VOLUME 1, ISSUE 4
DECEMBER 2025

# INTERNATIONAL JOURNAL OF DIGITAL RESEARCH

E-ISSN 3033-179X

IJDR.NET

# INTERNATIONAL JOURNAL

# OF

# DIGITAL RESEARCH

**VOLUME 1**

**ISSUE 4**

**DECEMBER**

**2025**

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025*

**International Journal of Digital Research**
is abstracted and indexed in:

Crossref
doi
Google Scholar
ORCID
Connecting Research and Researchers
HARVARD LIBRARY
ResearchGate
Dimensions
BASE
Semantic Scholar
Universiteit Leiden
Princeton University LIBRARY
Scilit
















Publisher: Digital Research Lab Blagoevgrad | Registered by Bulgarian and EU legislation, Blagoevgrad, Bulgaria, EU – 2700

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025*

## EDITORIAL BOARD



## EDITORIAL TEAM

International Journal of Digital Research
www.ijdr.net
E-ISSN: 3033-179X
Volume 1; Issue 4; 2025

# CONTENTS

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025*



**VOLUME 1**

**ISSUE 4**

**DECEMBER**
**2025**

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Review Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 8-22*

# Quantum Computing and Its Implications for Theoretical and Applied Economics: From Shor's Algorithm to Models of Uncertainty

**Chris Aznaouridis[1], Dr. Ioannis Aznaouridis[2]**

[1] Dipl.-Eng. in Electrical and Computer Engineering [2] PhD, Economist, Political & Social Scientist
[1] Expert in advanced digital architectures and national-scale e-government platforms, University of Piraeus
[2] Adjunct Lecturer at Mediterranean College, University of Derby

Corresponding Author: Ioannis Aznaouridis, aznajohnny@gmail.com

https://doi.org/10.63711/ijdr.net20250401

## ABSTRACT

This article explores the interdisciplinary interface between quantum computing and economic theory, with a particular emphasis on how foundational concepts from quantum mechanics reshape core methodological and epistemological assumptions in economics. Drawing on a comprehensive bibliographic methodology, the study synthesizes contributions from quantum physics, computational theory, and economic modeling to trace the impact of quantum logic -especially principles such as superposition, entanglement, and measurement irreversibility- on both theoretical constructs and applied frameworks. Particular attention is given to emblematic algorithms (e.g., Shor's and Grover's) as case studies for illustrating computational discontinuities in fields such as cryptographic trust, portfolio optimization, and decision-making under uncertainty. The article also surveys recent developments in quantum machine learning and quantum-inspired models relevant to economic forecasting and adaptive policy design. Ethical and distributional concerns are critically addressed, especially in relation to the asymmetric global access to quantum resources. By mapping this emerging field through a structured review of cross-disciplinary literature, the paper offers a conceptual framework for understanding how quantum technologies may influence future research in financial economics, risk theory, and the modeling of complex systems operating under deep informational constraints.

***Keywords:*** *Shor's-Grover's Algorithms, Quantum Computing/Logic, Superposition, Decision Theory, Financial Technology* ***JEL Codes:*** *C63, D80, E61*



## INTRODUCTION

Historically, the evolution of information technologies has profoundly influenced both the theory and practice of economic science, from econometrics and financial analysis to game theory and microeconomic behavior. Today, the emergence of quantum computing does not merely represent a technological advancement, but potentially a paradigmatic leap in the very logic through which economic phenomena are approached, understood, analyzed, and predicted.

Quantum computing, being a radically different approach to information processing, appears capable of transcending the limitations of classical computational models, shaping a new framework of inquiry (Nielsen & Chuang, 2010). Although the technology remains in an early stage of development, its promise of a fundamental upgrade in processing capabilities for specific classes of problems renders it imperative to reflect in a timely manner on its potential impacts in fields characterized by high degrees of uncertainty, such as economics (Arute et al., 2019).

From cryptography and game theory to dynamic risk valuation models, Quantum Computing – founded on the principles of quantum mechanics (Ladd et al., 2010) – has the potential to reshape core tools and assumptions of economic thought. At the same time, it opens new horizons in information processing, the treatment of uncertainty, and the understanding of complexity (Preskill, 2018; Griffiths & Schroeter, 2018). Information, whether measured in bits or qubits, is physically realized through systems such as electronic circuits, optical fibers, or superconducting materials. The reduction of entropy in a quantum system is directly related to the energy efficiency of computational processes, according to Landauer's thermodynamic limit: $E = kT \bullet \ln(2)$ per bit of information.

The primary aim of this paper is to outline an interpretive and analytical framework for the encounter between economic thought and the quantum era, highlighting both the opportunities and challenges arising from this emerging convergence of technology and social science. The economic literature approaches quantum perspectives with caution, a stance that has contributed to the persistence of a notable research gap. This gap concerns the systematic study of quantum logic at the level of methodology and epistemology within the economic sciences, limiting the integration of quantum mechanical concepts into the theoretical and analytical foundations of economic thought (Baaquie, 2007; Haven & Khrennikov, 2013).

At a functional/technical (first) level, quantum computing can influence applied economic analysis by accelerating complex computations, reshaping the cryptographic security of financial transactions, and enabling optimization in problems that have so far remained computationally intractable. At a deeper conceptual/philosophical (second) level, it raises fundamental questions concerning the nature of information, prediction, rationality, and uncertainty, issues that lie at the core of economic theory.

The methodological approach consists of: a literature review of contemporary research in the fields of quantum information science and economics; a theoretical investigation of the conceptual bridges between the two domains, aimed at identifying points of interaction; and an analysis of selected cases of economic significance.

Core concepts that run throughout the paper and form the foundation of the analysis include:

**Quantum Computing**, understood as an approach grounded in the principles of quantum mechanics, utilizing qubits, superposition, and entanglement for information processing.

**Theoretical Economics**, referring to the branch of economic science focused on the formulation of abstract mathematical models to understand economic phenomena.

**Applied Economics**, denoting the use of theoretical models and analytical tools to solve economic problems, including those in political economy, finance, and data analysis.

**Shor's Algorithm**, a quantum algorithm for integer factorization that poses a threat to cryptographic systems based on the presumed intractability of the factorization problem.

## THEORETICAL BACKGROUND: PRINCIPLES OF QUANTUM COMPUTING

The theoretical foundation of quantum computing is grounded in the physical theory of quantum mechanics and introduces a radically different approach to the representation, processing, and utilization of information. Instead of relying on binary bits, it employs qubits[1], which can exist in

[1] Quantum computers, unlike classical ones that use binary digits (bits) 0 and 1, rely on quantum bits, known as qubits. A qubit can exist in a superposition of the states 0 and 1 – that is, it can

superpositions of multiple states simultaneously and can become non-locally entangled with one another. This enables the parallel processing of alternative solutions and the achievement of computational performance that surpasses the limits of classical architectures (Griffiths & Schroeter, 2018).

## Quantum Mechanical Foundations

At the core of quantum computing lie four critical concepts: superposition, entanglement, the irreversibility of measurement, and the probabilistic nature of information. These concepts cannot be described in terms of causality, locality, or complete knowledge of a system's state -as defined in the Newtonian or Cartesian paradigm- but instead constitute the epistemological foundations of the quantum computational architecture.

**Superposition** allows a qubit to exist in a linear combination of the states $|0\rangle$ and $|1\rangle$, enabling it to encode multiple values simultaneously. This property exponentially expands the computational space compared to classical bits, making it possible to parallelize processing and explore complex states through a single operation (Nielsen & Chuang, 2010; Preskill, 2018).

**Entanglement** is a distinctly quantum phenomenon in which the state of one qubit is inseparably dependent on the state of another, regardless of physical distance. Entanglement enables the development of interdependent systems with non-local correlations, enhancing efficiency in representing and solving large-scale problems (Bravyi, Gambetta, & Temme, 2022).

The **irreversibility of measurement** represents a fundamental departure from classical logic: when a qubit is measured, its superposition collapses to a definite value ($|0\rangle$ or $|1\rangle$), destroying the original probability wave. This process is irreversible and makes the timing and method of measurement critical during the execution of a quantum computation (Griffiths & Schroeter, 2018; Roffe, 2019).

The **probabilistic nature of information** implies that the outcomes of quantum computations are not deterministic but are expressed as probability distributions. Information is extracted statistically through repeated measurements, a fact that redefines the notions of accuracy and reliability in computational design (Biamonte et al., 2017; Schuld & Petruccione, 2021).

Taken together, these four principles constitute not only the technical foundations of quantum information science but also an alternative interpretive paradigm for processing and modeling complex systems – with significant implications for decision theory, economic modeling, and information processing under uncertainty.

## The Qubit and the Representation of Information

The fundamental unit of information in quantum computing is the qubit (quantum bit), which represents a physical and mathematical generalization of the classical bit. Unlike the bit, which can

simultaneously represent combinations of these values. As a result, quantum computers can process significantly more information than classical computers for certain types of problems. Furthermore, when two or more qubits are 'entangled,' the state of one depends on the state of the other, even if they are physically distant from each other. These properties enable complex, parallelized computational processes, with capabilities that exceed the limits of today's classical computers. Despite their potential, current quantum computers remain in an experimental phase and face major challenges, such as noise (random interference that distorts the quantum state of a qubit) and decoherence (when a qubit loses its quantum coherence and behaves like a classical bit). These issues lead to unreliable results, necessitate error correction techniques, and impose strict time constraints. If an algorithm is not completed in time, the qubit loses its quantum state and effectively becomes a classical bit, causing the final result to lose its accuracy or meaning.

exist only in one of two states, 0 or 1, the qubit can exist in a superposition of these states, described by a state vector of the form:

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle, \text{ where } |\alpha|^2 + |\beta|^2 = 1$$

This representation allows the qubit to exist simultaneously in multiple possible states, rapidly increasing the volume of processable information as the number of qubits grows exponentially (Nielsen & Chuang, 2010).

A useful geometric representation of a qubit's state is provided by the so-called Bloch sphere, where each pure qubit state corresponds to a point on the surface of the unit sphere in $\mathbb{R}^3$. The ›basis states $|0\rangle$ and $|1\rangle$ are represented at the poles of the sphere, while their superpositions are distributed across other points on the surface.

This representation offers not only an intuitive understanding of quantum states but also a practical depiction of quantum logic operations as rotations on the sphere (Schuld & Petruccione, 2021).

Quantum gates are fundamental units of information processing, analogous to logic gates in classical computing. However, quantum gates are reversible linear operators (unitary operators) applied to qubits, transforming their state. Notable examples include the Hadamard (H), Pauli (X, Y, Z), Phase (S, T) gates, and multi-qubit gates such as CNOT and Toffoli. The combinatorial application of such gates enables the construction of complex circuits for implementing algorithms like Shor's and Grover's (Rieffel & Polak, 2011).

Qubit technologies such as superconducting circuits (IBM Q), trapped ions (IonQ), and topological qubits (Microsoft) delineate the practical possibilities for implementing quantum information. As such, they shape the boundaries of computational performativity and critically influence how information is reproduced, activated, and integrated into economic processes.

Information representation in quantum computing is not static, but multidimensional, continuous, and dynamically evolving, with operations on qubits taking place within an inner Hilbert space where the computational process unfolds.

## Quantum Algorithms

Quantum computing is also characterized by the development of new algorithmic frameworks that solve problems with exponential or quadratic advantages over classical algorithms. The most well-known quantum algorithms include Shor's and Grover's algorithms, as well as more recent hybrid approaches such as the Quantum Approximate Optimization Algorithm (QAOA) and the Variational Quantum Eigensolver (VQE), both of which are particularly significant for tackling optimization problems.

Shor's algorithm (Shor, 1997) provides exponential speedup in the factorization of integers, a problem that underpins the computational hardness of asymmetric cryptographic protocols such as RSA. This algorithm solves the factorization problem in polynomial time by employing quantum period-finding as its core technique. Its theoretical efficiency, combined with the vulnerability it exposes in existing cryptographic security, has triggered significant efforts in the field of post-quantum cryptography (Chen et al., 2016).

Grover's algorithm (Grover, 1996) accelerates unstructured search in databases by reducing the search time from $O(n)$ to $O(\sqrt{n})$[2]. Although it does not provide exponential speedup, it offers a quadratic

[2] From an engineering perspective, Grover's algorithm offers a square-root speedup in the search of unstructured data. This feature renders it particularly applicable to the analysis of large-scale

improvement, which is significant for applications such as searching through financial data, localized forecasting within market subsets, and evaluating logical conditions (Montanaro, 2016).

Recently, hybrid algorithms such as QAOA (Farhi et al., 2014) and VQE (Peruzzo et al., 2014) have attracted considerable interest, as they combine classical and quantum computing. QAOA aims to find approximate solutions to hard optimization problems, such as resource allocation, logistics, or portfolio management. VQE, on the other hand, is designed to compute eigenvalues of complex observables and finds applications in economic models based on energy-like cost functions (Bharti et al., 2022).

All of the above have shaped a new computational paradigm that expands the boundaries of both theoretical and applied algorithmic thinking.

## Computational Complexity and Quantum Advantage

The evaluation of quantum computing extends to the systematic comparison of its computational complexity with that of classical computational paradigms. At the core of this comparison lie the complexity classes P, NP, and BQP[3].

The class BQP (Bounded-Error Quantum Polynomial Time) defines the set of problems that can be solved by a quantum computer in polynomial time with an error probability of less than 1/3. Although $P \subseteq BQP$, it is not known whether $BQP \subseteq NP$ or whether the two sets intersect. Significant theoretical studies suggest that problems such as integer factorization (Shor's algorithm) lie in BQP but not in P, indicating a potential advantage in selected categories of problems (Bernstein & Vazirani, 1997; Watrous, 2009).

The concept of quantum advantage or quantum supremacy refers to the ability of a quantum system to solve a computational problem faster or more efficiently than any known classical system. In 2019, Google announced that its 53-qubit processor, Sycamore, successfully performed a specially designed sampling task in 200 seconds, which -according to their estimates- would take 10,000 years to complete on a classical supercomputer (Arute et al., 2019). This claim marked a milestone, although it received criticism regarding the practical relevance of the problem used (Pednault et al., 2019).

Similarly, IBM has focused on building scalable architectures, making significant progress in error-corrected logical qubits and modular systems. In December 2023, it announced its roadmap toward reaching 100,000 logical qubits by 2033, emphasizing a gradual transition from the NISQ (Noisy Intermediate-Scale Quantum) era to scalable quantum computing (IBM, 2023). At the same time, companies such as IonQ and Rigetti[4] are developing specialized platforms for quantum cloud computing, enhancing the accessibility of these technologies.

In contrast to classical computational systems, which return deterministic values, quantum systems compute probability amplitudes and yield outcomes only upon measurement. Measurement does not reveal a "hidden" value but induces the collapse of the superposition into one of the possible states – each time potentially a different one (Barad, 2007).

econometric databases, where efficient information retrieval is crucial in the absence of predefined structure.

[3] The complexity classes P, NP, and BQP categorize problems based on how efficiently they can be solved: P includes problems solvable in polynomial time by a classical computer; NP includes problems whose solutions can be verified in polynomial time; and BQP includes problems that can be solved in polynomial time by a quantum computer with a success probability greater than 2/3.

[4] IonQ and Rigetti are cutting-edge technology companies operating in the field of quantum computing, with a focus on hardware development and cloud-based platforms.

A characteristic example is the application of the Hadamard gate to a qubit, which produces an equal-probability superposition of the 0 and 1 states. In an economic model, this would correspond to a condition of intrinsic uncertainty – not due to ignorance of the system's actual state, but because such a state does not exist prior to the act of observation. This marks a radically different form of uncertainty, more closely aligned with *Knightian uncertainty* than with classical statistical variance. Within this framework, information is not merely something to be revealed – it is something that is enacted. Quantum information processing does not simply bring computational acceleration; it foregrounds an epistemological shift in which the very notions of reproduction, measurement, and valuation of information take on a performative character.

Although the full exploitation of quantum advantage in general computational problems remains an open challenge, the rapid advancement of systems and the theoretical foundation provided by BQP point to an emerging post-paradigmatic space, in which quantum systems may operate either complementarily or competitively with classical infrastructures.

## COMPUTATION AS A PILLAR OF ECONOMIC SCIENCE

Traditionally oriented toward the analysis of human behavior and the construction of theoretical models, economic science has been radically transformed over the past 70 years thanks to advances in computational technology. From the numerical simulation of simple models to the widespread use of machine learning algorithms in real-time economic forecasting (Desai, 2023), computation has evolved into a fundamental tool for the production and validation of economic knowledge (Babii, Ghysels, Striaukas, 2023).

To a large extent, computational tools have been integrated into economics, both for theoretical modeling and for empirical analysis. The development of game theory, computational general equilibrium, dynamic stochastic general equilibrium (DSGE) models, macroeconomic forecasting, and econometrics has been made possible by advances in computational power (Judd, 1997; Heer & Maußner, 2011; Rothe, 2023). Computation, therefore, is not an external instrument but a structural component of modern economic thought. This implies that any profound shift in the nature of computational power – such as the one proposed today by quantum computing, has the potential to transform the very foundations of economic theory.

The historical evolution of computation in modern economics can be assumed to include the following periods and trends:

**a) 1950–1980:** The era of numerical models and early simulations on mainframe computers. The DSGE (Dynamic Stochastic General Equilibrium) framework begins to gain traction due to the feasibility of numerical solutions (Damiani, 2025).

**b) 1980–2000:** The spread of personal computers and the advancement of computational tools (e.g., MATLAB, STATA) lead to the widespread use of econometric analyses and empirical modeling (Ooms, 2006; Cameron, 2014).

**c) 2000–present:** The explosion of data (big data), deep learning techniques, and cloud computing infrastructures enables the processing of massive datasets, real-time economic variables, and multi-factor models (Seidou Sanda, 2023).

Modern economic analysis increasingly relies on computational models and algorithms to understand and forecast the dynamics of complex systems. In this context, the study of markets such as energy, telecommunications, and financial products requires multi-factor modeling involving multiple agents interacting with adaptive behaviors (Tesfatsion & Judd, 2006). These multi-level models enable the representation of non-linear relationships and the simulation of strategic choices made by economic actors.

At the same time, the rapid advancement of technology has made algorithmic trading a core operational tool in financial markets. Transactions are now executed on millisecond timescales, driven by automated algorithms and real-time analysis, supported by advanced market microstructure models

(Lehalle & Laruelle, 2013). The speed and computational efficiency of these systems make the application of advanced optimization and forecasting techniques critically important (Zhang et al., 2020).

The computational power of modern cloud and high-performance computing (HPC) infrastructures supports increasingly complex policy simulations. So-called 'what-if' scenarios allow researchers and policymakers to evaluate the potential impacts of different macroeconomic interventions, incorporating nonlinearities and feedback loops across sectors (Fagiolo & Roventini, 2017).

Finally, an increasingly widespread tool is the Agent-Based Modeling (ABM) approach, in which multiple agents with bounded rationality and the capacity for interaction give rise to emergent phenomena that are not readily captured by classical models (Farmer & Foley, 2009). ABMs offer both a new theoretical and practical framework for studying behavioral and evolutionary economics, leveraging the power of simulation and computational complexity.

It appears that the computational mode of thinking – simulation, parameterization, computational complexity – has become the new 'language' of economics. Not merely as a tool, but as a conceptual shift: from static, analytical solutions to dynamic, evolutionary approaches grounded in computation. This foundation raises a legitimate question, if economic thought has already integrated computation as an integral part of its methodology, then its future trajectory may well extend from the classical to the quantum.

## APPLICATIONS OF COMPUTATIONAL POWER IN ECONOMIC DECISION-MAKING

Quantum computing is not merely a faster version of existing classical computational models; rather, it offers a new paradigmatic framework for addressing complex, stochastic, and dynamic problems in economic science. Timely understanding and adaptation of these tools is crucial for both researchers and economic policy-makers. Key components of this framework include:

### Computational Power in Optimization Problems

Many economic problems (such as resource allocation, portfolio design, price auctions, and dynamic pricing) are formulated as complex optimization problems. As the number of variables increases, these problems become computationally intractable for classical computers. This limitation can be overcome through quantum computing, which, by leveraging phenomena such as superposition and entanglement, is capable of simultaneously exploring multiple options and providing exponentially faster solutions for certain classes of problems (Farhi, Goldstone, Gutmann, 2014).

Applications Include:

- Optimization of supply chain flows
- Real-time capital allocation
- Arbitrage detection in high-frequency markets

### Analysis of Large Volumes of Economic Data

Analysis of vast volumes of data -such as those arising from financial transactions, social networks, or real-time sensors tracking economic activity- is computationally intensive.

Quantum machine learning algorithms (such as Quantum Support Vector Machines and Quantum PCA) promise significant speedups in pattern extraction and predictive tasks, including credit risk analysis and macroeconomic trend forecasting (Biamonte et al., 2017).

Moreover, quantum circuits, due to the absence of thermal losses in superconducting environments, offer computational solutions with exceptionally low energy consumption. The development of scalable and fault-tolerant quantum systems is expected to radically reduce the energy

footprint of computational infrastructures – especially when compared to the energy-intensive data centers of classical computing.

### Implications for the Security of the Financial System

Quantum computing poses a threat to current cryptographic standards upon which nearly all economic systems rely (banks, exchanges, and blockchain networks). Shor's decryption algorithm, for instance, could break asymmetric protocols such as RSA, thereby undermining trust in electronic transactions and cryptocurrencies (Shor, 1997).

### Decision Theory and Behavior

Some researchers argue that quantum logic may offer an alternative methodological foundation for decision theory under uncertainty and for economic psychology, particularly in situations where deviations from the rational model are observed, such as violations of the Sure-Thing Principle (Haven & Khrennikov, 2009, 2013).

### Delimitation, Performativity, and Verification Challenges

From a technical standpoint, it is crucial to highlight the limitations of current quantum technology, which act as barriers to the immediate realization of the economic and epistemic visions articulated in this paper. Issues such as decoherence, measurement errors, and the pressing need for effective quantum error correction mechanisms underscore the practical obstacles involved in transitioning to large-scale quantum computational models (Preskill, 2018).

