Zinc (Zn)

For Zn, the Regulation sets an LIV of ≥ 200 mg/kg, a WIV of ≥ 300 mg/kg and a CIV of ≥ 720 mg/kg. The highest measured soil Zn content was 400.0 mg/kg, while the lowest was 112.0 mg/kg. Eight out of the 20 sampled gardens contained Zn above the LIV while, in a further three out of the 20 sampled gardens, the Zn concentrations were above the WIV, with the highest value exceeding the WIV by 33.3%, which means that the soil in these gardens was contaminated.

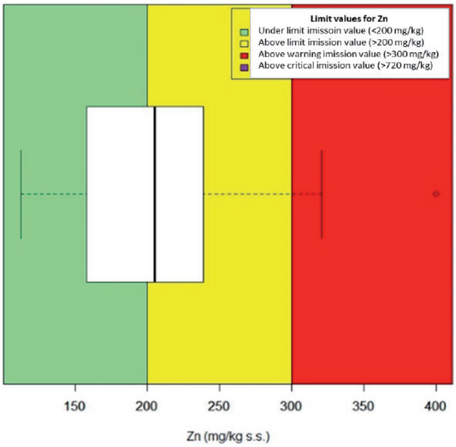


Figure 2: *Zinc content in the soil of the Legen gardens (mg/kg)*

3.1.3 Lead (Pb)

For Pb, the Regulation sets an LIV of ≥ 85 mg/kg, a WIV of ≥ 100 mg/kg and a CIV of ≥ 530 mg/kg. The highest Pb level was 106.6 mg/kg, which is above the WIV by 6.6%, so this particular garden soil was Pb contaminated. In all the remaining sampled gardens the Pb levels were below the LIV, with the lowest level being at 33.4 mg/kg.

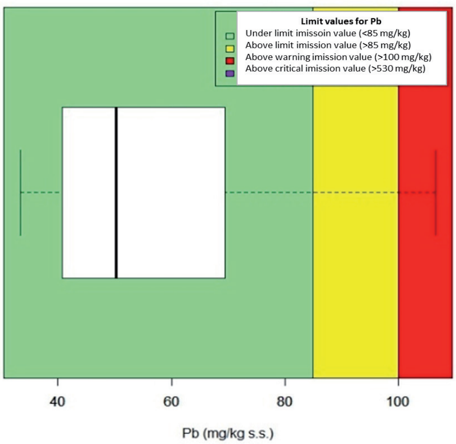


Figure 3: *Lead content in the soil of the Legen gardens (mg/kg)*

3.1.4 Other heavy metals included in the AQ251 analysis

For Arsenic (As), the Regulation sets an LIV of ≥ 20 mg/kg, a WIV of ≥ 30 mg/kg and a CIV of ≥ 55 mg/kg. The As content in the garden soils did not exceed the LIV anywhere. The lowest value measured was 9.5 mg/kg and the highest level was measured at 14.8 mg/kg.

For Cobalt (Co), the Regulation sets an LIV of ≥ 20 mg/kg, a WIV of ≥ 50 mg/kg and a CIV of ≥ 240 mg/kg. The Co content in the garden soils did not exceed the maximum LIV at any location. The lowest content was measured at 10.6 mg/kg, while the highest level was measured at 17.7 mg/kg.

For Chromium (Cr), the Regulation sets an LIV of ≥ 100 mg/kg, a WIV of ≥ 150 mg/kg and a CIV of ≥ 380 mg/kg. The Cr content in the gardens did not exceed the maximum LIV at any point. The lowest Cr content was measured at 31.0 mg/kg, while the highest level was 67.0 mg/kg.

For Copper (Cu), the Regulation sets an LIV of ≥ 60 mg/kg, a WIV of ≥ 100 mg/kg and a CIV of ≥ 300 mg/kg. The Cu content in the sampled gardens did not exceed the LIV at any point. The lowest Cu content was measured at 30.4 mg/kg, while the highest content was 57.2 mg/kg.

For Mercury (Hg), the Regulation sets an LIV of ≥ 0.8 mg/kg, a WIV of ≥ 2 mg/kg and a CIV of ≥ 10 mg/kg. The measured Hg levels in the soil of all the sampled gardens were below the LIV. The lowest content was measured at 0.07 mg/kg, while the highest level was 0.22 mg/kg.