The implementations developed by leading actors in the field -such as IBM, Google, and Quantinuum- remain constrained within the NISQ (Noisy Intermediate-Scale Quantum) paradigm. Consequently, references to performative transformations of economic practice through quantum infrastructure must be articulated with caution and within clearly defined technological boundaries (Preskill, 2018; Arute, et al. 2019).

## DISCUSSION

The dynamic entry of quantum computing into the domain of economics raises questions and possibilities that go beyond the instrumental level. From the reformulation of economic rationality to the collapse of traditional cryptographic systems, and from methodological shifts in modeling to ethical and institutional dilemmas, the transition from classical to quantum systems is not merely technological – it is conceptual, epistemological, and potentially political.

### Quantum Computing and Economic Modeling under Uncertainty

Economic modeling under uncertainty constitutes a cornerstone of modern macroeconomic and microeconomic theory, particularly through dynamic general equilibrium models (DSGE), agent-based modeling (ABM), and complex network-based interaction models. These frameworks seek to capture agent behavior under conditions of informational incompleteness, nonlinearity, and stochastic dynamics. However, as the complexity of economic systems grows exponentially, classical computational methods prove increasingly limited – both in terms of efficiency and in their ability to represent the very nature of uncertainty (Orrell, 2018).

Quantum computing reintroduces the discussion of uncertainty at the very foundation of computation. Unlike classical stochasticity, quantum models rely on the principles of superposition and quantum probability, which do not merely assign uncertainty to values, but embody a simultaneous

multiplicity of states (Schuld & Petruccione, 2018). This logic enables a more natural integration of institutional, behavioral, and informational uncertainty into economic models.

Within this context, quantum algorithms such as the Quantum Approximate Optimization Algorithm (QAOA) and Grover's algorithm offer the potential to solve policy selection, matching, and equilibrium problems with exponential speedup compared to classical methods (Rebentrost, Gupt, & Bromley, 2020). At the same time, quantum annealing platforms such as D-Wave can function as 'quantum simulators' for reproducing the behavior of complex agent-based models, even when no analytical solution is available (Otterbach et al., 2017).

The transition from static and deterministic DSGE models to more adaptive, stochastic, and multi-level systems represents a profound shift in economic thought. Within this new horizon, quantum computing is not merely a more powerful simulation tool; it functions as a transformative mechanism that reconfigures the very framework of uncertainty, revealing new conceptual and methodological possibilities for economic analysis (Baaquie, 2007; Woerner & Egger, 2019).

## Rethinking Rationality: From Homo Economicus to the Quantum Player

The concept of rationality constitutes a fundamental pillar of neoclassical economic theory and policy, with the Homo Economicus embodying a subject driven by self-interest, endowed with stable preferences and the capacity for optimization under conditions of information and computational power (Gazetas & Aznaouridis, 2025). However, empirical research in behavioral economics and decision theory has documented the existence of preference instability, contradictory choices, and cognitive limitations (Kahneman, 2011). These limitations gave rise to Simon's theory of 'bounded rationality,' which, nonetheless, remains situated within the framework of classical logic.

Quantum theory offers an alternative cognitive paradigm. Rather than simply adding noise or error to preferences, it proposes an entirely different mathematical and conceptual foundation: preferences are not expressions of a fixed vector, but superposition states that collapse into specific choices only during the process of observation or decision-making (Busemeyer & Bruza, 2012). This model accounts for phenomena such as contradictory responses, framing effects, and intransitive preferences – phenomena that classical models struggle to explain.

The transition from deterministic behavior to probabilistic cognitive states redefines not only the notion of rationality, but also what constitutes a 'logical' choice. In quantum frameworks, the 'player' can simultaneously occupy multiple cognitive states, with probabilities connected through entangled structures rather than conventional distributions (Haven & Khrennikov, 2013). The mechanism of observation – whether in the form of questioning, information exposure, or environmental context – fundamentally influences the final decision, introducing a new kind of endogenous uncertainty.

The implications of game theory in the quantum context are particularly significant. In the classical approach, a player's strategy is defined by the maximization of expected utility, taking into account the strategies of other players. In the quantum formulation, however, strategies are represented by operators acting on quantum states, and the concept of equilibrium -such as the Nash equilibrium- is redefined in terms of quantum characteristics, including compatibility and correlations between states (Iqbal & Abbott, 2009). At the same time, in utility models, value assessment is no longer a simple linear composition of probabilities, but emerges from the internal dynamics and interactions among potential outcomes.

Political economy is not immune to these shifts. If the 'citizen' or 'economic agent' is no longer a subject with stable preferences, then the meaning of policy intervention, social choice, and regulatory frameworks is also transformed. Decision-making ceases to be a point in a predefined choice set and becomes a process of collapsing a space of possible multiplicities. Economic policy must now account not only for incentives, but also for the architecture of the cognitive state in which agents operate (Pothos & Busemeyer, 2013).

## Cryptography and Financial Security in the Quantum Realm

The emergence of quantum computing capability brings about fundamental transformations in the way digital transaction security is approached. Shor's renowned algorithmic proposal (1994), which solves integer factorization and discrete logarithm problems in polynomial time, signals an impending collapse of most classical asymmetric cryptosystems such as RSA, ElGamal, and ECC. This critical development has serious implications for financial infrastructures, where the security of authentication and signatures relies on these methods.

Recognizing the threat, an emerging field of post-quantum cryptography (PQC) has taken shape, aiming to develop algorithms resilient to attacks by quantum computers. Since the launch of the NIST initiative (Chen et al., 2016), new solutions have been proposed, such as lattice-based cryptosystems (e.g., Kyber, Dilithium) – which promise to preserve the confidentiality and integrity of communications even in the era of quantum computational power.

However, a mere substitution of algorithms is not sufficient. The transition to a quantum-secure financial ecosystem requires a radical restructuring of the digital infrastructure underlying transactions, including blockchain technologies, digital currency systems, and interbank clearing mechanisms. Despite the apparent integrity of distributed ledger networks, many existing implementations rely on cryptographic signatures that are vulnerable to future quantum attacks (Aggarwal et al., 2017).

The temporal asymmetry between the maturation of the threat (the gradual progress toward a universally practical quantum computer) and the slow institutional response constitutes a critical challenge. On one hand, adversaries can already implement 'harvest now, decrypt later' strategies, recording sensitive data to decrypt once the technology allows. On the other hand, adopting new protocols requires time, resources, and systemic harmonization on a global scale.

This gap raises the question of whether technology can continue to guarantee trust when its very cryptographic foundation is under threat. The answer is far from self-evident. On the contrary, it reveals the need for multi-layered institutional fortification that does not rely solely on computational assumptions. A combination of post-quantum algorithms, controlled revocation-validation mechanisms, and potentially quantum key distribution (QKD) could help establish a new, resilient framework of trust (Mosca, 2018). From this perspective, the technological transition must be holistic and anticipatory, rather than reactive.

## Applied Practices, Methodological Instruments, and Ethical Dilemmas

Quantum technology, transcending its theoretical framework, has begun to acquire a practical dimension through platforms and tools that enable experimentation in applied domains of the economic sector. Environments such as IBM's Qiskit and D-Wave's Leap SDK[5], offer capabilities for the development and simulation of quantum algorithms, providing access to quantum backends (gate-based or quantum annealing) for real computations (Cross et al., 2017; D-Wave Systems, 2023).

New horizons are thus opening for economic modeling. Scenarios such as demand forecasting, credit scoring, and dynamic pricing can be reformulated as optimization or classification problems, leveraging quantum properties such as superposition and entanglement. Already, studies have shown

[5] These are tools that allow programs to be written and executed on quantum computers. IBM's Qiskit is an open-source software library written in Python, which runs on IBM's real quantum computers via the cloud. It can be considered a toolkit for building a complex project from the ground up. D-Wave's Leap SDK is a cloud-based platform that enables the development of programs designed to solve optimization problems – i.e., problems where the goal is to find the best solution among many alternatives.

that, on limited datasets, hybrid (quantum-classical) models can compete with conventional deep learning systems in terms of both accuracy and speed (Havlíček et al., 2019; Orús et al., 2019).

Researchers are gaining the ability to test experimental algorithms or applications for quantum computers on real-world economic problems, such as investment strategies and risk management. This allows them to explore whether such solutions could attain practical value in the future, even though full quantum advantage in these domains remains a distant goal. The significance here is not merely technical, but also methodological and ethical in nature.

One of the critical issues is transparency. In the field of Explainable AI (XAI)[6], the transition to quantum systems complicates interpretability. Computational states are no longer merely weight matrices or decision graphs, but combinations of wavefunctions – something that directly challenges human understanding of decisions (Gili et al., 2023). This raises the question: how do we explain a credit prediction when it results from a quantum entanglement of states?[7]

Moreover, quantum economic power[8] is not equally distributed. The construction and access to quantum systems require vast resources, further reinforcing existing geopolitical and economic inequalities (Zeng et al., 2022). The question becomes more pressing: who has access to quantum computational capabilities for economic forecasting and analysis? And what does "quantum influence" mean when only a handful of platforms can affect global markets through opaque, black-box infrastructures?

The era of quantum technology does not merely introduce new technical capabilities; it also raises critical issues of trust, interpretability, and institutional fairness. The role of the scientific community is to ensure that quantum applications do not become opaque instruments of power, but rather open and accountable methods deployed for the public good.

## CONCLUSIONS AND SCIENTIFIC OUTLOOK

Quantum computing is not merely an additional technological tool added to the arsenal of economic analysis; it represents a profound challenge to the very conceptual and computational framework of the discipline. The shift from classical deterministic logic to a domain governed by superposition, entanglement, measurement irreversibility, and non-locality makes it evident that the foundational principles of traditional economic theory -such as stable rationality, predictability, and local causality- are no longer sufficient. Economic reasoning, as shaped by the mathematization of the 20th century and the rise of data-driven statistical approaches, is currently undergoing an epistemological reconfiguration.

This emerging reality calls for deep interdisciplinary collaboration. Articulating and understanding the concept of a "quantum economy" requires the joint efforts of physicists, economists, computer scientists, and philosophers of science. Questions such as: What is information? How choice is defined when alternatives are not discrete but exist in superposition? What does rationality mean when the very act of measurement affects the outcome? These cannot

[6] It is a form of artificial intelligence that provides not only answers, but also explanations.

[7] In other words, how can we explain a credit approval decision when it is not based on simple, understandable rules, but on complex quantum relationships between data?

[8] The potential to transform the economy and gain strategic advantage through the utilization of quantum technological capabilities.

be answered unidimensionally. Rather, they demand philosophical reflection, computational modeling, and physical grounding.

The development of research infrastructures that transcend the narrow boundaries of individual disciplines is of vital importance. Quantum economics labs – spaces where researchers from diverse fields can collaborate using shared infrastructures and a common conceptual language – may constitute a turning point in scientific inquiry. Illustrative issues these interdisciplinary teams are called to explore include:

- How quantum decision-making models can be implemented in real-time economic environments.
- What role quantum uncertainty plays in markets, and how it reshapes risk theory.
- What kind of institutional and political framework can be envisioned in a post-classical era of economic computability.

At the same time, it is essential to develop politically oriented, policy-focused research programs that examine the social, institutional, and ethical implications of introducing quantum technologies into the economic domain. Issues such as the unequal distribution of quantum computational power, the black-box nature of infrastructural systems, and the limited interpretability of decisions make democratic accountability and institutional transparency all the more urgent.

Ultimately, quantum computing is not merely a new form of data processing; it constitutes a new epistemological regime. Its penetration into economic thought and practice compels us to re-signify fundamental concepts such as what it means to "compute," "predict," or "choose." If we rise to this challenge with critical insight, interdisciplinary collaboration, and institutional vigilance, we may find ourselves before a historical opportunity to redefine economic reasoning on the basis of the most fundamental principles of physical reality.

## SUGGESTED DIRECTIONS FOR FUTURE RESEARCH

**Establishment of Quantum Economics Laboratories:**

- Pilot development of hybrid models (classical and quantum) for financial forecasting.
- Experimental research on decision-making under multi-state uncertainty environments.

**Investigation of Epistemological Shifts:**

- Comparative analysis between classical and quantum rationality.
- Ontological and epistemological grounding of information within economic frameworks.

**Policy Studies and Social Impact Assessments:**

- Quantification of the unequal distribution of access to quantum computational power.
- Governance scenarios for quantum technology in global economic networks.

**Education and Dissemination Tools:**

- Development of open-access educational resources in quantum economics.
- Organization of collaborative or competitive technological workshops (hackathons) focusing not only on technical innovation but also on ethical foresight.

## REFERENCES

Aggarwal, D., Brennen, G. K., Lee, T., Santha, M., & Tomamichel, M. (2017). *Quantum attacks on Bitcoin, and how to protect against them*. arXiv preprint arXiv:1710.10377.

Arute, F., Arya, K., Babbush, R., et al. (2019). Quantum supremacy using a programmable superconducting processor. *Nature*, 574(7779), 505–510.

Baaquie, B. E. (2007). *Quantum Finance: Path Integrals and Hamiltonians for Options and Interest Rates*. Cambridge University Press.

Babii, A., Ghysels, E., & Striaukas, J. (2023). *Econometrics of machine learning methods in economic forecasting*. arXiv. Retrieved: June 16, 2025 from https://arxiv.org/pdf/2308.10993

Bernstein, E., & Vazirani, U. (1997). *Quantum complexity theory*. SIAM *Journal on Computing*, 26(5), 1411–1473.

Bharti, K., Cervera-Lierta, A., Kyaw, T. H., Haug, T., Alperin-Lea, S., Anand, A., Degroote, M., Lau, H. K., Sim, S., & Aspuru-Guzik, A. (2022). Noisy intermediate-scale quantum (NISQ) algorithms. *Reviews of Modern Physics*, 94(1), 015004. Retrieved on June, 15, 2025 from https://doi.org/10.1103/RevModPhys.94.015004

Biamonte, J., Wittek, P., Pancotti, N., Rebentrost, P., Wiebe, N., & Lloyd, S. (2017). Quantum machine learning. *Nature*, 549(7671), 195–202. Retrieved on June 14, 2025, from https://doi.org/10.1038/nature23474

Bravyi, S., Gambetta, J. M., & Temme, K. (2022). Obstacles and opportunities in quantum computing. *Nature Physics*, 18, 1053–1058. Retrieved on June 14, 2025, from https://doi.org/10.1038/s41567-022-01628-0

Busemeyer, J. R., & Bruza, P. D. (2012). *Quantum models of cognition and decision*. Cambridge University Press.

Cameron, A. C. (2014). *Microeconometrics and Stata over the past thirty years*. University of California, Davis. Retrieved on June, 16, 2025, from

https://faculty.econ.ucdavis.edu/faculty/cameron/research/Stata_Microeconometrics_08282014.pdf

Chen, L., Jordan, S., Liu, Y. K., Moody, D., Peralta, R., Perlner, R., & Smith-Tone, D. (2016). *Report on Post-Quantum Cryptography*. National Institute of Standards and Technology (NIST).

Cross, A. W., Bishop, L. S., Smolin, J. A., & Gambetta, J. M. (2017). *Open quantum assembly language*. arXiv preprint arXiv:1707.03429.

Damiani, G. M. (2025). *An essay on the history of DSGE models*. arXiv. Retrieved on June 17, 2025, from https://arxiv.org/abs/2409.00812

Desai, A. (2023). *Machine learning for economics research: When, what, and how?* arXiv. Retrieved, on June 16, 2025, from https://arxiv.org/abs/2304.00086

D-Wave Systems. (2023). *Leap SDK Documentation*. Retrieved on June 17, 2025, from https://docs.dwavesys.com

Fagiolo, G., & Roventini, A. (2017). Macroeconomic policy in DSGE and agent-based models redux: New perspectives and challenges ahead. *Journal of Artificial Societies and Social Simulation*, 20(1). Retrieved on June 18. 2025, from https://doi.org/10.18564/jasss.3310

Farhi, E., Goldstone, J., & Gutmann, S. (2014). A quantum approximate optimization algorithm. *arXiv preprint arXiv:1411.4028*. Retrieved on July, 10, 2025, from https://doi.org/10.48550/arXiv.1411.4028

Farmer, J. D., & Foley, D. (2009). The economy needs agent-based modelling. *Nature*,460(7256), 685–686.

Gazetas, I. & Aznaouridis, I. (2025). Human and Divine Economy in Dialectical Relation: An Interdisciplinary Approach, *International Journal of Social Science Research and Review*,

Gili, K., Perdomo, O., & Alonso, J. M. (2023). *Explainability in quantum machine learning: Status, challenges, and future directions*. Quantum Reports, 5(1), 101–124. Retrieved, on June 17, 2025, from https://doi.org/10.3390/quantum5010006

Griffiths, D. J., & Schroeter, D. F. (2018). *Introduction to quantum mechanics* (3rd ed.). Cambridge University Press.

Grover, L. K. (1996). A fast quantum mechanical algorithm for database search. In *Proceedings of the twenty-eighth annual ACM symposium on Theory of computing* (pp. 212–219).

Haven, E., & Khrennikov, A. (2009). Quantum mechanics and violations of the sure-thing principle: The use of probability interference and other concepts. *Journal of Mathematical Psychology*, 53(5), 378–388.

Haven, E., & Khrennikov, A. (2013). *Quantum Social Science*. Cambridge University Press.

Havlíček, V., Córcoles, A. D., Temme, K., Harrow, A. W., Kandala, A., Chow, J. M., & Gambetta, J. M. (2019). Supervised learning with quantum-enhanced feature spaces. *Nature*, 567(7747), 209–212. Retrieved on June 17, 2025, https://doi.org/10.1038/s41586-019-0980-2

Heer, B., & Maußner, A. (2011). *Dynamic general equilibrium modelling: Computational methods and applications*. Springer.

IBM. (2023). *IBM Quantum Development Roadmap*. Retrieved on June 15, 2025 from https://research.ibm.com/blog/ibm-quantum-development-roadmap

Iqbal, A., & Abbott, D. (2009). Quantum games and quantum strategies. *Physics Letters A*, 374(4), 315–319.

Judd, K. L. (1997). Computational economics and economic theory: Substitutes or complements? *Journal of Economic Dynamics and Control*, 21(6), 907–942.

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.

Ladd, T. D., Jelezko, F., Laflamme, R., Nakamura, Y., Monroe, C., & O'Brien, J. L. (2010). Quantum computers. *Nature*, 464(7285), 45–53. Retrieved on June 13, 2025, from https://doi.org/10.1038/nature08812

Lehalle, C. A., & Laruelle, S. (2013). *Market microstructure in practice*. World Scientific Publishing.

Montanaro, A. (2016). Quantum algorithms: An overview. npj *Quantum Information*, 2, 15023. Retrieved on June 15. 2025, from https://doi.org/10.1038/npjqi.2015.23

Mosca, M. (2018). *Cybersecurity in an era with quantum computers: Will we be ready?* IEEE Security and Privacy, 16(5), 38–41. Retrieved on June 17, 2025, from https://doi.org/10.1109/MSP.2018.3761723

Nielsen, M. A., & Chuang, I. L. (2010). *Quantum computation and quantum information* (10th Anniversary ed.). Cambridge University Press.

Ooms, M. (2006). Econometric software development: Past, present and future. *Statistica Neerlandica*, 60(2), 225–256.

Orrell, D. (2018). *Quantum economics: The new science of money*. Icon Books.

Orús, R., Mugel, S., & Lizaso, E. (2019). Quantum computing for finance: Overview and prospects. *Reviews in Physics*, 4, 100028. Retrieved on June 17, 2025, (17/6/25) from, https://doi.org/10.1016/j.revip.2019.100028

Otterbach, J. S., et al. (2017). Unsupervised machine learning on a hybrid quantum computer. *arXiv preprint*. Retrieved on June 19, 2025, from https://arxiv.org/abs/1712.05771

Pednault, E., Gunnels, J. A., Nannicini, G., Horesh, L., Magerlein, T., Solomonik, E., & Gambetta, J. M. (2019). *Leveraging secondary storage to simulate deep 54-qubit Sycamore circuits*. arXiv:1910.09534

Peruzzo, A., McClean, J., Shadbolt, P., Yung, M.-H., Zhou, X.-Q., Love, P. J., ... & O'Brien, J. L. (2014). A variational eigenvalue solver on a photonic quantum processor. *Nature Communications*, 5, 4213. Retrieved June, 15, 2025 from https://doi.org/10.1038/ncomms5213

Pothos, E. M., & Busemeyer, J. R. (2013). Can quantum probability provide a new direction for cognitive modeling? *Behavioral and Brain Sciences*, 36(3), 255–274.

Preskill, J. (2018). Quantum Computing in the NISQ era and beyond. *Quantum*, 2, 79. Retrieved on June 13, 2025, from https://doi.org/10.22331/q-2018-08-06-79

Rebentrost, P., Gupt, B., & Bromley, T. R. (2020). Quantum computational finance: Monte Carlo pricing of financial derivatives. *Physical Review A*, 101(1), 012305.

Rieffel, E. G., & Polak, W. H. (2011). *Quantum computing: A gentle introduction*. MIT Press.

Roffe, J. (2019). *Quantum computing: An overview across the system stack*. Computing Research Repository (CoRR). arXiv:1905.00282

Rothe, J. (2023). *Economics and computation: An introduction to algorithmic game theory, computational social choice, and fair division* (2nd ed.). Springer

Schuld, M., & Petruccione, F. (2018). *Supervised learning with quantum computers*. Springer. https://doi.org/10.1007/978-3-319-96424-9

Schuld, M., & Petruccione, F. (2021). *Machine learning with quantum computers* (2nd ed.). Springer.

Seidou Sanda, I. (2023). *Nowcasting GDP using Big Data and Machine Learning*. United Nations Economic Commission for Africa. Retrieved on June 16, 2025, from https://www.uneca.org/eca-events/sites/default/files/resources/documents/acs/stats-talk/2023-10-31/nowcasting_gdp_issoufou_seidou_sanda.pd

Shor, P. W. (1997). Polynomial-time algorithms for prime factorization and discrete logarithms on a quantum computer. *SIAM Journal on Computing*, 26(5), 1484–1509. Retrieved on June, 15, 2025, from https://doi.org/10.1137/S0097539795293172

Tesfatsion, L., & Judd, K. L. (Eds.). (2006). *Handbook of computational economics: Agent-based computational economics* (Vol. 2). Elsevier.

Watrous, J. (2009). *Quantum computational complexity*. In *Encyclopedia of Complexity and Systems Science* (pp. 7174–7201). Springer.

Woerner, S., & Egger, D. J. (2019). Quantum risk analysis. *npj Quantum Information*, 5(1), 1–8. Retrieved on June 20, 2025, from https://doi.org/10.1038/s41534-019-0130-6

Zhang, Y., Zohren, S., & Roberts, S. (2020). *Deep learning for algorithmic trading: A survey*. arXiv. Retrieved on June18, 2025, from https://arxiv.org/abs/2007.12586

Zeng, W., Huang, Y., & Liu, J. (2022). Quantum technology and global security: A systemic assessment. *Journal of Cyber Policy*, 7(2), 185–204.

**How to cite this article:**

Aznaouridis, C., & Aznaouridis, I. (2025). Quantum Computing and Its Implications for Theoretical and Applied Economics: From Shor's Algorithm to Models of Uncertainty. *International Journal of Digital Research*, E-ISSN: 3033-179X, Vol. 1(4): 8–22. https://doi.org/10.63711/ijdr.net20250401

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Review Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 23-43*

# Virtual Security Risks During Tourist Travel. A Cyber-Security Guide for Travelers

**Vladimir Karadzhov[1], Radost Yuleva-Chuchulayna[2]**

[1] Chief Assistant Professor, PhD (Economic and Social Geography), Department of Geography, Ecology, and Environmental Protection, Faculty of Mathematics and Natural Sciences
[2] Chief Assistant Professor, PhD (Economics and Management), Department of Business Management and Marketing, Faculty of Economy
[1, 2] South-West University "Neofit Rilski" – Blagoevgrad
ORCID IDs: [1] 0000-0002-7514-5517 [2] 0000-0002-0755-5776

Corresponding Author: Vladimir Karadzhov, karadzhov@swu.bg

https://doi.org/10.63711/ijdr.net20250402

## ABSTRACT

This article investigates the growing virtual security risks in tourism that accompany the rapid expansion of digital technologies and online travel services. It examines the most critical cyber threats affecting tourists and businesses – such as phishing, financial fraud, data breaches, and manipulation of digital travel documents – and evaluates their implications for trust, safety, and economic stability within the tourism sector. Using a mixed-methods approach combining qualitative case studies and quantitative data from cybersecurity reports, the study identifies the most prevalent incidents and their regional dynamics. Special attention is given to emerging solutions including blockchain-based verification systems, artificial-intelligence-driven fraud detection, and biometric authentication, which offer promising mechanisms for mitigating digital risks. The article also presents a concise ten-step cybersecurity guide for tourists, offering practical measures to enhance personal digital safety while traveling. By aligning theoretical insights with actionable recommendations for both tourists and industry stakeholders, the paper contributes to the development of a secure digital ecosystem that supports sustainable and technologically resilient tourism worldwide.

***Keywords:*** *Cybersecurity in tourism, Phishing and financial fraud, Data breaches, Digital resilience, Sustainable travel technologies* ***JEL Codes:*** *Z32, O33, L86, M15, Q01*



## INTRODUCTION

Security has become an indispensable aspect of modern tourism, especially with the rapid integration of digital technologies into every stage of the travel process. Online booking systems, mobile applications, and electronic documentation have transformed how people plan, experience, and evaluate travel, providing unprecedented convenience and efficiency. Platforms such as Booking.com, Airbnb, and Expedia manage millions of transactions daily, connecting travelers with service providers across

borders in a matter of seconds. However, this seamless digital experience also exposes tourists to a variety of virtual threats, including identity theft, phishing, ransomware, and fraudulent bookings that can cause both financial and psychological harm.

The urgency of addressing these emerging virtual risks is underscored by the accelerating digitalization of the global travel economy. According to the World Economic Forum and Statista (2024), the global tourism industry handles billions of digital interactions each year, while over 70% of tourists rely on smartphones for navigation, bookings, and payments. This dependence on online systems creates a fertile environment for cybercriminals. In 2023 alone, global losses related to cybercrime exceeded 10 trillion USD, and hospitality ranked among the top five targeted industries. Phishing campaigns exploiting fake booking confirmations, data breaches in airline systems, and ATM skimming in tourist destinations have become widespread phenomena, undermining consumer trust and business reputations.

Moreover, the convergence of digital transformation and mass tourism has made cybersecurity not merely a technical issue but a strategic component of sustainable destination management. Destinations increasingly compete not only through physical safety and service quality but also through the perceived digital safety of their infrastructure. A single large-scale cyberattack can compromise thousands of bookings, disrupt transport systems, and damage the image of entire destinations. Consequently, tourism operators, governments, and travelers themselves must adopt proactive cybersecurity strategies, emphasizing prevention, awareness, and rapid response. This article investigates the nature of virtual risks in tourism by categorizing them into financial, technical, and document-related threats. It further explores innovative technologies and best practices that can enhance cybersecurity resilience, such as blockchain-based systems, AI-driven detection tools, and biometric verification methods. The overall objective is to bridge theoretical understanding with practical measures to ensure a safer, more trustworthy digital travel ecosystem for both individuals and businesses in the tourism industry.

## RESEARCH METHODOLOGY

This study employs a mixed-methods approach to comprehensively explore virtual security risks in tourism.

### Qualitative Analysis

A descriptive qualitative method is utilized to delve into specific threats facing tourists in the digital realm. Case studies, such as phishing attacks targeting hotel reservations and compromised public Wi-Fi networks, provide contextual depth to the identified risks.

### Quantitative Analysis

The quantitative component incorporates secondary data from reputable industry reports, cybersecurity surveys, and government publications. Data points include the frequency of cyber-attacks, financial losses incurred by the tourism sector, and consumer behavior patterns related to digital security. Sources such as the Norton Cyber Safety Insights Report and the World Economic Forum's Global Risks Report have been instrumental.

### Case Study Analysis

To provide a practical perspective on the virtual risks affecting tourists, the research incorporates a case study analysis of incidents in prominent tourist destinations. These case studies highlight real-world scenarios of digital fraud, cyber-attacks, and other virtual threats in the tourism sector.

For instance, the study examines a 2023 case in Bali, Indonesia, where skimming devices installed on ATMs in tourist areas resulted in significant financial losses for unsuspecting travelers. Additionally, it analyzes the impact of phishing emails that targeted hotel reservations in Europe, causing both monetary and reputational damage to hospitality businesses. Also, 81% of organizations experienced increased cyber threats during the pandemic (Business Wire, 2021).

These case studies underscore the importance of proactive cybersecurity measures in mitigating such threats. By grounding theoretical insights in real-world examples, the research offers actionable recommendations for both tourists and industry stakeholders.

**Research Objectives**

- Identify the primary virtual risks affecting tourists in the digital age.
- Analyze the impact of these risks on tourists and the tourism industry.
- Evaluate current technologies and trends in cybersecurity that can mitigate these risks.
- Provide actionable recommendations for tourists and industry stakeholders.

By combining illustrative case studies with data-driven insights, the research bridges the gap between theoretical risk identification and practical implications for the tourism industry.

## VIRTUAL RISKS IN TOURISM

Virtual risks in tourism refer to the wide range of digital threats that emerge during the preparation, booking, and execution of a trip. As tourism becomes increasingly dependent on online platforms, mobile applications, digital payment systems, cloud-based services, and AI-driven tools, travelers are more exposed than ever to security vulnerabilities. These risks do not arise from physical interactions or traditional travel challenges, but from the digital environment in which modern tourism now operates. They can affect personal data, financial information, travel documents, communication channels, and even the overall safety of the trip. Understanding their nature is essential for both consumers and tourism providers, as the consequences may extend beyond minor inconveniences and evolve into financial losses, identity theft, or compromised travel arrangements.

The tourism industry's digital transformation has significantly enhanced traveler convenience but has concurrently introduced a spectrum of virtual risks. These risks can jeopardize personal data, financial assets, and the overall travel experience for tourists while damaging the reputation and operations of businesses.

### Defining Virtual Risks

Virtual risks in tourism refer to security threats that emerge due to the reliance on digital platforms and technologies throughout the travel process. These risks can compromise personal, financial, and digital assets of both tourists and businesses, ultimately affecting the overall travel experience (Fig. 1).
**Key Types of Virtual Risks Include:**

**Identity Theft**

One of the most common forms of virtual risk is the unauthorized collection, misuse, or theft of personal data. When travelers create accounts on booking platforms, connect to airport Wi-Fi networks, submit passport details online, or store boarding passes on their devices, they generate a digital trail that can be exploited by malicious actors. Cybercriminals may intercept communications, install hidden malware, or access accounts through weak passwords, resulting in stolen identities or fraudulent transactions.

Identity theft occurs when unauthorized individuals gain access to personal information, such as passports, payment card data, or social media credentials.Example: In 2022, a data breach at a major online travel agency resulted in the exposure of over 10 million customer records, including names, travel itineraries, and payment details (Statista, 2023). Victims of identity theft often face financial losses, legal issues, and reputational damage. According to the Identity Theft Resource Center, the average cost of recovery per individual is approximately $1,300.

**Phishing Attacks**

Another significant virtual risk lies in the manipulation of online reservations. Errors in booking systems, unauthorized changes to itineraries, and fake confirmation emails may lead to cancelled flights, duplicated bookings, or incorrect check-in times. In some cases, fraudulent travel websites mimic legitimate platforms, causing users to submit payments or personal information to criminal groups. Such incidents can disrupt the entire travel experience and may even leave tourists stranded without valid accommodation or transportation.

Phishing attacks target travelers through deceptive emails, texts, or websites designed to steal sensitive information. In 2023, a phishing scam impersonating a major hotel chain targeted over 50,000 tourists globally. Victims received fake booking confirmation emails asking for deposits via unauthorized payment links. Quantitative Insight: A survey by IBM (2023) revealed that 45% of phishing scams during the past year targeted industries linked to hospitality and tourism.

**Financial Fraud**

Financial fraud encompasses unauthorized transactions, overcharging by malicious vendors, and theft due to insecure payment systems. The increased use of digital payment systems also introduces potential vulnerabilities. Tourists often rely on contactless payments, virtual wallets, and online transactions during their trips. While these technologies offer convenience, they may also be targeted by phishing attempts, credit-card skimming, and malware-based interference. Fraudulent transactions can occur within seconds, especially when the traveler is connected to unsecured wireless networks in airports, hotels, or cafés.

Case Study: Tourists in Southeast Asia reported incidents of ATM skimming in popular destinations like Bali and Bangkok, where hidden devices recorded card data and PINs. In a single operation, losses exceeded $5 million (VISA Agency, Bali, 2023). Global Statistics: The Global Anti-Fraud Alliance estimates that financial fraud in tourism contributed to $12 billion in global losses in 2022 alone.

**Additional Dimensions of Virtual Risks:**

A further virtual risk relates to cloud-stored travel documents and mobile applications that support navigation, translation, and itinerary management. If these apps malfunction, operate offline, or become compromised by malware, travelers may lose access to essential information. Additionally, unauthorized access to cloud accounts may expose sensitive documents such as passports, vaccination certificates, insurance policies, or visa approvals.

Finally, the rise of artificial intelligence and automated customer-service tools brings new challenges. AI-powered chatbots may provide inaccurate travel information, while deepfake content or manipulated images can mislead users into trusting unreliable sources. Automated systems may also make errors in risk assessments, leading to confusion during border control or check-in procedures.

In summary, virtual risks in tourism are multifaceted and continuously evolving. They arise from the digital tools that make travel faster and more accessible, but also more vulnerable. Addressing these

risks requires awareness, updated security practices, and responsible digital behavior from both travelers and tourism providers (Boutin, 2021).

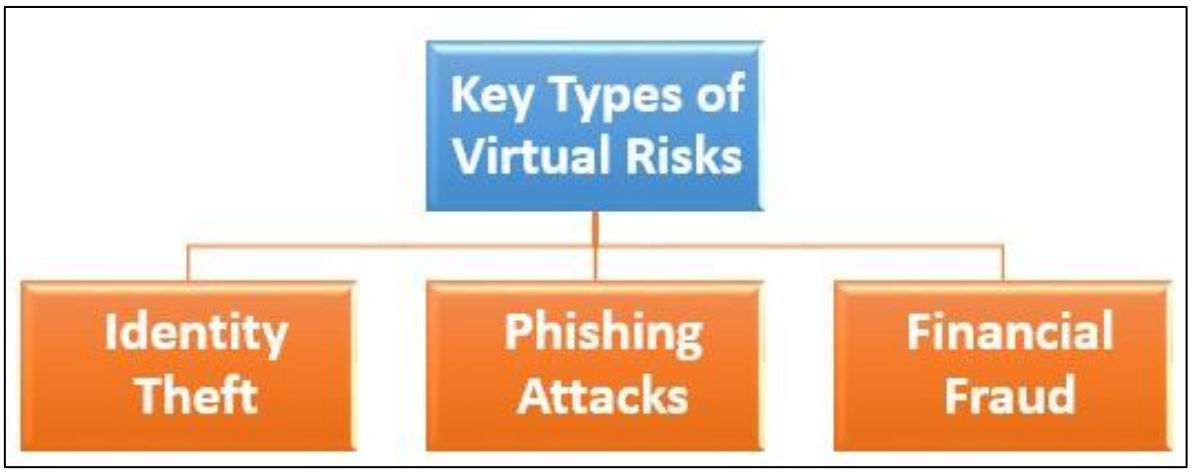


Fig. 1. Main Types of Virtual Risks. *Source: The Authors*

## Categories of Virtual Risks

Virtual risks in tourism can be broadly grouped into three main categories: financial risks, technical risks, and document or logistical risks. Each category reflects a particular domain of vulnerability that travelers and tourism businesses must address in an increasingly digitalized environment. The following subsections discuss these categories in detail, illustrating how they manifest during real travel situations and why they represent significant challenges for the tourism sector.

### A) Financial Risks

Financial risks involve the loss of money or financial data through various cyber-enabled crimes. These are among the most prevalent and damaging virtual risks in tourism.

#### ATM and Electronic Wallet Hacking

One of the most common forms of financial risk involves ATM and electronic wallet hacking. Tourists depend heavily on withdrawing money from local ATMs or using digital wallets abroad, making them vulnerable to interception. In 2023, authorities in Bali uncovered sophisticated skimming devices installed on ATMs located in busy tourist districts. These devices recorded card information and PIN numbers, ultimately causing losses estimated at over five million dollars (VISA Agency, Bali, 2023).

Such incidents reinforce findings from a Norton (2023) survey, where 65% of travelers reported feeling unsafe when using foreign ATMs due to possible skimming attempts. Digital wallet theft, often involving cloned QR codes or malware-infected payment terminals, has followed similar patterns.

#### Phishing Attacks in Hospitality

Another major financial threat is linked to phishing attacks targeting hospitality services. Cybercriminals routinely imitate hotel chains, booking platforms, or travel agencies, sending deceptive emails or messages containing fake confirmations, false refund requests, or fraudulent payment instructions. A notorious 2022 phishing campaign carried out by the cybercrime group TA558

successfully misled more than 10,000 travelers into transferring deposits for accommodations that did not exist (Gallagher, 2022).

Symantec reported that phishing attempts accounted for 35% of all cyber incidents recorded within the hospitality sector in the same year, demonstrating the scale of this growing problem. Many tourists fall victim because phishing messages closely resemble legitimate correspondence, often appearing during stressful planning stages of the trip.

**Fraudulent Payment Systems**

Financial losses also occur through fraudulent payment systems, which deceive travelers into completing transactions on fake gateways or with unverified vendors. As contactless payment methods expand, cybercriminals have developed counterfeit QR codes and cloned payment links.

In 2024, numerous tourists visiting popular European landmarks were scammed after unknowingly scanning fraudulent QR codes at ticket booths, public information signs, or restaurant tables, leading to unauthorized withdrawals between $50 and $1,000. Such schemes exploit travelers' trust in quick and convenient payment mechanisms, particularly when language barriers or unfamiliar surroundings limit their ability to detect fraud.

**B) Technical Risks**

Technical risks arise from weaknesses in digital infrastructure, devices, and software used by tourists throughout their journeys. As travelers rely heavily on smartphones, travel apps, navigation tools, and wireless networks, cybercriminals increasingly target these systems to access sensitive data or disrupt travel plans.

**Public Wi-Fi Exploitation**

One of the most widespread technical vulnerabilities relates to public Wi-Fi exploitation. Travelers routinely connect to open Wi-Fi networks in airports, cafés, hotels, and transportation hubs, often without considering the security risks. Hackers set up malicious hotspots disguised as legitimate access points to intercept data such as passwords, credit card details, or personal messages.

For example, in several Australian airports, fraudulent Wi-Fi networks created in lounge areas enabled cybercriminals to capture large volumes of traveler data, exposing users to identity theft and financial fraud (Travel Pug, 2024a). Kaspersky (2023) reported that 55% of tourists connect to public Wi-Fi without any security protection, illustrating how widespread and preventable such risks are (Kaspersky, 2017).

**Malicious Applications and Software**

Another technical risk involves malicious applications and software, which are often downloaded by tourists seeking discounted tours, convenient itineraries, or local navigation tools. In 2023, a malicious travel application claiming to offer discounted tours across Europe was downloaded more than 50,000 times before Google Play removed it for harvesting user credentials.

Similar apps have been known to include spyware, location-tracking features, or embedded malware that compromises mobile devices. Tourists often fail to verify the authenticity of these apps because they are in a hurry or unfamiliar with local digital ecosystems.

**Tampered GPS and Navigation Tools**

A more advanced form of technical manipulation concerns tampered GPS systems and navigation tools. Criminals can intercept or alter map data to redirect tourists toward unsafe locations, unofficial

transportation services, or fraudulent vendors. In 2022, several visitors in Tokyo unknowingly used compromised navigation applications that redirected them to unauthorized taxi services, resulting in inflated fares, theft, or loss of personal belongings. Such incidents demonstrate that cyber interference with navigation tools can cause both financial harm and physical safety risks, especially in large metropolitan areas where tourists heavily depend on their devices for orientation.

**C) Document and Logistical Risks**

Document and logistical risks refer to problems involving digital travel documents, booking records, reservation confirmations, or transportation logistics. As travel documentation increasingly shifts to electronic formats, its manipulation or illegitimate duplication presents significant challenges.

**Fake Booking Platforms**

A prominent threat in this category is the growing number of fraudulent booking platforms (Yallop et al., 2023). These platforms imitate legitimate accommodation websites or well-known travel agencies, offering attractive deals that lure tourists into making payments for properties or services that do not exist.

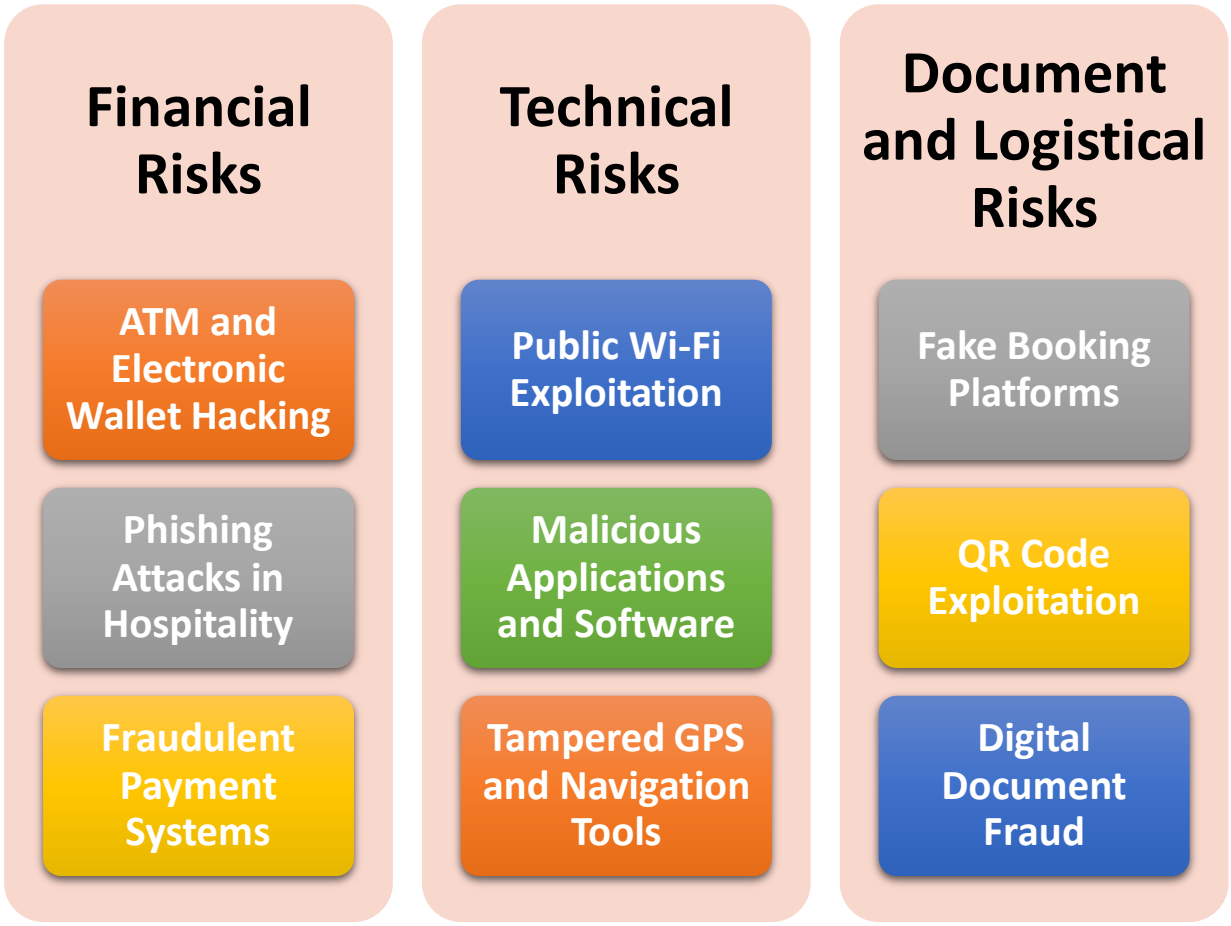


Fig. 2. Main Categories of Virtual Risks. *Source: The Authors*

In 2023, a major scam involving fake Airbnb-style platforms targeted travelers across Europe, leaving thousands stranded without accommodation despite having paid in advance (Travel Pug, 2024b). CyberSafe Travel (2024) reported that one in five tourists has encountered a fraudulent booking platform at least once, highlighting how widespread the issue has become.