For Molybdenum (Mo), the Regulation sets an LIV of ≥ 10 mg/kg, a WIV of ≥ 40 mg/kg and a CIV of ≥ 200 mg/kg. The measured soil levels of Mo in all the sampled gardens were below the LIV. The lowest levels were measured at 1.1 mg/kg, while the highest level reached 2.8 mg/kg.

For Nickel (Ni), the Regulation sets an LIV of ≥ 50 mg/kg, a WIV of ≥ 70 mg/kg and a CIV of ≥ 210 mg/kg. The Ni content in the soil of the gardens did not exceed the maximum LIV. The lowest Ni content was measured at 25.2 mg/kg, while the highest Ni content was 41.1 mg/kg.

3.2 Standard nutrient analysis

3.2.1 Soil acidity and plant-available potassium and phosphorus content in the garden soil

Soil acidity varied in the sampled gardens and is presented in Figure 4. Ten out of the 20 sampled gardens had neutral soils, i.e., a pH value between 6.8 and 7.2, while the remaining gardens had moderately acidic soils (pH values between 5.6 and 6.7). The average pH value in the sampled gardens was 6.7, presented with the red line in Figure 4. The acidity of the soil in the sampled gardens was generally lower compared with the natural or uncultivated soils of the Legen settlement.

The phosphorus soil content in the sampled gardens is presented in Figure 5. One garden was supplied with medium phosphorus, but otherwise no garden was supplied optimally with phosphorus. The soils of 18 out of the 20 sampled gardens (90%) had an extreme phosphorus oversupply.

In the case of potassium soil content, 50% of the sampled gardens were supplied extremely with potassium. One garden was depleted in potassium, two out of the 20 sampled gardens had a medium potassium content, while five out of the 20 gardens were supplied optimally, and two gardens were oversupplied with potassium. The results are presented in Figure 6.