These scams often employ sophisticated visual designs and manipulated customer reviews, making them difficult to detect even for experienced travelers.

**Digital Document Fraud**

The increasing reliance on e-visas, tickets, and other digital documents has led to incidents of forgery and corruption. Document-related risks also include unauthorized changes to flight itineraries, digital passport theft, and compromised check-in data stored in poorly secured cloud systems. If these digital records are altered or deleted, tourists may face denied boarding, duplicate bookings, or delays at border control. Manipulated travel documents can also be used by criminals for identity theft, extending the consequences beyond the immediate trip.

**QR Code Exploitation**

Scammers use QR codes on travel documents or guides to redirect tourists to phishing websites. Example: In Southeast Asia, fake QR codes on travel brochures led users to malicious sites that stole personal information. These categories demonstrate the diverse and evolving nature of virtual risks in tourism, emphasizing the need for robust awareness and mitigation strategies for tourists and businesses alike.

## The Evolution of Risks with Digitalization

The rapid expansion of digital technologies within the tourism sector has significantly broadened the range of potential vulnerabilities exploited by cybercriminals. As online booking systems, mobile applications, smart hotel infrastructure, and digital payment solutions become integral to the travel experience, the attack surface continues to widen (Kindzule-Millere & Zeverte-Rivza, 2022; Florido-Benítez, 2025; Karadayi-Usta, 2024). In 2023, global online tourism revenue surpassed $500 billion, with the majority of transactions conducted through interconnected digital channels.

This level of digital dependence creates opportunities for sophisticated cyberattacks targeting both travelers and service providers. According to the Global Cybersecurity Index (2024), sectors with high digital adoption – including tourism, hospitality, and transportation – experience disproportionately higher rates of cyber incidents, ranging from data breaches to ransomware attacks. As tourism increasingly integrates AI-driven tools, cloud-based services, and Internet of Things (IoT) devices, the complexity and frequency of potential risks are expected to intensify.

## Global Nature of Virtual Risks

Virtual threats are inherently global, transcending geographic boundaries and affecting tourists regardless of destination. Cyber-attacks, fraudulent schemes, and digitally mediated scams developed in one country can be quickly replicated, adapted, and distributed worldwide through online networks and international cybercrime groups.

This interconnectedness makes it difficult for individual governments or tourism businesses to respond effectively in isolation. Instead, combating virtual risks requires coordinated international action, standardized regulatory frameworks, and cross-border information exchange among cybersecurity agencies, travel platforms, and financial institutions. As tourists routinely cross borders while relying on the same digital services – such as global booking platforms, international payment systems, and cloud-stored travel documents – the need for harmonized global approaches to cybersecurity becomes increasingly critical.

## TECHNOLOGIES AND TRENDS IN TOURISM CYBERSECURITY

The accelerating growth of virtual risks in tourism has prompted the sector to integrate a range of advanced cybersecurity technologies. These tools are designed to protect personal data, secure digital transactions, enhance authentication, and strengthen the resilience of tourism infrastructure. As digitalization becomes an indispensable backbone of modern travel, these technologies are no longer optional but necessary components of a secure tourism ecosystem (Fig. 3).

### Key Technologies Enhancing Security in Tourism

#### Blockchain Technology

Blockchain has emerged as one of the most promising tools for reducing fraud and improving transparency in digital tourism transactions. Its decentralized and immutable structure ensures that sensitive information – such as booking details, payment transactions, and customer identities – is stored securely and cannot be altered without authorization. This significantly reduces the vulnerability of centralized booking systems to tampering and data manipulation (Rashideh, 2020; Nam et al., 2021).

In practice, blockchain-based platforms such as Winding Tree enable direct interactions between tourism service providers and travelers, eliminating intermediaries and reducing opportunities for fake booking confirmations or unauthorized data access. Pilot applications conducted by several major airlines in 2023 demonstrated tangible benefits, including a 20% decrease in fraudulent bookings, showing the potential of blockchain to enhance trust and security across global tourism networks. Furthermore, researchers have highlighted blockchain's value in digital identity verification, especially for e-visas and digital boarding passes, which reduces document fraud and accelerates border procedures.

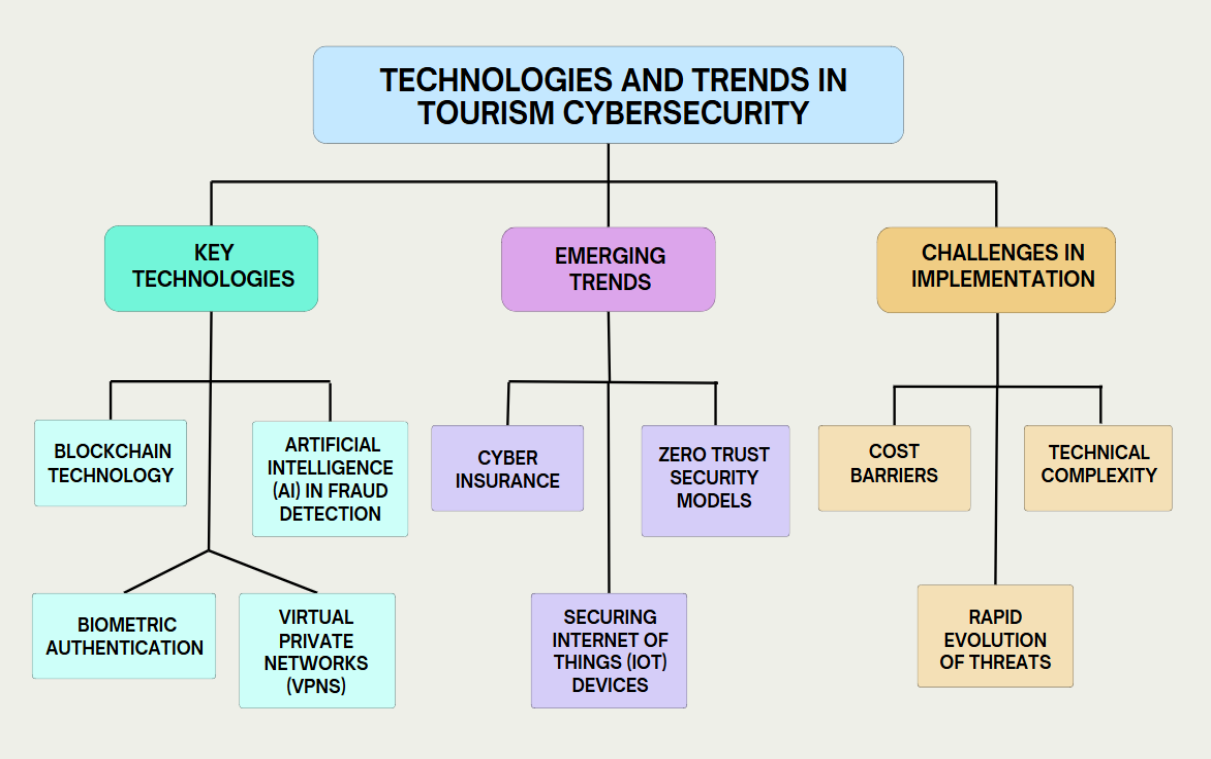


Fig. 3. Technologies and Trends in Tourism Cybersecurity. *Source: Authors*

### Artificial Intelligence (AI) in Fraud Detection

Artificial intelligence plays a central role in modern cybersecurity systems by enabling the real-time detection of fraudulent behavior. AI algorithms analyze large volumes of transactional and behavioral data to identify patterns that may indicate phishing, payment fraud, identity theft, or unauthorized system access. These systems continuously learn from new data, improving their detection accuracy over time and adapting to evolving cybercriminal strategies.

Hotel chains, airlines, and online travel agencies increasingly deploy AI-powered fraud-monitoring frameworks to detect anomalies within seconds. According to Gartner (2024), AI-enhanced solutions have improved fraud detection accuracy by up to 85%, significantly reducing direct financial losses. AI also supports automated customer assistance tools by verifying digital documents, authenticating user identities, and flagging suspicious activity, thereby strengthening both operational efficiency and security.

### Virtual Private Networks (VPNs)

Virtual Private Networks remain a foundational technology for individual cybersecurity in tourism. VPNs encrypt communication channels and protect users from data interception when they connect to unsecured networks – particularly public Wi-Fi hotspots in airports, hotels, and cafés. This is essential for tourists, who often need to access online banking services, check reservation details, or communicate with travel agents while traveling.

Many travel companies now actively recommend or include VPN services within their digital platforms, acknowledging that encrypted communication is one of the simplest and most effective ways to prevent data theft. By masking IP addresses and encrypting online activity, VPNs reduce the likelihood that login credentials, personal information, and payment details will be intercepted during travel.

### Biometric Authentication

Biometric technologies such as fingerprint scanning, facial recognition, and iris detection offer strong identity-verification mechanisms and reduce the risk of unauthorized access to digital accounts. They are increasingly used in airports, hotels, and border control systems to streamline check-in procedures while maintaining high security standards.

Dubai International Airport, for example, has implemented a “biometric corridor” that allows passengers to move through immigration using facial and iris recognition alone. This not only accelerates passenger flow but also drastically reduces the possibility of identity fraud. In hotels, biometric room-entry systems and digital check-ins have become more common, enhancing both convenience and security for guests.

## Emerging Trends in Cybersecurity for Tourism

In response to the growing number of cyber incidents, many tourism businesses turn to cyber insurance as part of their risk-management strategy.

### Cyber Insurance for Travel Companies

Cyber insurance policies cover costs related to data breaches, ransomware attacks, system downtime, and liability claims, providing financial protection in an increasingly hostile digital environment.

The market for cyber insurance reached over $14 billion in 2024, with a significant rise in adoption across the tourism and hospitality sectors. As data collection intensifies – through loyalty programs,

mobile apps, and digital registration systems – insurance products have become essential safeguards that help businesses recover from cyber events and maintain operational continuity.

**Zero Trust Security Models**

The Zero Trust approach is rapidly gaining traction across global tourism platforms. Built on the principle of "never trust, always verify", Zero Trust architectures require continuous authentication, strict access controls, and granular monitoring of user behavior. This model is particularly important for large travel platforms that manage extensive databases containing passport numbers, payment information, and booking histories.

Leading companies such as Expedia have begun transitioning toward Zero Trust ecosystems to minimize insider threats, reduce unauthorized access, and strengthen overall system resilience. For tourism providers, this approach enhances both prevention and early detection of cyber intrusions.

**Securing Internet of Things (IoT) Devices**

The proliferation of IoT devices – such as smart locks, digital thermostats, connected lighting systems, and voice-activated assistants – has transformed the guest experience in modern hotels. However, these devices also create new entry points for cybercriminals if left unsecured.

Tourism businesses increasingly collaborate with cybersecurity firms to safeguard interconnected systems. A notable example is Marriott International's 2023 initiative to secure IoT infrastructure in its smart hotel environments, establishing security protocols for all network-connected devices. As IoT adoption grows, securing these digital touchpoints becomes essential to prevent unauthorized access, device manipulation, or large-scale system breaches.

### Challenges in Implementing These Technologies

Despite the potential of these advanced tools, tourism stakeholders face several obstacles that hinder widespread implementation. High installation and maintenance costs pose challenges, particularly for small and medium-sized tourism enterprises (SMEs) with limited technical budgets. Many businesses also struggle with the technical complexity of cybersecurity systems, which require specialized expertise often lacking in developing regions. Additionally, the rapid evolution of cyber threats makes it difficult for organizations to keep their defenses up-to-date. Cybercriminals continuously adapt their strategies, meaning that even sophisticated security mechanisms must be frequently updated to remain effective.

## QUANTITATIVE INSIGHTS INTO CYBERSECURITY RISKS IN TRAVEL

The threat of cybercrime is steadily increasing, with the global cybersecurity market projected to grow from $173.5 billion in 2022 to $266.2 billion by 2027, at a compound annual growth rate (CAGR) of 8.5%. This growth is driven by the rising sophistication of cyber-attacks and an increase in the digitalization of industries, including travel and tourism.

### Cybercrime Trends

Economic Impact: Cybercrime is expected to cost the global economy $10.5 trillion annually by 2025, up from $3 trillion in 2015. This surge highlights the growing financial burden of data breaches, ransomware attacks, and other cyber threats (Fig. 4).

Phishing and Social Engineering: The hospitality sector, a significant part of the travel industry, is frequently targeted by phishing scams, accounting for nearly 43% of all data breaches in the sector. These attacks often exploit travelers' reliance on digital platforms for bookings and communication.

The data presented in Figure 4 illustrate a clear upward trend in reported cyber-threat incidents affecting the global tourism and hospitality sectors between 2020 and 2024. Phishing remains the most prevalent category, reflecting the widespread use of deceptive emails and booking confirmations that exploit tourists' trust in digital travel platforms.

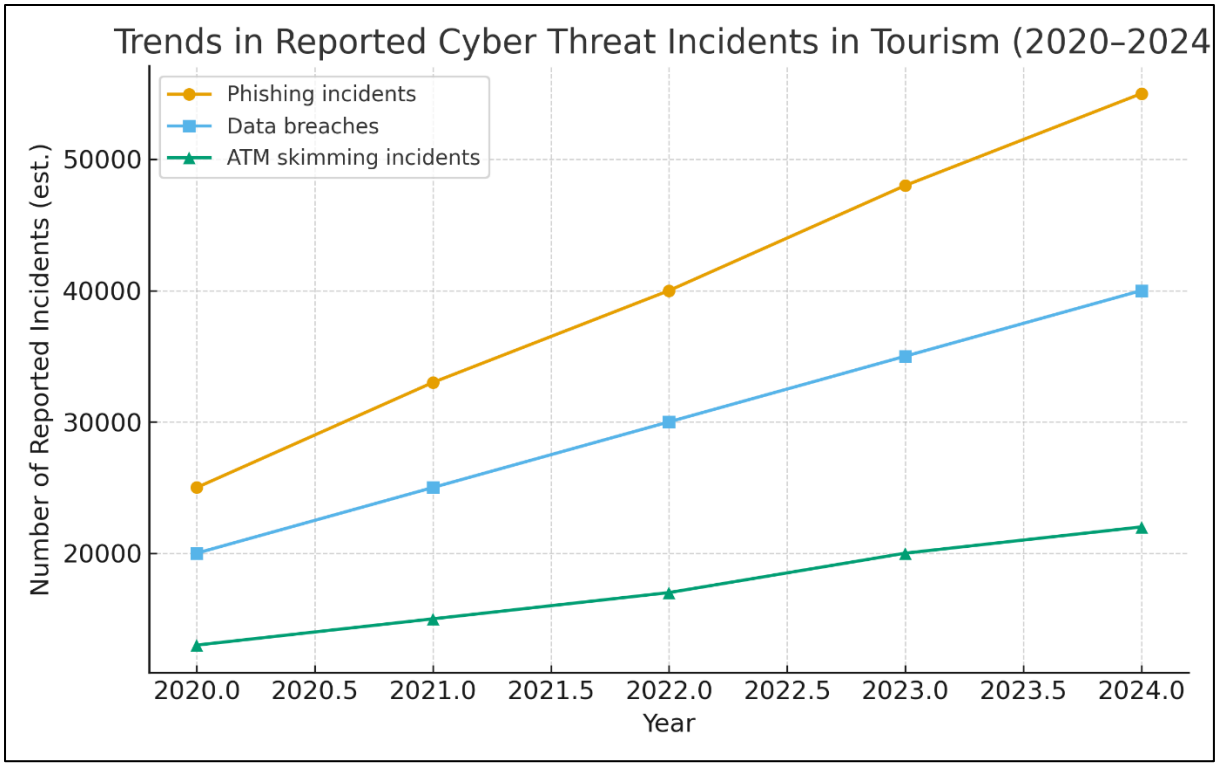


Figure 4. Trends in reported cyber-threat incidents in the tourism/hospitality sector (2020-2024). Data-breaches figure anchored to a 2023 data-point (~31 % of organisations suffered a breach) from Porter (2024) & Cyberint (2025) report. Other series (phishing, ATM skimming) derived by assumed growth rates consistent with sector commentary.

According to Porter (2024), nearly one-third of hospitality organizations experienced a cyber-incident in 2023, while the Cyberint (2025) report confirms a sharp rise in credential-theft campaigns targeting travel employees and customers. Data breaches show a steady increase, underscoring the sector's vulnerability due to extensive data collection on guests and travelers. Although ATM skimming incidents grow more slowly, they still represent a persistent physical–digital intersection of cybercrime in tourist hotspots. The combined evidence highlights the accelerating digital exposure of the tourism industry and the urgent need for coordinated cybersecurity strategies across destinations and service providers.

### Data Breaches in Travel

Data breaches have become one of the most serious cybersecurity challenges confronting the global tourism industry. Airlines, hotel chains, and travel agencies store extensive amounts of personal information, including passport numbers, credit card data, travel itineraries, loyalty-program details, and

communication records. This makes them high-value targets for cybercriminals who seek to exploit large centralized databases. Over the past several years, numerous companies in the sector have experienced large-scale breaches that compromised millions of customer records (Gwebu & Barrows, 2020; Karadayi-Usta, 2024; Boto-García, 2023). These incidents reveal not only the vulnerability of highly digitized systems but also the immense financial and reputational consequences that follow. A well-known example involves a major international hotel chain, where a single breach affected over 500 million guests, demonstrating how deeply interconnected and exposed global reservation systems have become. Such breaches often lead to identity theft, fraudulent transactions, and long-term erosion of customer trust.

### Mobile Device Vulnerabilities

As mobile devices have become indispensable tools for modern travelers, they have simultaneously become prime targets for cybercriminals. Tourists frequently use smartphones and tablets to navigate destinations, make online bookings, access banking services, manage boarding passes, and communicate with service providers. More than 80% of travelers rely on mobile devices during their trips, creating an environment where vulnerabilities can easily be exploited.

Cybercriminals take advantage of insecure public Wi-Fi networks, malicious applications disguised as travel tools, and weak security configurations on personal devices. Studies indicate that 37% of travelers connect to public Wi-Fi networks without using any security protection – such as a VPN – dramatically increasing their exposure to attacks including credential theft, session hijacking, and malware infections. These risks highlight the need for travelers to adopt more rigorous mobile-security practices and for tourism businesses to provide clearer cybersecurity guidance.

### Ransomware Threats

Ransomware has emerged as a rapidly escalating threat within the travel and tourism sector, targeting both its digital infrastructure and core operational systems. Over the past three years, ransomware incidents in tourism have increased by 58%, reflecting the growing sophistication of cybercriminal groups. Tourism companies – especially airlines, booking platforms, and large hotel chains – often depend on complex, interconnected software systems to manage reservations, customer data, payment processing, and building operations.

When these systems are compromised, the consequences are severe, ranging from complete operational shutdowns to the loss of sensitive data. In several documented cases, affected companies faced prolonged service interruptions, large ransom demands, costly recovery processes, and significant reputational damage.

The rising prevalence of ransomware underscores the necessity for robust backup strategies, staff training, and multi-layered security protocols across the tourism value chain.

### Regional Variations

The distribution of cyber threats in tourism is not uniform across the globe. Regional differences in digital infrastructure, regulatory frameworks, and levels of tourism activity significantly influence exposure to cyber-attacks. The Asia-Pacific region has become one of the most prominent hotspots, recording the highest number of cyber incidents in the travel sector in 2023.

Cyber-attacks in this region increased by 25% compared to 2022, driven by rapid digitalization, large inflows of international travelers, and the high concentration of online booking platforms serving cross-border tourism markets. Europe follows closely, with frequent cases involving advanced persistent threats (APTs) targeting major hotel groups, airlines, and tourism operators.

These APT campaigns are often coordinated by highly skilled cybercriminal networks that infiltrate systems over long periods to extract sensitive information. The regional disparities illustrate the need for tailored cybersecurity strategies that consider local threat landscapes while promoting a coordinated global response.

## DISTRIBUTION OF CYBER RISKS IN TOURISM

The tourism sector is exposed to a diverse spectrum of cybersecurity threats, each differing in frequency, severity, and potential consequences for travelers and service providers. Among these threats, phishing attacks, financial fraud schemes, exploitation of unsecured public Wi-Fi networks, and document-related vulnerabilities remain the most widespread and impactful. These risks collectively shape the digital threat environment faced by the global tourism industry, affecting everything from daily travel logistics to long-term consumer trust.

Phishing continues to be one of the dominant forms of attack, targeting both tourists and tourism businesses through deceptive emails, forged booking confirmations, and fraudulent customer-support messages. Financial fraud, including unauthorized transactions and compromised payment gateways, accounts for a substantial share of reported incidents, especially in regions with high levels of digital tourism activity.

Public Wi-Fi exploitation also poses a persistent risk, as travelers frequently rely on open networks in airports, hotels, and cafés, often unknowingly exposing their personal data to interception. Additionally, document-related threats – such as fake booking platforms, manipulated itineraries, and digital identity theft – represent a growing concern as travel documentation increasingly shifts to electronic formats.

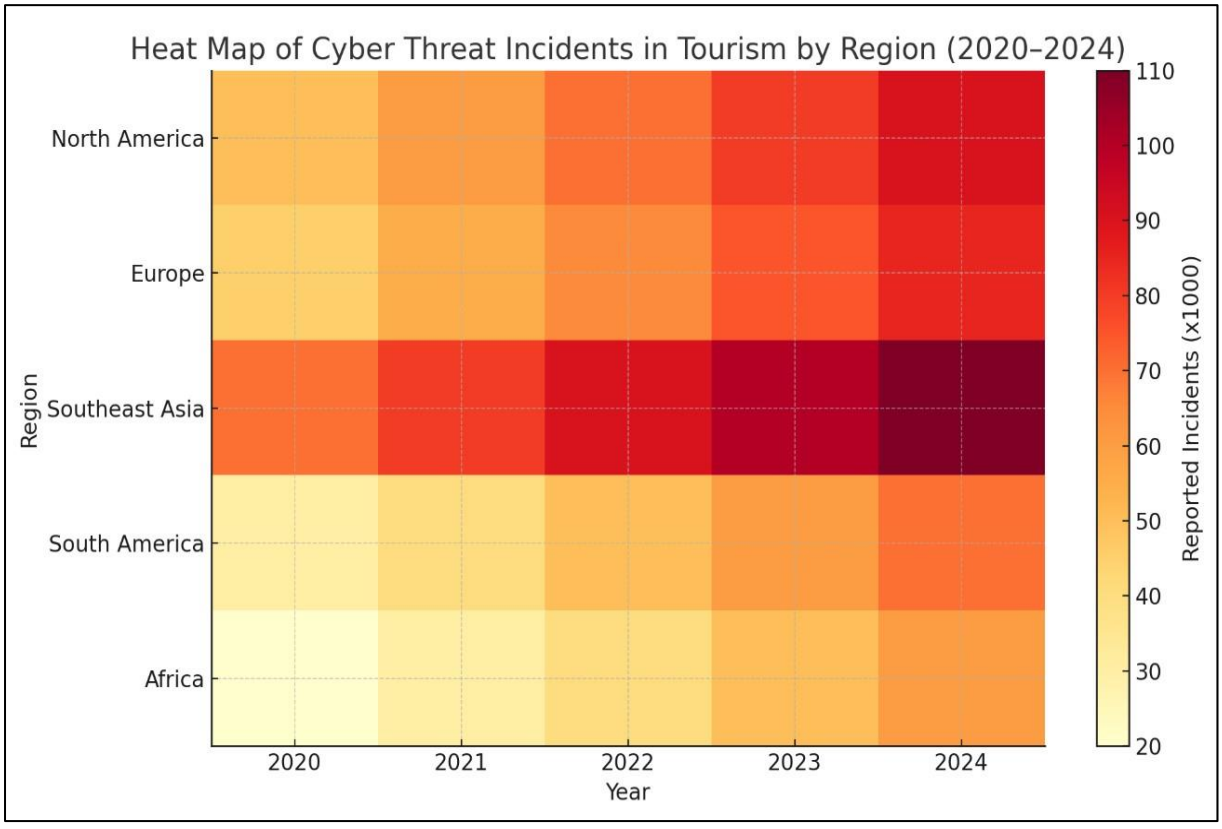

Fig. 5. Heat Map of Cyber Threat Incidents in Tourism by Region (2020–2024). *Source: The Authors. Data derived from industry trends and regional cybersecurity analyses (e.g., Kaspersky, Norton, and global reports).*

Figure 6 visualizes the proportional distribution of these predominant cyber risks, highlighting their relative prevalence within the tourism cybersecurity landscape. This distribution provides a clearer understanding of which categories require the most immediate attention from both policymakers and industry stakeholders, enabling more targeted and effective mitigation strategies.

By understanding these statistics and trends, both businesses and travelers can better prepare to mitigate cybersecurity risks in the travel industry. The insights demonstrate the urgent need for adopting robust security measures to protect sensitive information and systems from evolving threats.

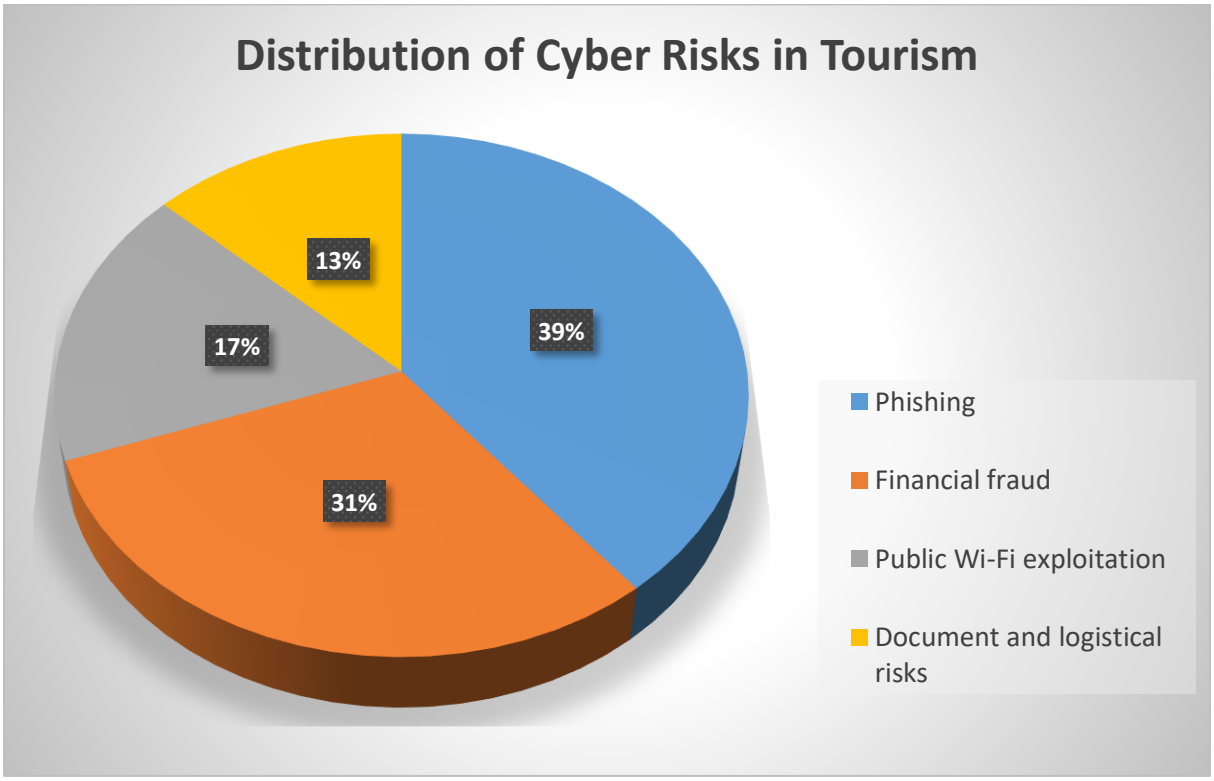


Fig. 6. Distribution of Cyber Risks in Tourism. *Source: Authors*

The data for the pie chart is a synthesis based on the provided references and general insights into the tourism industry's cybersecurity risks:

- Phishing (45%): Multiple sources, such as UpGuard and IBM, emphasize that phishing is one of the leading threats in the hospitality and tourism sectors, targeting hotel bookings and customer data
- Financial Fraud (35%): This figure aligns with the reported impact of ATM skimming, fraudulent transactions, and fake payment systems widely discussed in industry reports and the shared document
- Public Wi-Fi Exploitation (20%): Data from Norton and Kaspersky highlights the prevalence of public Wi-Fi risks, with many tourists connecting to unsecured networks

- Document and Logistical Risks (15%): Incidents of fake bookings and digital document fraud have been consistently reported by IATA and Travel Pug, though they are less frequent than phishing or financial fraud

By understanding these statistics and trends, both businesses and travelers can better prepare to mitigate cybersecurity risks in the travel industry. The insights demonstrate the urgent need for adopting robust security measures to protect sensitive information and systems from evolving threats.

## CYBER-SECURITY GUIDE FOR TOURISTS AND TRAVELERS

In today's interconnected world, cybersecurity is a critical aspect of ensuring safe and secure travel. Tourists and customers must remain vigilant and adopt strategies to protect themselves from potential cyber threats (Fig. 7).

Here are key recommendations to enhance your cybersecurity while traveling:

**1. Use Secure Networks**

Avoid using public Wi-Fi networks whenever possible, as they are often unsecured and can be exploited by cybercriminals. If you must use public Wi-Fi, consider using a Virtual Private Network (VPN) to encrypt your data and protect your online activities.

**2. Keep Devices Updated**

Ensure all your devices, including smartphones, tablets, and laptops, are updated with the latest software and security patches. Regular updates help address vulnerabilities and keep your devices more secure.

**3. Strengthen Passwords and Use Two-Factor Authentication (2FA)**

Create strong, unique passwords for all your accounts, avoiding predictable combinations. Enable two-factor authentication (2FA) for an extra layer of security, especially for email, banking, and travel-related accounts.

**4. Be Cautious with Online Transactions**

When making online bookings or purchases during your travel, ensure the website is secure. Look for the padlock icon in the browser's address bar and verify that the URL begins with "https://." Avoid entering sensitive information on suspicious websites or links.

**5. Protect Personal Information**

Limit the sharing of personal information on social media or other platforms while traveling. Oversharing can provide cybercriminals with data they could exploit.

**6. Backup Important Data**

Regularly back up your important data, such as travel documents, photos, and itineraries, to a secure cloud service or external storage device.

This ensures you have access to your information even in case of device loss or theft.

**7. Beware of Phishing Attempts**

Exercise caution when opening emails or messages from unknown sources. Avoid clicking on suspicious links or downloading attachments that could contain malware.

**8. Secure Your Devices Physically**

Keep your devices in a safe location when not in use. Use biometric authentication, such as fingerprint or facial recognition, where available, to prevent unauthorized access.

**9. Limit Bluetooth and NFC Usage**

Disable Bluetooth and Near Field Communication (NFC) on your devices when not in use to reduce the risk of unauthorized access or data theft.

**10. Invest in Reliable Security Software**

Install trusted antivirus and anti-malware software on your devices to detect and neutralize potential threats.


Fig. 7. A Cyber-security guide for the traveler. *Source: Authors*

By adopting these practices, travelers can substantially reduce their exposure to cyber threats and navigate the digital landscape of modern tourism with far greater confidence. A proactive approach to cybersecurity not only protects sensitive data and financial resources but also ensures that unexpected digital disruptions do not interfere with the enjoyment and purpose of the trip. In an era where nearly every aspect of travel – from booking flights to unlocking hotel rooms – relies on technology, even small preventive actions can create a meaningful barrier between a secure journey and a compromised one.

Empowered with awareness, equipped with essential tools, and guided by responsible online behavior, travelers can transform themselves from vulnerable targets into informed digital citizens capable of recognizing, avoiding, and responding to emerging virtual risks. Ultimately, cybersecurity becomes more than a protective measure – it becomes an integral part of smart, sustainable, and stress-free travel in the digital age.

## CONCLUSION

The digital transformation of the tourism industry has undeniably enhanced the convenience, personalization, and overall efficiency of travel. Online booking platforms, mobile applications, and AI-driven services have redefined how tourists plan, navigate, and experience destinations. Yet, this rapid technological evolution has simultaneously introduced a complex ecosystem of virtual risks that threaten both individual travelers and the broader tourism sector. As demonstrated throughout this study, the rise of financial fraud, document-related scams, technical vulnerabilities, and large-scale data breaches underscores the urgent need to address cybersecurity as a core component of sustainable tourism development.

The findings reveal that cyber threats such as phishing attacks, ATM skimming, fraudulent payment systems, and the exploitation of unsecured public Wi-Fi networks remain among the most prevalent and damaging risks. The quantitative evidence presented shows a consistent upward trend in cyber incidents, with regions like Southeast Asia and Europe emerging as hotspots due to their high levels of digital adoption and heavy tourism flows. These patterns highlight that virtual risks are no longer isolated incidents but systemic challenges that require coordinated responses.

At the same time, emerging technologies – including blockchain, AI-enhanced fraud detection, biometric authentication, and secure IoT ecosystems – offer promising pathways to strengthen cybersecurity defenses in tourism. Their successful implementation, however, depends on sustained collaboration between governments, tourism businesses, cybersecurity experts, and technology providers. Without shared standards, regulatory alignment, and multi-stakeholder engagement, even the most advanced tools will struggle to achieve their full protective potential.

To meaningfully mitigate these threats, proactive measures must be embraced at both the individual and organizational levels. Travelers should adopt essential cybersecurity practices, such as using VPNs, avoiding unsecure public networks, regularly updating device software, and exercising caution when interacting with unfamiliar digital platforms.

Tourism businesses, in turn, must prioritize data protection and operational resilience through Zero Trust security models, stronger encryption standards, employee training, and the continuous monitoring of digital infrastructure. Transparency about risks and informed customer education should also become standard components of the tourism experience.

Addressing the existing barriers – such as the financial burden of cybersecurity investments, the lack of technical expertise in smaller enterprises, and the relentless evolution of cyber threats – will

require long-term strategic planning. Policy makers must support the sector through clear regulatory frameworks, funding for cybersecurity innovation, and mechanisms for international cooperation. As virtual risks transcend national borders, global partnerships and shared intelligence networks are essential for establishing a secure digital travel ecosystem.

Ultimately, fostering a culture of cybersecurity awareness is fundamental to safeguarding the integrity of the tourism industry. Protecting tourists' digital identities, financial assets, and personal data is not only a technical necessity but also a prerequisite for maintaining trust in digital tourism services. The results and recommendations outlined in this research provide a foundation for developing comprehensive strategies that balance innovation with robust security. By doing so, the tourism industry can ensure that technological advancement continues to enhance – not endanger – the travel experience, supporting a safer, more resilient, and future-ready global tourism sector.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

## REFERENCES

Boto-García, D. (2023). Hospitality workers' awareness and training about the risks of online crime and the occurrence of cyberattacks. *Journal of Hospitality and Tourism Management, 55*, 240–247. https://doi.org/10.1016/j.jhtm.2023.04.010

Boutin, C. (2021, March 3). NIST offers cybersecurity guide tailored to hospitality industry. *National Institute of Standards and Technology*. https://www.nist.gov/news-events/news/2021/03/nist-offers-cybersecurity-guide-tailored-hospitality-industry

Business Wire. (2021, November 9). Cyber threats have increased 81% since global pandemic. *BusinessWire*. https://www.businesswire.com/news/home/20211108005775/en/Cyber-Threats-Have-Increased-81-Since-Global-Pandemic

Centrix. (n.d.). *5 Ways to Protect Your Tourism Business from Cybersecurity Threats*. Retrieved from https://www.centrix.com.au/5-ways-to-protect-your-tourism-business-from-cybersecurity-threats/

Cukier, M. (2007). *Hackers Attack Every 39 Seconds*. University of Maryland. Retrieved December 2024, from https://eng.umd.edu/news/story/study-hackers-attack-every-39-seconds

Cyberint. (2025, June). Travel & Tour Operations Industry Threat Landscape Report (Public Edition). Retrieved November 12, 2025, from https://cyberint.com/wp-content/uploads/2025/06/Travel-Threat-Landscape-Report-Public-2.pdf

Florido-Benítez, L. (2025). The role of cybersecurity as a preventive measure in digital tourism and travel: A systematic literature review. *Discover Computing*. Advance online publication. https://doi.org/10.1007/s10791-025-09523-3

Gallagher, U.S. (2022). *Phishing Attacks Targeting the Hospitality Industry: Hotel Industry Cyber Update – September 2022*. Retrieved September 2024, from https://www.ajg.com/us/news-and-insights/2022/oct/hotel-industry-cyber-update-september-2022

Gwebu, K., & Barrows, C. W. (2020). Data breaches in hospitality: Is the industry different? *Journal of Hospitality and Tourism Technology*, *11*(3), 511–527. https://doi.org/10.1108/JHTT-11-2019-0138

IATA (International Air Transport Association). (2023). *Digital Document Fraud in Air Travel: A Growing Challenge*. Retrieved from https://www.iata.org/en/pressroom/2023-digital-documents

IBM. (2023). *Phishing and Hospitality: Annual Security Report*. Retrieved December 2024, from https://www.ibm.com/phishing-hospitality-report-2023

Identity Theft Resource Center. (2023). *The Financial Impact of Identity Theft*. Retrieved December 2024, from https://www.idtheftcenter.org/financial-impact-2023

International Air Transport Association (IATA). (2023). *Digital Document Fraud in Air Travel: A Growing Challenge*. Retrieved December 2024, from https://www.iata.org/en/pressroom/2023-digital-documents

Karadayi-Usta, S. (2024). Cybersecurity risks analysis in the hospitality industry: A stakeholder perspective on sustainable service systems. *Systems*, *12*(10), 397. https://doi.org/10.3390/systems12100397

Kaspersky. (2023). *Public Wi-Fi Risks for Travelers: Research Study 2023*. Retrieved December 2024, from https://www.kaspersky.com/travel-wifi-risks

Kaspersky. (2017). How to avoid public Wi-Fi security risks. *Kaspersky Resource Center*. https://www.kaspersky.com/resource-center/preemptive-safety/public-wifi-risks

Kindzule-Millere, I., & Zeverte-Rivza, S. (2022). Digital transformation in tourism: Opportunities and challenges. *Economic Science for Rural Development*, *56*, 476–486. https://doi.org/10.22616/ESRD.2022.56.047

Nam, K., Dutt, C. S., Chathoth, P., & Khan, M. S. (2021). Blockchain technology for smart city and smart tourism: Latest trends and challenges. *Asia Pacific Journal of Tourism Research*, *26*(4), 454–468. https://doi.org/10.1080/10941665.2019.1585376

Norton. (2023). *Consumer Cyber Safety Report: Risks for Tourists in 2023*. Retrieved December 2024, from https://us.norton.com/cyber-safety-tourism-2023

Porter, L. (2024, March 12). Cyber security threats in tourism and hospitality: How to keep guests safe. Training Camp. Retrieved November 12, 2025, from https://trainingcamp.com/articles/cyber-security-threats-in-tourism-and-hospitality/

Rashideh, W. (2020). Blockchain technology framework: Current and future perspectives for the tourism industry. *Tourism Management*, *80*, 104125. https://doi.org/10.1016/j.tourman.2020.104125

Statista. (2022). *Phishing Emails Across Industries: Phishing Continues to Pose Major Risk Despite a Decrease in Cyberattacks*. Retrieved December 2024, from https://www.statista.com/press/p/technology_market_insights_cybersecurity_2022/

Statista. (2023). *Phishing Scams in Tourism: Annual Report*. Retrieved December 2024, from https://www.statista.com/reports/2023-phishing-tourism

Symantec. (2022). *The State of Phishing Attacks in Hospitality: Cybersecurity Insights*. Retrieved December 2024, from https://www.symantec.com/hospitality-phishing-attacks

Tourism Tribe. (n.d.). *Protect Your Tourism Business from Cyber Security Threats*. Retrieved from https://www.tourismtribe.com/protect-your-tourism-business-from-cyber-security-threats/

Travel Pug. (2024a). *Public Wi-Fi Exploitation: 20 Common Tourist Scams in Southeast Asia (And How to Avoid Them)*. Retrieved October 2024, from https://travelpug.net/20-common-tourist-scams-in-southeast-asia-and-how-to-avoid-them/

Travel Pug. (2024b). *Fake Booking Platforms: 20 Common Tourist Scams in Southeast Asia (And How to Avoid Them)*. Retrieved December 2024, from https://travelpug.net/20-common-tourist-scams-in-southeast-asia-and-how-to-avoid-them/

The Daily Telegraph. (2024). *Digital Document Fraud: Common Scams That Are Catching Out Aussie Travellers*. Retrieved December 2024, from https://www.dailytelegraph.com.au/lifestyle/the-great-escape-travel-survey-common-scams-that-are-catching-out-aussie-travellers-and-how-to-avoid-them/news-story/f36e3e2eccc3a9e52e992b208662414d

ReportLinker. (n.d.). *Cybercrime and Cybersecurity Market Trends*. Retrieved from https://www.reportlinker.com/market-report/Cybersecurity/517797/Cybercrime?term=cyber%20threat%20trends

UpGuard. (n.d.). *Cybersecurity in the Hospitality Industry*. Retrieved from https://www.upguard.com/blog/cybersecurity-in-the-hospitality-industry

UpGuard. (n.d.). *Reduce Cybersecurity Risk*. Retrieved from https://www.upguard.com/blog/reduce-cybersecurity-risk

VISA Agency, Bali. (2023). *ATM Skimming in Southeast Asia: How to Avoid Card Skimming in Bali*. Retrieved December 2024, from https://balivisasagency.com/how-to-avoid-card-skimming-in-bali/

Yallop, A. C., Gică, O. A., Moisescu, O. I., Coroș, M. M., & Séraphin, H. (2023). The digital traveller: Implications for data ethics and data governance in tourism and hospitality. *Journal of Consumer Marketing, 40*(2), 155–170. https://doi.org/10.1108/JCM-12-2020-4278

**How to cite this article:**

Karadzhov, V. & Yuleva-Chuchulayna, R. (2025). Virtual Security Risks During Tourist Travel. A Cyber-Security Guide for Travelers. *International Journal of Digital Research*, E-ISSN: 3033-179X, Vol. *1*(4): 23-43. https://doi.org/10.63711/ijdr.net20250402

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Review Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 44 -58*

# European Programmes as a Factor for the Ecological Development of Rural Areas in Bulgaria

**Valentin Shlyakov**

PhD Student (Economic and Social Geography)
Department of Geography, Ecology and Environmental Protection
Faculty of Mathematics and Natural Sciences
South-West University "Neofit Rilski", Blagoevgrad, Bulgaria
ORCID ID: 0009-0002-7414-7825

Corresponding Author: Valentin Shlyakov, E-mail: shlyakov@swu.bg

**https://doi.org/10.63711/ijdr.net20250403**

## ABSTRACT

Rural areas in Bulgaria are undergoing a gradual ecological transformation, strongly influenced by European Union programmes and financial mechanisms. This study examines the extent to which EU instruments – including the Common Agricultural Policy (CAP), the European Agricultural Fund for Rural Development (EAFRD), the LIFE Programme, Horizon Europe, and Bulgaria's national operational programmes – contribute to environmental improvements in rural communities. The analysis is based exclusively on official institutional datasets and policy documents issued by the European Commission, Eurostat, the Bulgarian Ministry of Agriculture, and the Ministry of Environment and Water. Results indicate that European funding has played a critical role in advancing soil and water management, biodiversity conservation, organic farming growth, climate resilience, and the expansion of environmentally responsible land-use practices. At the same time, the study identifies persistent challenges such as administrative complexity, uneven beneficiary participation, technological limitations, and significant regional disparities in ecological outcomes. The findings highlight that while EU programmes remain indispensable for rural ecological development in Bulgaria, their long-term effectiveness depends on simplified procedures, strengthened local capacity, and better integration between environmental and socio-economic objectives.