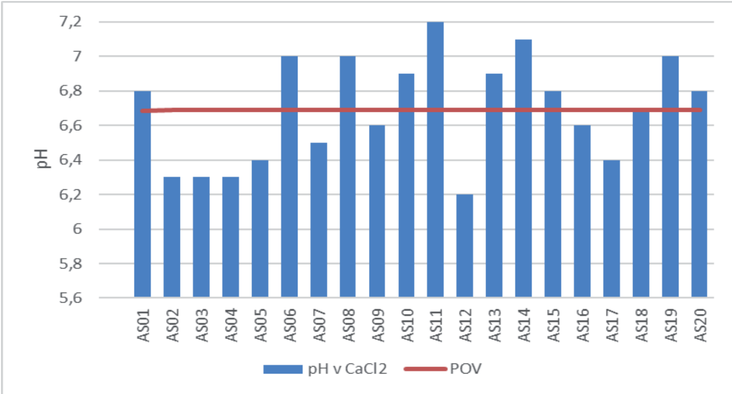


***Figure 4**: Soil acidity of the sampled gardens in relation to the measured pH value*

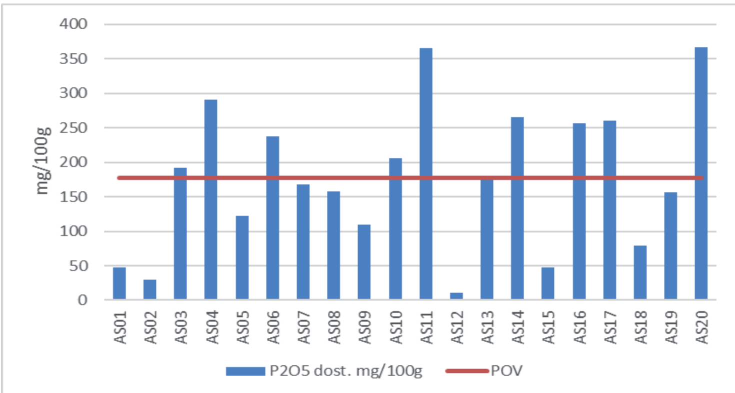


***Figure 5**: Plant-available phosphorus concentration in the soil of the sampled gardens*

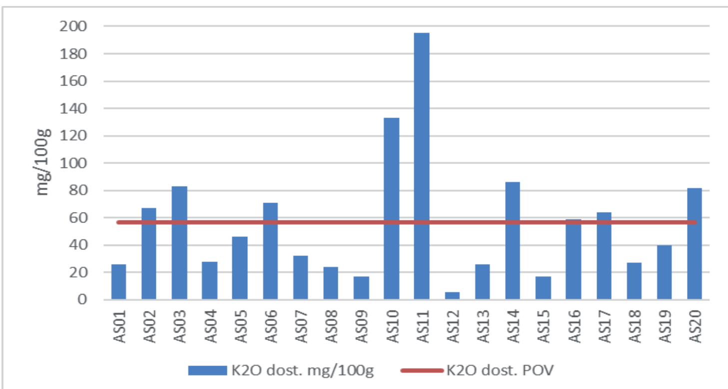


***Figure 6**: Plant-available potassium concentration in the soil of the sampled gardens*

3.2.3 Soil organic matter content (SOM)

The total SOM in 5 out of the 20 gardens belonged to the medium-humic soil class, with organic matter below 4 %. 15 out of the 20 gardens (75%) could be ranked to soils rich in SOM. The highest SOM content was measured at 8.68 %. On average, the soil in the gardens in Legen is humic, with an average SOM content of 5.6%, marked with the red line in Figure 7, where the results are presented.

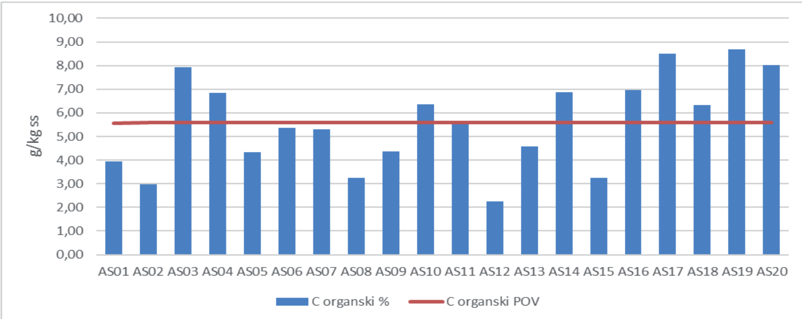


Figure 7: *Total organic carbon concentration in the soil of the sampled gardens*

3.3 Results of the survey questionnaire

Based on the results of the survey we concluded that in the settlement Legenska village, the owners are generally fertilizing once a year, except for the owners of one garden, who tend to fertilize once every two years. In 60% of the sampled gardens the owners apply manure, in 20% they use homemade compost, and in the remaining 20% they use mineral fertilizers. In this settlement, none of the garden owners used coal ash in their garden, but they used wood ash. In three sampled gardens the owners do not apply any pest and plant weed control products, while insect and other pest control agents were used in two gardens.

Based on the survey, conducted in the settlement Krnice, the owners of the sampled gardens mostly fertilize once a year, apart from one garden, which is fertilized twice a year. In Krnice 40% of garden owners use manure for garden fertilization, 40% of them use horse manure or various briquettes, and the remaining 20% use homemade compost. No one uses coal ash or any other pest or weed control products in the gardens of this settlement.

In Krnice-Šmartno, the owners of the sampled gardens fertilize once a year. The owners use farm manure in 60% of the sampled gardens, homemade compost in 20% and mineral fertilizers in the remaining 20%. The owners of this settlement also use wood ash. With the usage of the questionnaire, we gained the information that untested soil was brought from elsewhere to two of the gardens.