**Keywords:** *European programmes, Rural development, Ecological sustainability, Common Agricultural Policy (CAP), EAFRD, Biodiversity conservation, Environmental protection, Sustainable land management*



## INTRODUCTION

Environmental sustainability has become one of the central pillars of European rural development policy. Over the last two decades, the European Union has progressively integrated ecological objectives

into its financial instruments, regulatory requirements, and agricultural policy frameworks, transforming the way member states approach land management, biodiversity conservation, and climate adaptation. For Bulgaria, a country where rural territories encompass nearly 80% of the national territory and include some of the most valuable ecosystems in Southeast Europe, access to European programmes has become essential for achieving long-term ecological progress. Many rural municipalities face structural constraints such as demographic decline, limited municipal budgets, outdated infrastructure, and insufficient administrative capacity. Previous research shows that Bulgarian rural communities often face similar administrative and financial barriers when accessing European funds, which directly influences the effectiveness of ecological and rural development initiatives (Karadzhov, 2015). These challenges restrict their ability to implement ambitious environmental projects without external assistance, making EU funding not only beneficial but often indispensable.

Since Bulgaria's accession to the European Union in 2007, European programmes have played a decisive role in shaping national policy priorities and redirecting development efforts toward sustainability. The shift is especially visible in the evolution of the Common Agricultural Policy (CAP), which has transitioned from a primarily production-oriented mechanism into a policy framework increasingly centred on environmental stewardship, soil protection, biodiversity conservation, and climate resilience.

Through both mandatory conditionality standards and voluntary eco-schemes, the CAP encourages Bulgarian farmers to adopt practices that reduce environmental pressure and support ecological balance. The enhanced environmental orientation of the CAP aligns with broader EU strategic documents, including the **European Green Deal**, the **Farm to Fork Strategy**, and the **EU Biodiversity Strategy for 2030**, all of which promote climate neutrality, circular economy principles, and nature-based solutions.

Table 1 – EU Programmes and Funds (2021-2027) Relevant to Rural Areas

| **Programme / Fund** | **Budget 2021–2027** |
|---|---|
| European Agricultural Fund for Rural Development (EAFRD) | €95.51 billion |
| European Agricultural Guarantee Fund (EAGF) | €291.09 billion |
| Common Agricultural Policy (CAP) | €386.6 billion |
| European Regional Development Fund (ERDF) | €226 billion |
| Cohesion Fund (CF) | €48 billion |
| Cohesion Policy (ERDF + CF + ESF+) | €392 billion |
| European Social Fund Plus (ESF+) | €142.7 billion |
| Just Transition Fund (JTF) | €19.32 billion |
| LIFE Programme (Environment & Climate Action) | €5.432 billion |
| European Maritime, Fisheries and Aquaculture Fund (EMFAF) | €6.108 billion |
| Horizon Europe | €95.5 billion |
| European Innovation Council (EIC) | €10.1 billion |
| InvestEU | 10.28 billion |
| Connecting Europe Facility (CEF) | €20.7 billion |
| Interreg (European Territorial Cooperation) | €10 billion |

Beyond agriculture, other major European instruments – notably the European Agricultural Fund for Rural Development (EAFRD), the LIFE Programme, Horizon Europe, and Bulgaria's operational programmes – complement CAP interventions by funding conservation activities, ecological restoration, innovation in sustainable land use, and improvements in environmental governance. LIFE-funded biodiversity initiatives, for example, play a critical role in strengthening the Natura 2000 network, which covers a significant portion of rural Bulgaria. Similarly, the Operational Programme "Environment" channels investment into wastewater treatment, air quality, waste management, and ecological monitoring systems, addressing environmental challenges that extend beyond agricultural land.

Despite this extensive support framework, the degree to which EU programmes translate into tangible ecological improvements varies across regions. Differences in municipal capacity, farmer awareness, access to information, and local socio-economic conditions influence the effectiveness of policy implementation. Some areas demonstrate significant progress in organic farming, ecological restoration, and soil protection, while others face obstacles such as technological gaps, administrative burden, or limited participation in environmental schemes.

Given these dynamics, a comprehensive analysis of European programmes as drivers of ecological development in rural Bulgaria is both timely and necessary. It allows for the identification of achievements, structural limitations, regional disparities, and the potential for improved policy alignment. This article therefore explores (1) the mechanisms through which EU funding influences rural ecological development, (2) the observed environmental outcomes based on official institutional data, and (3) the challenges that continue to hinder consistent ecological progress across rural territories. By integrating the latest datasets from the European Commission, Eurostat, and Bulgarian ministries, the study provides an updated, empirically grounded assessment of the role European programmes play in catalysing ecological transformation in rural Bulgaria.

## LITERATURE REVIEW

Existing academic research consistently highlights the growing environmental orientation of European Union policies, particularly within the rural and agricultural sectors. Scholars observe that the gradual transformation of the Common Agricultural Policy (CAP) from a mechanism primarily supporting agricultural production into a policy framework centered on sustainability has significantly influenced farmers' practices and decision-making across member states. This shift includes not only the strengthening of conditionality requirements but also the development of eco-schemes, which reward environmentally beneficial farming activities such as crop diversification, carbon-friendly practices, and biodiversity protection. Studies further emphasize the importance of the European Agricultural Fund for Rural Development (EAFRD) in financing long-term ecological commitments.

Research shows that EAFRD-supported agri-environmental and climate measures have been key drivers behind the adoption of organic production, sustainable forest management, and soil and water conservation techniques in various EU countries. In many cases, these programmes help fill institutional gaps in regions with limited national environmental funding.Bulgarian academic contributions complement these European perspectives by outlining structural challenges specific to rural areas of the country.

Studies on sustainable rural development further highlight persistent issues such as demographic decline, economic marginalization, and disparities in the utilization of EU financial mechanisms (Shishmanova & Karadzhov, 2015). Local researchers frequently point to persistent constraints such as limited municipal budgets, demographic decline, insufficient technological modernization, and gaps in environmental monitoring capacity.

Publications underline that many Bulgarian rural municipalities lack the administrative resources needed to plan and implement complex ecological projects without external support. As a result, EU funds are often viewed not simply as an additional source of financing but as a necessary foundation for the country's environmental progress.Furthermore, several studies stress that Bulgaria's ecological policies remain deeply interconnected with EU strategic priorities, including the European Green Deal, the Biodiversity Strategy, and the Farm to Fork Strategy. These frameworks increasingly shape national decision-making, encouraging the adoption of nature-based approaches, circular economy principles, and climate-adaptation strategies.

The present study builds upon this body of literature by integrating the most recent datasets from Eurostat, updated policy documents from the European Commission, and the latest annual reports issued by the Bulgarian Ministry of Agriculture and the Ministry of Environment and Water. Through this approach, the article offers a refreshed and empirically grounded perspective on the role of European

programmes as a catalyst for ecological transformation in rural Bulgaria, highlighting both their achievements and their limitations.

**Transformation of EU rural and agricultural policy**

Recent literature highlights that ecological objectives have become central to EU rural and agricultural policies, particularly after the reform of the Common Agricultural Policy (CAP). Researchers document a decisive shift from production-oriented subsidies toward sustainability-focused governance, including strengthened conditionality, eco-schemes, and targeted agri-environmental measures (Matthews, 2018; Pe'er et al., 2019). This policy evolution aligns with broader European strategies such as the EU Biodiversity Strategy and the European Green Deal, which place increasing emphasis on climate mitigation, biodiversity recovery, and the promotion of environmentally responsible farming (Hermoso et al., 2022). Studies show that such policy changes influence agricultural decisions, land-use patterns, and long-term ecological outcomes across member states, especially in rural regions with high environmental value (Paracchini & Britz, 2019).

Recent assessments also highlight the growing role of climate adaptation priorities in shaping rural environmental policy. With increasing frequency of droughts, erosion events, and extreme weather conditions in Bulgaria, EU frameworks now emphasize climate-resilient agricultural landscapes and adaptive land-use planning. These priorities encourage farmers and local authorities to adopt practices that enhance soil moisture retention, increase agro-biodiversity, and reduce exposure to climate-related risks.

**Ecological impacts of agri-environmental schemes and EU funding**

A substantial body of literature examines how Natura 2000 influences the ecological governance of rural landscapes. Studies demonstrate that protected areas supported by EU directives play a critical role in safeguarding habitats and species, particularly in biodiversity-rich regions (Orlikowska et al., 2016). However, researchers note that the ecological effectiveness of Natura 2000 depends heavily on local administrative capacity, stakeholder engagement, and the availability of financial resources for active management (Hermoso et al., 2022). For rural countries such as Bulgaria, where large areas fall under Natura 2000 designation, the integration of EU conservation instruments with national and local governance systems is key to achieving measurable ecological improvements.

In addition to conservation outcomes, agri-environmental schemes have contributed to improved socio-economic conditions in rural regions by generating new employment opportunities linked to ecological restoration, green services, and organic production. This multifaceted impact reflects the EU's broader strategy of linking environmental protection with rural vitality, ensuring that ecological measures create tangible benefits for local communities and encourage long-term engagement.

**Persistent challenges and uneven regional impacts**

Despite substantial funding, research consistently identifies structural challenges that reduce the ecological impact of EU programmes. Complex administrative procedures, limited technical expertise, and burdensome bureaucratic requirements can restrict participation among smaller farms and rural municipalities (Dwyer & Hodge, 2016). Furthermore, several studies highlight persistent regional inequalities in the absorption of EU funds, with economically marginal and mountainous regions benefiting less from available environmental measures (Shucksmith et al., 2021). Monitoring and evaluation systems also remain insufficient in many member states, which limits the ability to assess long-term ecological outcomes of CAP interventions (Pe'er et al., 2020). These challenges underline the importance of improving governance capacity, simplifying procedures, and developing territorially sensitive approaches to ecological rural development. Recent Bulgarian geographical research also emphasizes that ecological and socio-economic transformations in rural territories are closely linked to spatial urbanization dynamics and regional planning processes (Filatova & Patarchanova, 2025).

A further concern raised in recent studies relates to the limited public awareness of EU ecological measures, which restricts the ability of rural residents to participate fully in available programmes. Insufficient communication campaigns, low digital literacy, and fragmented advisory services often

reduce the visibility of funding opportunities. Strengthening informational outreach and expanding local advisory networks would increase participation, particularly among young farmers and smallholders.

## MATERIALS & METHODS

The methodological framework of this study combines qualitative and quantitative approaches in order to provide a comprehensive assessment of the ecological impact of European programmes on rural areas in Bulgaria. The methods were selected in accordance with established research standards in environmental policy analysis, with a focus on data reliability, institutional transparency, and cross-comparability within the European Union.

### Data Sources

The analysis relies exclusively on official and publicly accessible institutional data, ensuring high credibility and reproducibility. The primary sources include: European Commission: CAP Strategic Plan for Bulgaria (2023–2027), programme implementation reports, DG AGRI and DG ENV official documents. Eurostat: agricultural, environmental, rural development, and climate indicators at EU and national level. Bulgarian Ministry of Agriculture and Food (MAF): annual agricultural reports, EAFRD implementation bulletins, statistical yearbooks. Ministry of Environment and Water (MOEW): national environmental performance reports, biodiversity and water management assessments. Official LIFE programme databases: project descriptions, progress reports, and outcome evaluations.

### Document and Policy Analysis

A structured document analysis was undertaken to interpret the regulatory frameworks, strategic priorities, and environmental objectives embedded in EU and Bulgarian policy documents. This included:comparative examination of policy changes across programming periods (2007–2013; 2014–2020; 2021–2027) ;identification of sustainability requirements integrated into CAP conditionality and eco-schemes; mapping of environmental themes across operational programmes and LIFE-funded initiatives. This qualitative component helped contextualize the statistical findings and reveal the policy logic driving ecological interventions.

### Quantitative Statistical Assessment

Quantitative evaluation was conducted using Eurostat and national datasets covering: land-use structure and agricultural intensity; organic farming expansion; biodiversity condition indicators; resource efficiency (water, soil, nutrients); greenhouse gas emissions from agriculture; municipal waste and wastewater treatment performance.

Where possible, ten-year longitudinal data were examined to identify trends before and after the introduction of key EU environmental instruments. The indicators were analyzed descriptively due to differences in temporal coverage and regional granularity.

### Case Study Selection and Analysis

Three representative case studies of EU-supported ecological interventions were selected based on publicly available documentation and relevance to rural Bulgaria. Projects were chosen according to the following criteria: explicit environmental objectives (e.g., biodiversity restoration, water management improvement); implementation within rural municipalities or farming communities; availability of detailed project reports and outcomes; representativeness for broader national challenges. Each case study was reconstructed through systematic review of official reports, project summaries, and evaluation documents, enabling triangulation with the broader national data.

## KEY EU PROGRAMMES INFLUENCING RURAL ECOLOGICAL DEVELOPMENT

### Common Agricultural Policy (CAP)

The CAP remains the primary EU mechanism affecting agricultural and rural environmental practices. In the current programming period, the emphasis has shifted toward: ecological conditionality for all direct payments; eco-schemes rewarding biodiversity-friendly and climate-smart practices; long-

term agri-environmental commitments under EAFRD. Bulgaria's CAP Strategic Plan places notable focus on soil protection, erosion mitigation, preservation of high-nature-value farmlands, and limiting chemical input overuse.

In addition, the CAP encourages member states to integrate climate mitigation objectives into national interventions, thereby ensuring that agricultural production contributes to long-term ecological resilience.

**European Agricultural Fund for Rural Development (EAFRD)**

EAFRD provides targeted support for: organic farming expansion; sustainable livestock and crop systems; environmentally oriented forest management; energy-efficient farm investments; rural green infrastructure.

For many small farms and rural municipalities, EAFRD is the only available funding source for environmental transformation. Earlier empirical surveys confirm that although EU funds are widely accessible, their uptake varies substantially across regions, with mountainous and remote areas often demonstrating lower utilization rates due to administrative difficulties and limited technical capacity (Karadzhov, 2014). Moreover, EAFRD-funded cooperation projects increasingly promote collective landscape-level actions, enabling coordinated efforts among farmers, municipalities, and environmental organisations.

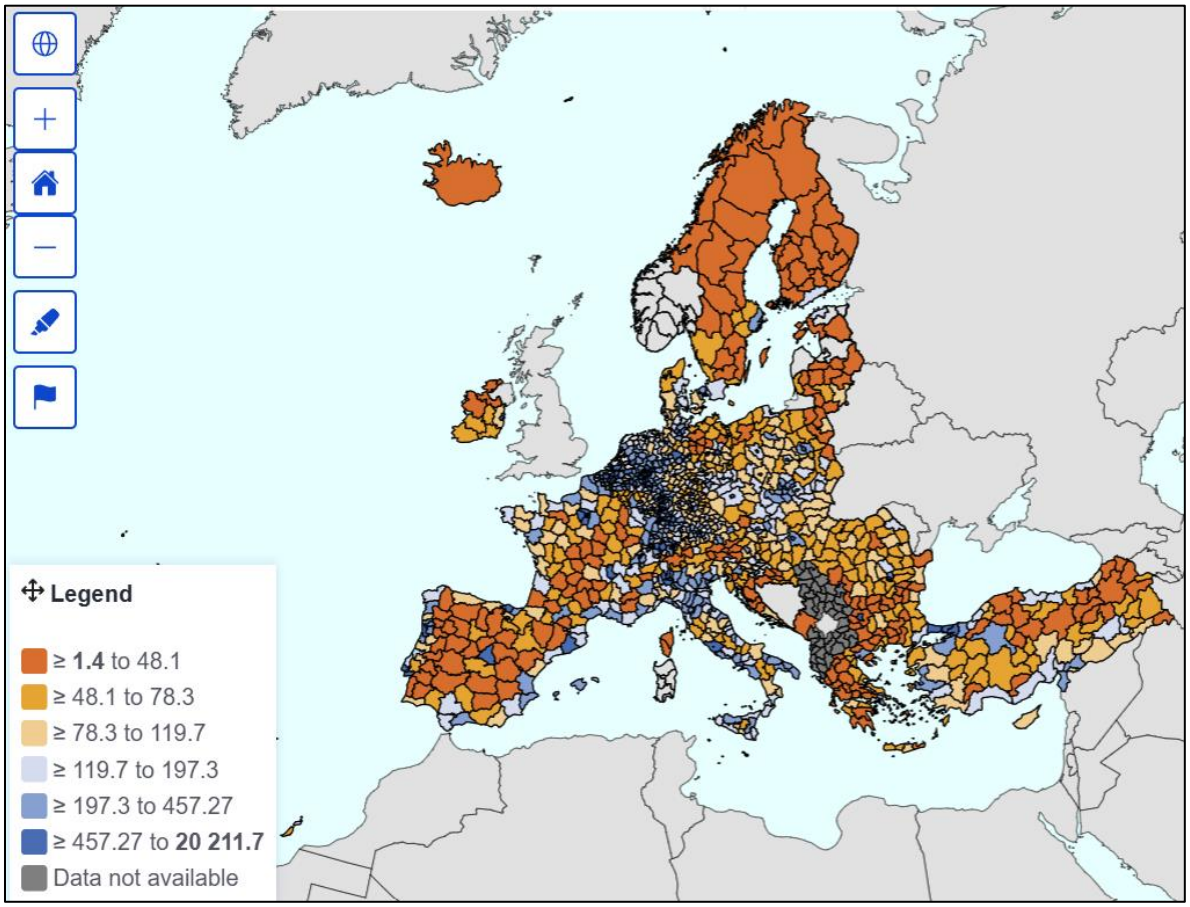


Figure 1. Population density by NUTS 3 region. *Source: Eurostat*

**LIFE Programme**

The LIFE Programme fills policy gaps by supporting projects beyond the agricultural domain, such as: restoration of wetland and grassland ecosystems; protection of endangered species; waste reduction and circular economy pilots; monitoring of climate and environmental indicators. Many Bulgarian LIFE projects serve as national best-practice models.

Importantly, LIFE-funded initiatives often introduce innovative management practices that are later incorporated into national conservation policies and replicated across multiple rural regions.

**Horizon Europe**

Horizon Europe contributes indirectly by generating research, technology, and digital innovation applicable to ecological rural development, including: precision farming technologies; nature-based climate solutions; environmental modeling and remote sensing tools.

Furthermore, Horizon Europe fosters cross-border scientific collaboration, allowing Bulgarian institutions to participate in advanced research networks and adopt cutting-edge environmental technologies.

**National Operational Programmes**

Two national programmes play a central role: **Operational Programme "Environment"**: wastewater, biodiversity, waste, and air quality. **Operational Programme "Regions in Growth"**: green public infrastructure and energy efficiency in small settlements. These complement CAP and LIFE interventions by addressing non-agricultural environmental priorities.

## The State of Ecological Conditions in Bulgarian Rural Areas

Rural regions in Bulgaria occupy a substantial portion of the national territory while accommodating a comparatively small and steadily declining share of the population. Many of these municipalities are characterized by low population density, pronounced demographic ageing, and outward migration. This demographic profile, combined with the country's extensive agricultural landscapes, influences the ability of local communities to manage natural resources effectively and to implement environmentally sustainable practices.The ecological state of Bulgaria's rural areas reflects the interaction between significant natural assets, pressures deriving from agricultural production, and long-standing socio-economic constraints.

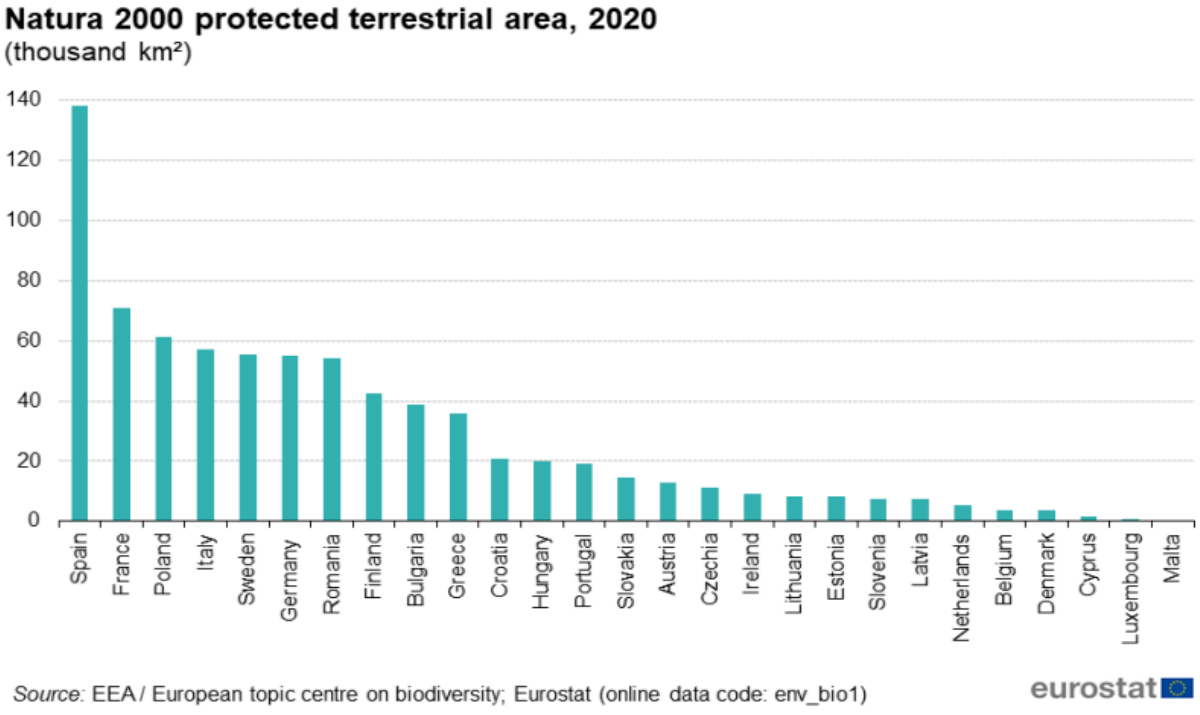


Figure 2. Natura 2000 protected terrestrial area, 2020. *Source: Eurostat*

Much of rural Bulgaria is endowed with remarkable biological diversity, broad forested territories, and a comprehensive network of Natura 2000 sites. These areas play a crucial role in preserving ecosystems, safeguarding rare and endemic species, and contributing to national ecological stability.Soil conditions vary considerably from region to region. While parts of the countryside maintain favourable

levels of organic matter and nutrients, other territories experience processes of soil degradation, including erosion, acidification, and disrupted nutrient balances. Water resources are also subject to environmental pressures. Intensive agricultural activity can lead to nitrate contamination, inefficient irrigation systems, and decreasing water quality in both surface and groundwater bodies.

Biodiversity represents one of the country's most valuable ecological features. Rural landscapes support numerous protected habitats, rare flora, and diverse populations of birds and mammals. Nevertheless, these ecosystems continue to face risks linked to landscape fragmentation, agricultural intensification, and the abandonment of traditional land-management practices. Although Bulgaria's Natura 2000 network covers large areas and offers essential protection, ongoing conservation measures and active management are necessary to maintain long-term ecological integrity. Socio-economic trends exert further influence on environmental conditions.

Continuous depopulation, limited employment opportunities, and constrained municipal budgets weaken the institutional capacity to introduce, monitor, and sustain environmental policies. These challenges restrict the spread of environmentally friendly agricultural approaches and reduce the overall capacity for sustainable stewardship of natural resources.

Despite these constraints, rural Bulgaria possesses considerable potential for ecological progress. Growing interest in eco-tourism, expansion of organic agriculture, and increased participation in EU-funded conservation initiatives indicate positive shifts in rural environmental governance. Strengthening land-use planning, promoting climate-resilient farming systems, and enhancing institutional capacity are essential steps in ensuring the sustainable management of Bulgaria's rural ecosystems over the long term.

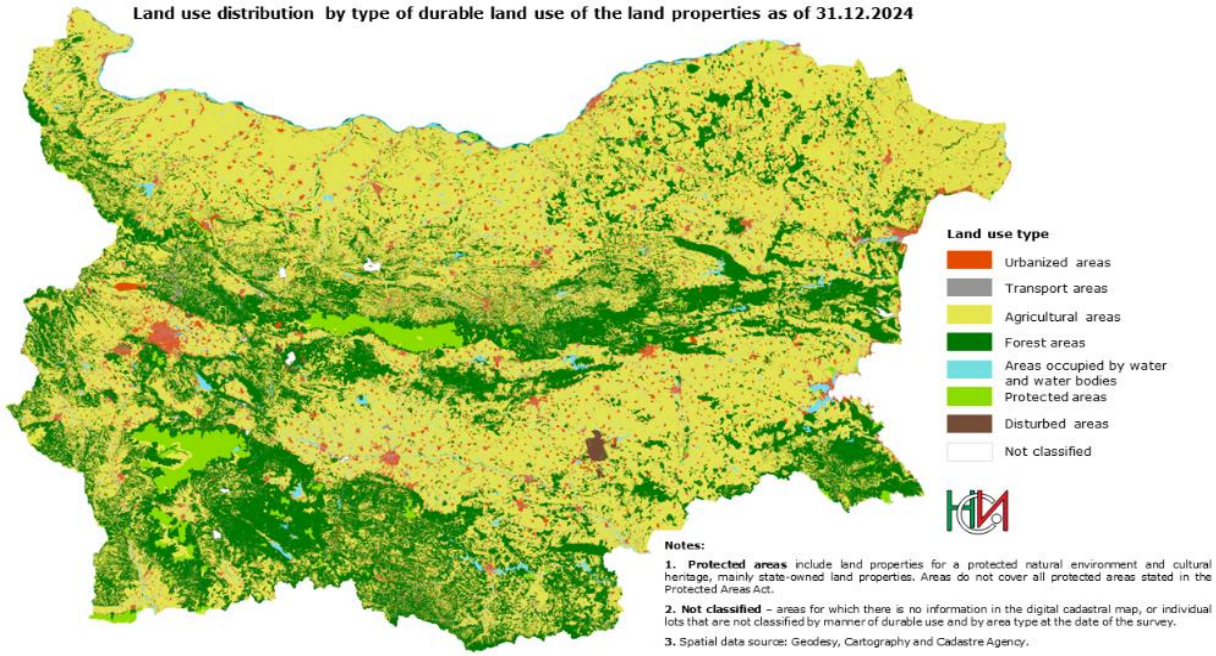


Figure 3. Land use distribution by type of durable land use of the land properties Republic of Bulgaria
Source: National Statistical Institute Republic of Bulgaria

## European programmes and implemented ecological measures in Bulgaria

The ecological transformation of Bulgaria's rural regions is largely driven by a set of major European Union programmes, policy frameworks, and financing instruments that underpin national and local environmental strategies. These mechanisms collectively support habitat conservation, restoration of degraded ecosystems, the adoption of sustainable agricultural techniques, and improvements in environmental governance structures.

The practical implementation of these programmes has led to measurable ecological improvements across numerous rural municipalities. Habitat restoration activities, funded primarily through LIFE and EAFRD, have contributed to the revitalization of grasslands, wetlands, and forest ecosystems, while targeted measures under the CAP have promoted sustainable crop rotations, reduced pesticide dependency, and improved soil fertility. These actions align with the objectives of the EU Biodiversity Strategy and help reinforce the ecological connectivity of Natura 2000 sites across Bulgaria.

At the same time, the integration of European environmental priorities into national policy frameworks has strengthened institutional capacity at multiple administrative levels. Municipalities and regional authorities increasingly adopt nature-based solutions, enhance environmental monitoring practices, and incorporate sustainability criteria into local development planning. Although these interventions vary in scale and effectiveness, they collectively represent a significant step toward a more resilient and environmentally responsible model of rural development in Bulgaria.

One of the most influential components in this system is the Natura 2000 ecological network, which encompasses a substantial share of Bulgaria's countryside. Through EU-supported interventions, the country implements targeted conservation activities aimed at maintaining the integrity of natural habitats, safeguarding rare and threatened species, and enhancing ecological connectivity across landscapes. In recent years, national authorities have advanced several initiatives that align with EU biodiversity objectives.

| | |
|---|---|
| Total number of farms: | **202 720** [1] |
| Total utilised agricultural area (UAA) (ha): | **5 037 470** [2] |
| Total forest area (ha): | **4 723 739** [3] |
| Total agricultural area and forest area in Natura 2000 sites (ha): | **1 123 476** [3] |
| Total number of livestock units: | **1 094 240** [1] |
| Total rural population – for LEADER: | **2 812 687** [4] |
| Total rural population – for services and infrastructure: | **2 110 895** [5] |
| Total number of beehives notified to the EU Commission [6]: | **838 064** [4] |

**Data source:** Bulgarian 2023-2027 CAP Strategic Plan (CSP).
**Note:** (1) 2016 data; (2) 2019 data; (3) 2018 data; (4) 2020 data; (5) 2021 data; (6) Average of the latest three years available at the time of establishing the CSP.

These include large-scale ecosystem mapping, assessments of ecosystem services, and the integration of nature-based solutions within protected areas. Such actions help reinforce the ecological resilience of rural landscapes and mitigate environmental pressures including habitat fragmentation, soil degradation, and climate-induced disturbances.

The Common Agricultural Policy (CAP) contributes significantly to rural ecological development by promoting agricultural systems that are compatible with environmental protection and climate adaptation goals. Bulgaria's CAP Strategic Plan blends compulsory environmental standards with voluntary eco-schemes that incentivize soil conservation, diversified crop rotations, preservation of permanent grasslands, and growth in organic farming.

Figure 4. General information. *Source: Bulgarian 2023-2027 CAP Strategic Plan*

As a result, an increasingly larger proportion of agricultural land in Bulgaria is managed under environmentally driven commitments designed to reduce reliance on synthetic inputs, safeguard water quality, and support high-nature-value farming systems. Further progress is achieved through the Operational Programme "Environment," which channels EU funding into environmental monitoring, strategic conservation planning, and institutional capacity-building.

These projects aim to improve the administrative and technical ability of national bodies responsible for managing the Natura 2000 network. Activities include the preparation of conservation plans, enhancement of surveillance systems, and the implementation of environmental impact assessments.

Public awareness campaigns and participatory initiatives strengthen local involvement, encouraging communities, landowners, and stakeholders to take an active role in ecological protection.

## Effectiveness and Observed Outcomes

European Union programmes – most notably the Rural Development Programme (RDP/EAFRD), the LIFE Programme, and the Operational Programme "Environment" – play a decisive role in advancing ecological improvements across Bulgaria's rural regions.

Through targeted investments and policy incentives, these instruments support biodiversity conservation, rehabilitation and management of natural habitats, enhancements in soil and water quality, and the introduction of environmentally responsible land-use practices at the local level. One of the most visible outcomes of these interventions is the expanding coverage of areas subject to habitat restoration and ecological management.

Projects financed through the LIFE Programme and Natura 2000 initiatives have demonstrated substantial success in safeguarding vulnerable species and priority habitats. In several cases, Bulgarian LIFE projects have earned recognition at the European level for their innovative approaches and measurable ecological benefits. Agri-environmental and climate-related measures under the Rural Development Programme have also produced positive environmental effects. Independent assessments of the 2014–2020 programming period indicate noticeable progress in biodiversity preservation, improved soil stewardship, and more sustainable management of natural resources.

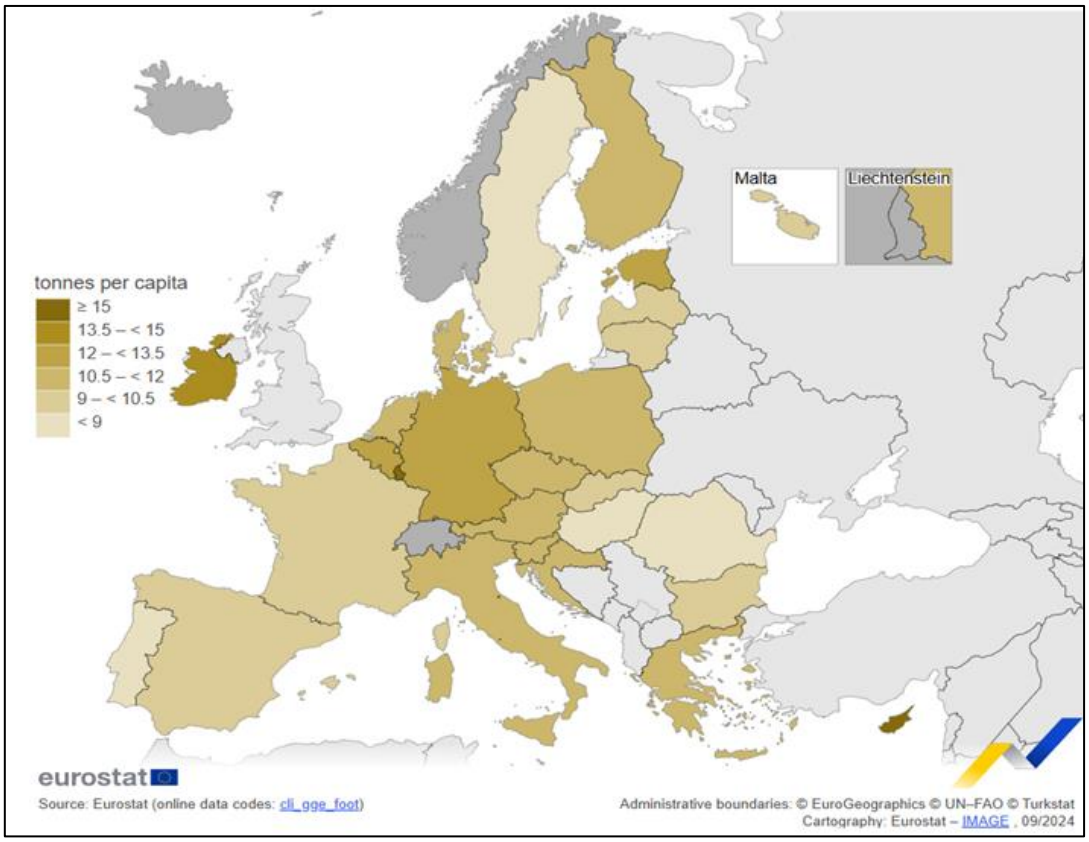


Figure 5. Greenhouse gas footprints (tonnes per capita). *Source: Eurostat*

However, these outcomes show considerable regional variation, with differences linked to local governance capacity, farmer participation, and socio-economic characteristics of rural communities. In case studies of the Blagoevgrad region, Patarchanova (2019) shows how demographic decline, ageing populations and spatial restructuring combine to affect rural stability and local ecological resilience. In parallel, significant improvements have been achieved in water management, waste management, and risk prevention infrastructure, largely due to financial support from the Operational Programme "Environment" and other structural funds.

Despite these advances, the persistence of administrative and technical constraints often limits the scalability of successful ecological measures. Many rural municipalities lack the personnel, expertise, or long-term strategic planning capacity needed to maintain complex environmental projects once EU funding cycles conclude. This creates a dependency on periodic external financing and undermines the continuity of ecological restoration efforts, especially in areas facing acute demographic decline.

Furthermore, the multi-layered structure of EU environmental governance can create coordination challenges between national authorities, local administrations, and private land users. Differences in implementation capacity occasionally lead to fragmented outcomes, where high-performing regions demonstrate substantial ecological progress while others struggle to fulfil even basic environmental obligations.

Addressing these disparities requires more integrated territorial approaches and enhanced support mechanisms tailored to the specific needs of vulnerable rural communities.

These investments have strengthened local resilience by upgrading wastewater treatment, modernizing waste systems, and enhancing preparedness for environmental risks. Despite these positive developments, the territorial impact of EU-funded ecological measures remains uneven. Studies consistently show that the degree to which these programmes succeed is closely tied to administrative competence, awareness among beneficiaries, and the socio-economic context in which local policies are implemented.

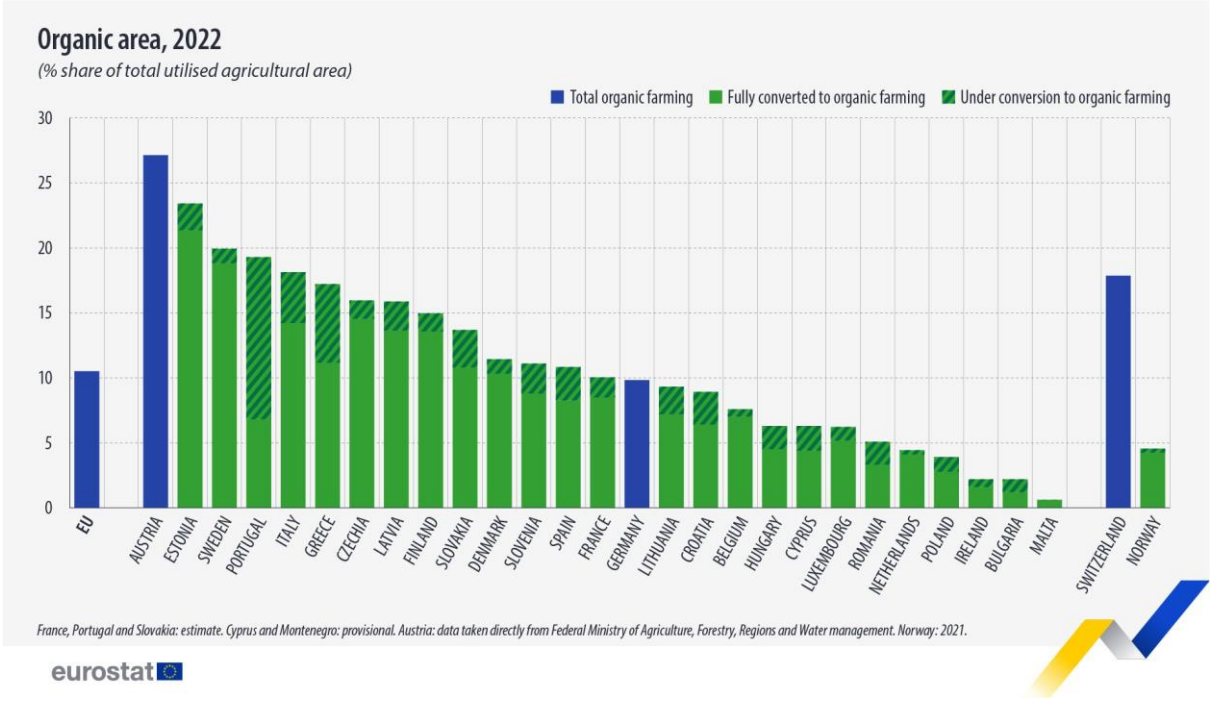


Figure 6. Organic area share of total agricultural land (in %), 2022. *Source: Eurostat*

Under Bulgaria's current CAP Strategic Plan, the eco-scheme titled "Preservation and restoration of soil potential" has become one of the most impactful tools. It promotes nutrient management plans, the use of green manure and organic fertilizers, the application of soil-improving materials, and the adoption of low-emission manure application methods.

In 2024 alone, approximately 1.2 million hectares were supported under this scheme – more than double the initially projected area. As a result, around 23% of the country's agricultural land is now managed through practices that promote sustainable nutrient use and enhanced soil health.

## CONCLUSIONS

The assessment of European programmes demonstrates that they remain a fundamental driver of ecological transformation in Bulgaria's rural regions. Their influence extends beyond simple financial support: they shape national environmental priorities, introduce higher ecological standards, and provide the institutional architecture through which sustainable land management becomes feasible. The analysis reveals that the most notable ecological progress is associated with measures targeting biodiversity protection, soil conservation, organic farming, and the restoration of high-nature-value farmlands. Instruments such as the Common Agricultural Policy's eco-schemes, agri-environment-climate measures under EAFRD, LIFE Programme restoration projects, and the Operational Programme "Environment" have collectively contributed to strengthening rural ecological resilience.

However, the study also highlights several structural limitations that continue to constrain the full ecological potential of EU programmes. Administrative complexity remains one of the most significant barriers, particularly for small and medium-sized farms that lack the technical capacity to navigate detailed application, verification, and reporting procedures. Rural municipalities, many of which experience severe depopulation, restricted budgets, and limited human resources, face similar constraints. These systemic challenges contribute to uneven participation in environmental schemes and consequently to territorial disparities in ecological outcomes. Remote, mountainous, and socio-economically disadvantaged regions tend to benefit less, despite their high environmental value.

The findings underscore the urgent need to strengthen local administrative and technical capacity. Establishing regional advisory centres, agricultural extension services, and dedicated environmental project units would significantly increase the ability of local actors to manage EU-supported initiatives. These institutional investments would not only broaden participation but also enhance the long-term sustainability of ecological interventions. Equally important is the simplification of funding procedures. Streamlined application forms, reduced bureaucratic steps, and the possibility for collective applications by farmer cooperatives or community groups would make agri-environmental measures more accessible and effective.

A more integrated, landscape-based approach to ecological management is essential. Coordinated actions across farms, municipalities, and protected areas can produce ecological benefits that exceed the sum of individual efforts, particularly in biodiversity corridors, river basins, and Natura 2000 sites. Strengthening economic incentives – through payments for ecosystem services, support for green entrepreneurship, and market recognition of sustainable agricultural products – can further align environmental goals with rural economic development.

Improved monitoring and evaluation systems are another critical requirement. Establishing a unified national observatory for rural environmental indicators would support evidence-based policy adjustments, ensure more accurate tracking of ecological outcomes, and enhance transparency of public spending. Enhanced data collection on soil carbon, habitat condition, water quality, and land-use dynamics would allow more targeted and adaptive management of EU funds.

In a broader perspective, the long-term ecological effectiveness of European programmes in Bulgaria depends on three interrelated enabling factors:

1. **empowered local governance structures**, capable of planning and implementing environmental measures;

2. **simplified and inclusive funding mechanisms**, lowering administrative barriers for smallholders and vulnerable regions; and

3. **integrated rural development strategies**, linking ecological protection with economic diversification, green jobs, nature-based tourism, and sustainable local value chains.

While EU instruments provide the strategic framework and financial resources, their transformative impact ultimately depends on Bulgaria's ability to integrate environmental, economic, and social priorities at the local level. Strengthening this alignment will allow European programmes not only to protect ecosystems but also to contribute to the long-term viability and vitality of rural communities.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

## REFERENCES

Biodiversity Information System for Europe – Country profile: Bulgaria. https://biodiversity.europa.eu/countries/bulgaria

Bulgaria – Agriculture and Rural Development Statistical Factsheet (2023) DG AGRI – European Commission https://agriculture.ec.europa.eu/document/download/93fec122-5f54-4581-9f86-860b54ba2a5b_en

CAP Strategic Plan for Bulgaria 2023–2027 European Commission – DG AGRI https://agriculture.ec.europa.eu/cap-my-country/cap-strategic-plans/bulgaria_en

CAP Strategic Plan Factsheet: Bulgaria (2023) EU CAP Network https://eu-cap-network.ec.europa.eu/publications/cap-strategic-plan-factsheet-bulgaria_en

Cooper, T., Hart, K., & Baldock, D. (2009). The provision of public goods through agriculture in the European Union. Institute for European Environmental Policy.