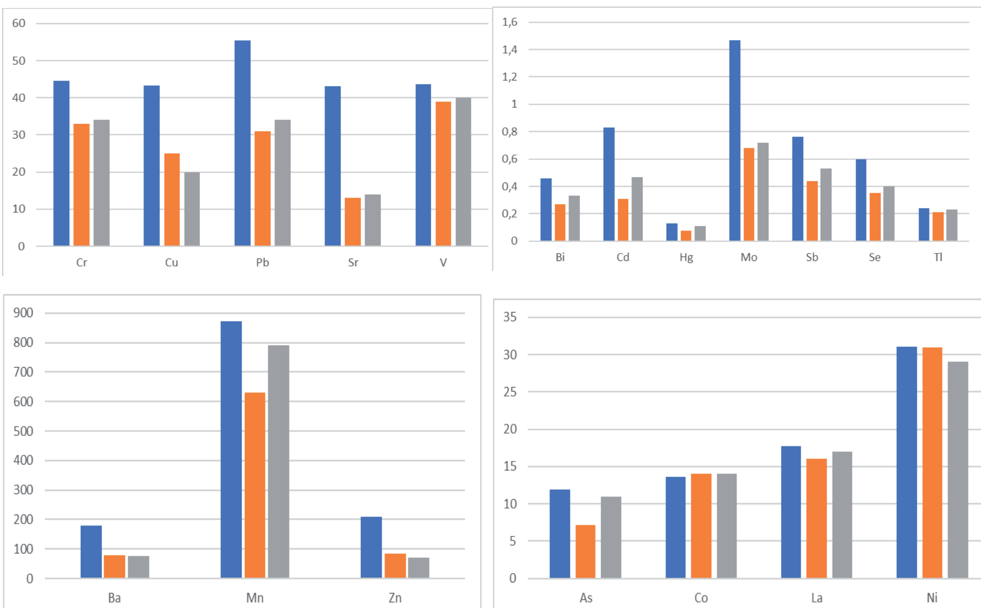
In the Bellevue settlement, the owners of the sampled gardens fertilize once a year. They use farm manure in 60% of the sampled gardens, homemade compost in 20% of the gardens, and mineral fertilizers in the remaining 20% of the gardens. The results of the survey showed that there is no use of coal ash in this settlement. In one of the gardens a plant protection product is used as a pest and plant weed control agent.

4 DISCUSSION

4.1 Comparison of the obtained results with a study on the geochemical background of soils in Slovenia

The HM content in garden soils analysis were compared with the Soil Geochemical Background Survey in Slovenia *[1]* with the median of each HM content in soils of the Eastern Alps and with the median of each HM in soil of the entire Slovenia. We excluded those elements whose measured value was less than 1 µg/kg. The comparison is shown in the combined Figure 9 below.

The results of the comparison showed that the metal contents of Ba, Mn, Zn, Cr, Cu, Pb, Sr, V, Cd, Mo, Sb, Se, B, U and Ca exceed the natural background concentrations for the Eastern Alps, as well as for the overall Slovenia. The contents of the metals Co, La, Ni, Tl, Hg, Bi, Al, Fe and Mg did not show any significant deviation from the other measured values for the Eastern Alps and for Slovenia as a whole. The comparison showed an elevated As content compared to the results for the Eastern Alps. In the case of Ga, the analyzed gardens had higher levels than in the survey for Slovenia as a whole, but lower than the values for the Eastern Alps. Whereas for Sc and Th, the results obtained for the gardens were lower than the Eastern Alps and the total Slovenia results. The elevated Cu levels are most likely due to the use of Cu-based plant protection products and the use of manure, which can contain it. The elevated Pb levels are most likely due to the imported soil to the AS19 garden and the proximity to the traffic corridors, as the Pb levels were higher in Bellevue, which is considered to be a more urban and rather busy settlement. Furthermore, the elevated Cr levels in the garden soils are probably due to the deposition of wood ash obtained by burning wood that has been coated with Cr containing wood preservatives. The Cd, Mo, Sb and Se levels were significantly elevated compared to the Eastern Alps and Slovenia. This is likely due to the use of particular mineral fertilizers and emissions from individual fireplaces in Legen, which should be investigated in future studies.



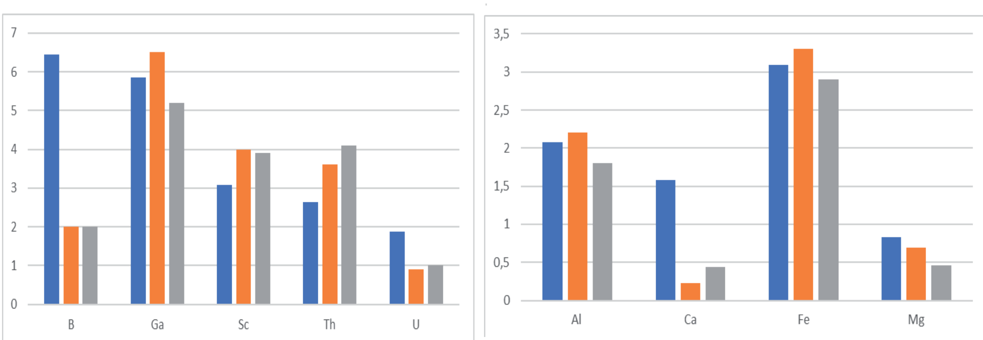


***Figure 8**: Results of the analyzed HM contents (mg/kg) in garden soil (blue column) in comparison with the study for the Eastern Alps (orange column) and total Slovenia (gray column)*

5 CONCLUSIONS

Two HM (Zn and Cd) contents in soil were above the LIV and two HM (Zn and Pb) were above the WIV. Zn was above the LIV in eight out of 20 gardens, with a maximum increase of 39.5%, and exceeded the WIV in three gardens with a maximum increase of 33.3% above the WIV. In the soil of five out of 20 gardens the Cd concentration was measured above the LIV according to the Regulation, with a maximum increase of 60%. Pb exceeded the WIV in one garden soil only, with a maximum increase of 6.6% above the WIV. On the other hand, the LIV for As, Co, Cr, Cu, Hg, Mo and Ni were not exceeded according to the Regulation.

The elevated Pb concentrations in one garden was probably due to newly introduced and untested soil imported from other locations. It is therefore crucial that we ensure that the soil is of good quality and uncontaminated before adding it to our gardens, fields or grasslands. Zn is an important micronutrient for plant growth, so it is added to the soil with various organic fertilizers. It can be assumed that the Zn content could be elevated due to the usage of livestock manure, which contains on average 24.4 g/m^3 Zn. Also, livestock manure could elevate the Cd concentrations in the soils of four gardens. Contributing to the high Zn and Cd content in livestock manure are also the mineral and vitamin supplements fed to animals, Zn coated stable equipment that is prone to excessive corrosion (in the case of Zn), and disinfectants (in the case of Cd). 92-96 % of Zn and 72-80 % of Cd are excreted in animal faeces *[16].*

Comparison with the scientific study on the Natural geochemical background *[1]* shows that, for all the metals included in the comparison, excluding Al, Fe, Ga, Sc, Th and Co, the values in the sampled garden soils were higher than in the Eastern Alps and Slovenia as a whole. This suggests that the owners of the sampled gardens have contributed to the elevated HM concentrations in the soil of their gardens through the use of livestock manure, wood ash and untested soil imported from elsewhere.

The results on the supply of plant-available potassium (K_2O) and phosphorus (P_2O_5) in the gardens showed a predominantly extreme supply, and, according to the classification, most of the gardens can be classified as Class E – heavily oversupplied. The elevated content is due mainly to the addition of fertilizers based on these two nutrients, which are added by the owners for fertilization and to improve soil fertility. We recommend limited use of fertilizers in the gardens sampled, and total non-use, at least for 5 to 10 years, in gardens with extreme stocking rates (Class E).

As an extension of the work, it would be beneficial to analyze garden soils in an additional research of garden soils in the Municipality of Slovenj Gradec, and especially those located in the town center, would contribute additional knowledge and insight of soil quality and therefore the safety of the food produced in vegetable gardens in the area.

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Nomenclature

(Symbols)	(Symbol meaning)
HM	Heavy metals
PM	Parent Material
SOM	Soil Organic Matter
LIV	Limit immission value
WIV	Warning immission value
CIV	Critical immission value
FEP	Faculty of Environmental Protection
EPA	Environmental Protection Act
RS	Republic of Slovenia
Al	Aluminum
As	Arsenic
B	Boron
Ba	Barium
Bi	Bismuth
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Ga	Gallium
Hg	Mercury
La	Lanthanum
Mg	Magnesium

Mn	Manganese
Mo	Molybdenum
Ni	Nickel
Pb	Lead
Sb	Antimony
Sc	Scandium
Se	Selenium
Sr	Strontium
Th	Thorium
Tl	Thallium
U	Uranium
V	Vanadium
Zn	Zinc

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