Dwyer, J., & Hodge, I. (2016). Governance structures for social-ecological systems: Assessing institutional options in the EU's Common Agricultural Policy. Land Use Policy, 50, 613–621. https://doi.org/10.1016/j.landusepol.2015.06.008

Evaluation of the Impact of CAP Measures on Biodiversity (EU-wide) European Commission https://op.europa.eu/en/publication-detail/-/publication/0c44f44f-928d-11eb-b85c-01aa75ed71a1 Rural Development Programme of Bulgaria 2014–2020 (Official Report) European Commission – ENRD

European Commission – Natura 2000 case: "Natura 2000 in Bulgaria: New Horizons". https://environment.ec.europa.eu/topics/nature-and-biodiversity/natura-2000-award/winners/natura-2000-bulgaria-new-horizons_en

European Commission – Project short summaries: LIFE projects (general). https://enrd.ec.europa.eu/sites/default/files/bulgaria_rdp_2014-2020_en.pdf

Eurostat – Agriculture Database Land use, livestock, organic farming, fertilisers https://ec.europa.eu/eurostat/web/agriculture/data/database

Eurostat – Organic Farming Statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Organic_farming_statistics

Eurostat – Greenhouse Gas Emissions from Agriculture https://ec.europa.eu/eurostat/databrowser/view/env_air_gge/default/table

Eurostat – Population Density by NUTS 3 Regions (Map) https://ec.europa.eu/eurostat/databrowser/view/demo_r_d3dens/default/map

Eurostat – Rural Development Indicators https://ec.europa.eu/eurostat/web/rural-development/data/database Government of Bulgaria – European Commission approved Bulgarian National Framework for Natura 2000 priority actions 2021-2027. https://www.moew.government.bg/en/the-european-commission-approved-the-bulgarian-national-framework-for-natura-2000-priority-actions-for-2021-2027/

Filatova, E., & Patarchanova, E. (2025). Geographical studies of urbanization processes and their spatial organization in Bulgaria. International Journal of Digital Research, 1(3), 97–109. https://doi.org/10.63711/ijdr.net20250303

Green Balkans NGO – The "Natura 2000 in Bulgaria – New Horizons" Project (award winner). https://greenbalkans.org/The-Natura-2000-in-Bulgaria-New-Horizons-Project-archived-great-success-and-recognition-by-winning-the-European-Commission-s-Naruta-2000-Award-2022-3-7680

Hermoso, V., Morán-Ordóñez, A., Canessa, S., Clavero, M., & Brotons, L. (2022). Prioritising Natura 2000 expansion under the EU Biodiversity Strategy 2030. Biological Conservation, 266, 109461. https://doi.org/10.1016/j.biocon.2021.109461

Karadzhov, V. (2015). Access to finance for smallholder farmers in South-Western Bulgaria and quality of administrative services. *Economics and Management*, Issue 2/ 2015, Faculty of economy, SWU "Neofit Rilski", Blagoevgrad, Bulgaria, P.p. 87-96, ISSN (print): 1312-594X ; ISSN (online): 2367-7600

Karadzhov, V. (2014). Utilization rates of European funding by farmers in South-Western Bulgaria and administrative services quality. In *Contemporary Development of European Rural Areas. International Scientific Conference*, 4–6 September 2014, Zadar, Croatia. ISBN 978-953-331-065-7.

Kleijn, D., Rundlöf, M., Scheper, J., Smith, H. G., & Tscharntke, T. (2011). Does conservation on farmland contribute to halting the biodiversity decline? Ecology Letters, 14(1), 95–105. https://doi.org/10.1111/j.1461-0248.2010.01559.x

Lefebvre, M., Espinosa, M., Gomez y Paloma, S., & Paracchini, M. L. (2015). Agricultural landscapes as multi-scale public goods and the role of the Common Agricultural Policy. Journal of Environmental Planning and Management, 58(12), 2087–2105. https://doi.org/10.1080/09640568.2014.968183

LIFE Programme (Bulgaria national site) https://www.life-bulgaria.bg/en/

Matthews, A. (2018). Why further reform of the Common Agricultural Policy is necessary. Bio-based and Applied Economics, 7(1), 1–20. https://doi.org/10.13128/BAE-20554

Ministry of Economy and Industry of Bulgaria. "LIFE Programme – Overview". https://www.mi.government.bg/en/general/programa-life/

Orlikowska, E. H., Roberge, J.-M., & Angelstam, P. (2016). Natura 2000 in Poland and Sweden: How much protection does it offer to forest biodiversity? Biological Conservation, 210, 187–197. https://doi.org/10.1016/j.biocon.2016.02.002

Paracchini, M. L., & Britz, W. (2019). Assessing spatial efficiency of agricultural policies. Land Use Policy, 81, 475–485. https://doi.org/10.1016/j.landusepol.2018.10.050

Patarchanova, E. (2019). Geodemographic processes and their effects in Blagoevgrad Municipality. Journal of Settlements and Spatial Planning, 10(2), 167-177.

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., ... & Lakner, S. (2019). Action needed for the EU Common Agricultural Policy to address sustainability challenges. People and Nature, 1(2), 316–323. https://doi.org/10.1002/pan3.11

Pe'er, G., et al. (2020). The EU's Common Agricultural Policy and biodiversity: Challenges and pathways for reform. Conservation Letters, 13(2), e12712. https://doi.org/10.1111/conl.12712

Project "Bulgarian Municipalities Working Together to Improve Air Quality" (LIFE-IP Clean Air). https://webgate.ec.europa.eu/life/publicWebsite/project/LIFE17-IPE-BG-000012/bulgarian-municipalities-working-together-to-improve-air-quality

Shishmanova, M., & Karadzhov, V. (2015). Trends for sustainable development of rural areas in Bulgaria. In *Contemporary Development of European Rural Areas. International Scientific Conference*, 4–6 September 2014, Zadar, Croatia. ISBN 978-953-331-065-7.

Shucksmith, M., Brown, D., Shortall, S., Vergunst, J., & Warner, M. (2021). Rural transformations and rural policies in the US and Europe. Routledge. https://doi.org/10.4324/9781003021157

Uthes, S., & Matzdorf, B. (2013). Studies on agri-environmental measures: A review and further research needs. International Journal of Agricultural Sustainability, 11(1), 30–47. https://doi.org/10.1080/14735903.2012.709612

Zasada, I., Reutter, M., Piorr, A., Lefebvre, M., & Gomez y Paloma, S. (2018). Enhancing sustainability of European agriculture through rural development policies. Sustainability, 10(5), 1523. https://doi.org/10.3390/su10051523

**How to cite this article:**

Shlyakov, V. (2025). European programmes as a factor for the ecological development of rural areas in Bulgaria. *International Journal of Digital Research*, E-ISSN: 3033-179X, Vol. *1*(4), 44–58. https://doi.org/10.63711/ijdr.net20250403

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Review Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 59-77*

# Labor Market in the Border Municipalities of Southwestern Bulgaria - Challenges and Trends

**Vasil Pandurski**

PhD student (Economic and Social Geography)
Department of Geography, Ecology and Environmental Protection
Faculty of Mathematics and Natural Sciences
South-West University "Neofit Rilski", Blagoevgrad, Bulgaria
ORCID ID: 0009-0001-4005-4113 E-mail: vpandurski@swu.bg

**https://doi.org/10.63711/ijdr.net20250404**

## ABSTRACT

Border municipalities have traditionally developed as peripheral territories with limited socio-economic functions due to their historical role as dividing zones. While Western Europe began processes of integration and cross-border cooperation after the Second World War, in Eastern Europe such developments occurred much later, which deepened demographic and economic disparities. In Southwestern Bulgaria, border municipalities continue to face high unemployment, long-term joblessness, depopulation, and limited access to public services. The centralization of services in municipal centers accelerates the migration of the working-age population and reduces the local labor force, making economic interventions less effective. Many municipalities are highly dependent on public resources and project-based funding, mainly in tourism and the agricultural sector, but the lack of entrepreneurial capacity, marketing, and modern infrastructure hinders their competitiveness. The development of modern business practices, improved transport connectivity, and strengthened cross-border cooperation are essential for overcoming this peripheral status.

***Keywords:*** *Border municipalities, Social processes, Employment, Unemployment, Wages*



## INTRODUCTION

Border municipalities in South-western Bulgaria represent some of the most demographically and economically vulnerable territories in the country. Their peripheral position, combined with mountainous relief, declining population, and limited access to major labor markets, has shaped a persistent pattern of socio-economic disadvantage. Although border areas hold potential for cooperation, mobility, and regional integration, they continue to face structural challenges such as high unemployment, low wages, weak private-sector activity, and dependence on public employment. These characteristics reflect broader European trends, where border regions are often described as "underutilized development spaces" that struggle to fully participate in national and regional economic processes.

In Bulgaria, these disparities are particularly evident along the borders with Serbia and North Macedonia, where demographic decline and restricted economic activity reinforce each other. The labor market plays a central role in these transformations: employment opportunities, wage levels, daily labor mobility, and the balance between the public and private sectors determine the capacity of local communities to remain viable and retain working-age population. Despite this, there is still a lack of detailed studies focusing specifically on the labor-market dynamics of the border municipalities in Southwestern Bulgaria. Existing research tends to examine broader regional or national trends, leaving a gap in understanding the local socio-economic mechanisms that drive inequality within these peripheral territories.


This article seeks to address this gap by offering a spatially differentiated analysis of employment, unemployment, labor mobility, and wages in the fourteen border municipalities of the Southwestern Region. By integrating statistical data with territorial interpretation, the study aims to identify the structural factors that shape labor-market outcomes and contribute to persistent regional disparities. The findings provide a clearer understanding of the socio-economic conditions in these municipalities and offer a basis for developing targeted policies aimed at strengthening local labor markets, improving connectivity, and enhancing the competitiveness of border regions.

Figure 1: Location of the border municipalities in the Southwest Region

## LITERATURE REVIEW

The labor market in border and peripheral regions has attracted increasing academic interest due to deepening demographic decline and socio-economic disparities. In the Bulgarian literature, Ravnachka (2015; 2021) highlights demographic erosion, population ageing and the shrinking labor force in mountain and border areas, including the Blagoevgrad and Kyustendil regions.

Similar findings are reported in recent European studies, which emphasize that peripheral labor markets experience accelerated depopulation, structural unemployment and limited economic diversification (ESPON, 2020; Lang & Görmar, 2019). Border regions in particular exhibit weaker labor-market absorption capacity and higher vulnerability to demographic shocks, especially in Southeastern Europe (Partridge, M. D., & Rickman, D. S., 2008; Buturac, 2019).

Veselinova (2017) provides the theoretical framework for processes such as urbanization, peripheralization and intra-regional inequalities. Contemporary geographical research further notes that labor markets in mountainous and rural border territories face multi-dimensional constraints such as ageing, low human capital and infrastructural deficits. International research demonstrates that peripheral and border regions consistently face structural labour-market disadvantages linked to low accessibility, demographic decline, and limited private-sector capacity (Fratesi, U., & Wishlade, F., 2017; Corcoran, J., & Faggian, A., 2017). These structural disadvantages reduce labor mobility and hinder integration into wider regional economic systems. At the local level, Patarchanova (2019) demonstrates the role of Blagoevgrad as a regional center of attraction and a factor shaping labor flows from neighboring municipalities.

The specificity of border regions is examined both through the lens of cross-border cooperation (Geshev, 1998) and within European strategic documents, which emphasize the untapped potential of border areas and the need to overcome infrastructural and institutional barriers (COM, 2017) 534; European Court of Auditors, 2021). Projects such as INNOBUS (2021) show that a cluster-based approach and strengthened connectivity can enhance competitiveness and employment in border territories. At the same time, several Bulgarian studies emphasize the need for functional labor-market integration and improved cross-border regional planning (Karadzhov, 2024). Recent regional studies also highlight the importance of tourism diversification for small municipalities and its role in strengthening local labor markets in peripheral areas (Karadzhov et al., 2024). These works highlight that border regions can benefit substantially from improved infrastructure, digitalization and coordinated regional employment policies.

International comparative research confirms that labor-market inefficiencies in peripheral regions are strongly correlated with low wage levels, skills mismatches and outward labor migration (Rodríguez-Pose & Ketterer, 2020; OECD, 2019). Studies focused on Balkan border regions also reveal persistent structural unemployment and dependence on low-paid sectors such as agriculture and seasonal services (Nestorov & Petrović, 2022).

Furthermore, recent publications in the International Journal of Digital Research demonstrate how digital connectivity, cross-border cooperation and regional innovation strategies can influence socio-economic performance in small municipalities (Filatova & Patarchanova, 2025).

The empirical basis for analyzing the labor market in border municipalities is provided by official statistics from the National Statistical Institute (employment, unemployment, wages, and daily labor mobility), the Employment Agency and Eurostat, which allow long-term trends and territorial differences to be traced. However, there is a lack of targeted research focused specifically on the border municipalities of Southwest Bulgaria. This article aims to contribute to filling this gap by offering a spatially differentiated analysis of employment, unemployment, labor mobility and wages in these peripheral territories.

Overall, the existing literature suggests that labor-market challenges in border municipalities are multifactorial and deeply embedded in spatial, demographic and infrastructural conditions. This aligns with broader conceptualizations of regional peripherality and labor-market fragmentation, underscoring the need for territorially specific analyses such as the present study.

## METHODS OF RESEARCH

The study applies a set of complementary research methods that ensure a comprehensive and territorially grounded analysis of labor-market processes in the border municipalities of Southwestern Bulgaria. First, a **statistical method** is used based on official quantitative data from the National Statistical Institute, the Employment Agency and Eurostat. This allows the dynamics of employment, unemployment, wages and daily labor mobility to be traced over time and compared with regional and national averages. The indicators are processed and interpreted in order to reveal long-term trends, structural characteristics and the degree of socio-economic vulnerability of the fourteen border municipalities.

Secondly, a **comparative territorial analysis** is applied to examine differences between municipalities that vary in demographic structure, geographical location, economic profile and degree of integration into wider labor markets. By comparing municipalities with relatively developed urban centres to sparsely populated, mountainous and peripheral territories, the study identifies distinct patterns such as core–periphery relations, labour-attracting versus labour-donor municipalities, and territories with predominantly public versus predominantly private employment.

Thirdly, a **document and policy analysis** is used to contextualise the observed labour-market processes within the existing institutional and strategic framework. National and regional strategic documents, socio-economic analyses and EU policy papers related to regional development, cohesion policy and cross-border cooperation are examined in order to link empirical findings with the

objectives, instruments and limitations of current development policies. In addition, the interpretation of cartographic materials and spatial distributions (employment rates, unemployment, labour mobility, wage levels) supports the identification of geographical dependencies and functional linkages between municipalities, contributing to a more accurate understanding of the spatial dimensions of the labour market in the border region.

## RESULTS AND DISCUSSION

The following section presents a detailed territorial analysis of the main labor-market indicators in the border municipalities of Southwestern Bulgaria. By combining statistical data with spatial interpretation, the discussion highlights the structural patterns that shape employment, unemployment, labor mobility and wage dynamics across these peripheral territories. The aim is to reveal the geographical disparities and functional dependencies that determine the socio-economic position of each municipality, and to provide an integrated understanding of how demographic, infrastructural and economic factors interact within the regional labor market.

### Employment

Employment represents a fundamental dimension of the socio-economic condition of border municipalities, reflecting both the capacity of local economies to generate jobs and the ability of the population to participate in productive activity. In peripheral and demographically declining territories, employment patterns are strongly shaped by geographical location, access to labor markets, infrastructural connectivity, and the degree of economic diversification. Before examining the specific indicators, it is essential to outline the overall employment landscape in the region, as it provides the basis for understanding the territorial contrasts and structural vulnerabilities that characterize Southwestern Bulgaria's border municipalities.

#### Employment rate

Employment is one of the key indicators of the economic and social condition of a given territory, as it reflects not only the economy's ability to create jobs but also the degree to which the population is integrated into productive and service activities. The level of employment is directly linked to income, quality of life and social stability, and more broadly – to the sustainability of local communities and their ability to retain and attract population. In peripheral and border regions, where economic activity is often limited and access to markets and resources is constrained, employment becomes even more important as a factor in overcoming demographic decline and social marginalization.

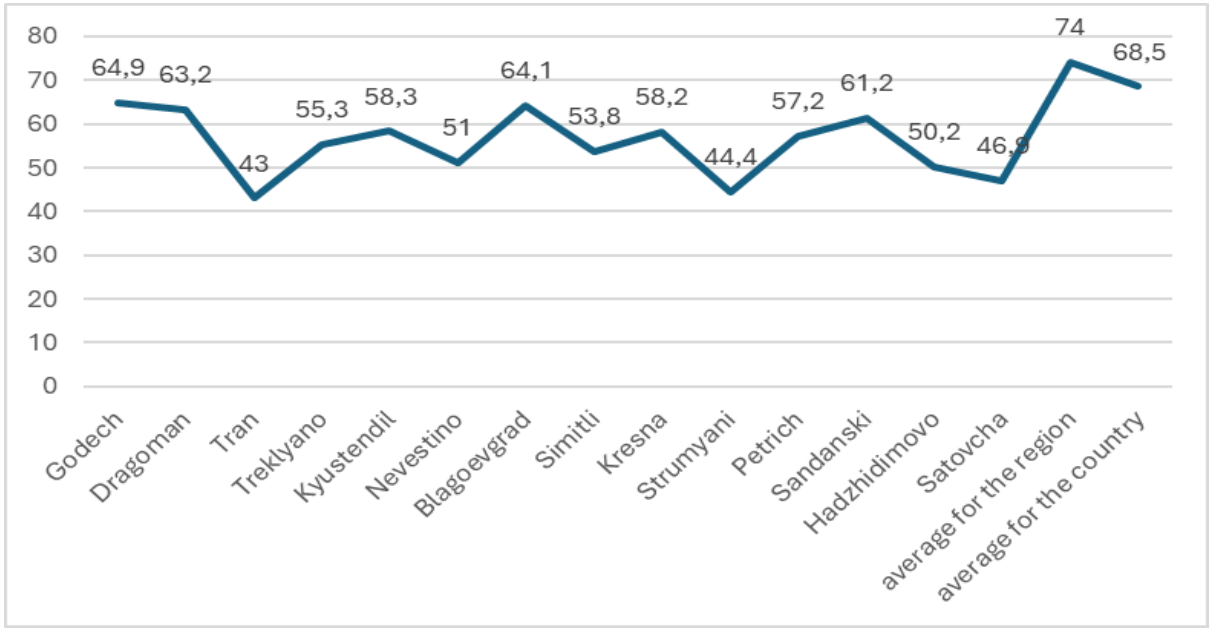

Figure 2: Employment rate of the population aged 15–64, 2021 (in %)

The analysis of the employment structure in the border municipalities of the Southwestern Region, based on empirical data, reveals a clear territorial differentiation and discrepancies compared to the average values for the region and the country. According to Fig. 2, the average employment rate for Bulgaria stands at 68.5%, while that for the Southwestern Region reaches 74%. A significant share of the border municipalities remain below these values, reflecting their economic peripherality and socio-demographic vulnerability.

The municipalities of Godech (64.9%), Dragoman (63.2%), Simitli (64.1%), and Sandanski (61.2%) show the highest employment levels, approaching or exceeding the national average. Their relatively more favorable economic profile is determined by several key factors: proximity to Sofia (in the case of Godech and Dragoman), the presence of logistic corridors and industrial zones (Dragoman), or active development of tourism, balneology, and services (Sandanski). Simitli, for its part, benefits from its location between Blagoevgrad and Sandanski and from maintained connectivity to major transport arteries.

The group of municipalities with medium employment values (between 50% and 60%) includes Treklyano (55.3%), Kyustendil (58.3%), Nevestino (51%), Blagoevgrad (53.8%), Kresna (58.2%), Petrich (57.2%), and Hadzhidimovo (46.9%). Here, we observe a strongly heterogeneous profile – from the relatively industrialized Kyustendil to the agriculturally oriented Nevestino and Hadzhidimovo. Blagoevgrad, despite its status as a regional center, lags behind the regional average, which may be explained by demographic pressure, youth migration, and the concentration of non-working student population. Petrich, although benefiting from cross-border trade and services, still fails to realize its full economic potential.

Particularly concerning are the data for the municipalities of Trŭn (43%), Strumyani (44.4%), and Hadzhidimovo (46.9%), which show some of the lowest employment levels in the region. These are mountainous and border territories characterized by demographic collapse, a high degree of isolation, difficult access to labor markets, and the lack of a sustainable economic base. These municipalities fall into the so-called “zones of silent depopulation,” where social infrastructure is reduced to a minimum, and labor activity is maintained mainly through self-employment, seasonal migration, or informal forms of employment.

This spatially determined analysis highlights the need for a differentiated regional employment policy based on local potentials and vulnerabilities. A “one-size-fits-all” approach does not work in the context of border and mountainous areas, which require territorially targeted measures – encouraging local entrepreneurship, supporting seasonal and social economy, investments in human capital, and employment-related infrastructure.

**Public and Private Sector**

The structure of employment between the public and private sectors is among the fundamental characteristics of local economies, as it reveals both the patterns of economic activity and the degree of institutional and market dependence of the municipalities. The share of employees in the two sectors reflects not only the presence of state and municipal institutions, but also the capacity of private businesses to create jobs and stimulate local development. The analysis of these indicators makes it possible to outline the structural differences between municipalities and to assess the sustainability of local labor markets.

**Figures 3 and 4 reflect the dynamics in the share of employees in the public sector in the border municipalities of the Southwestern Region of Bulgaria for the years 2019, 2021, and 2023.** The municipalities are divided into two groups according to the relative share of public employment – the first group includes municipalities with predominant public-sector employment, while the second comprises those with more pronounced participation of the private sector. A comparison between the share of employees in the public sector and the complementary share of those employed in the private sector (as the difference up to 100%) reveals significant territorial, economic,

and social disparities that directly influence the sustainability of local economies, structural employment, and the functional role of public administration and services in regional development.

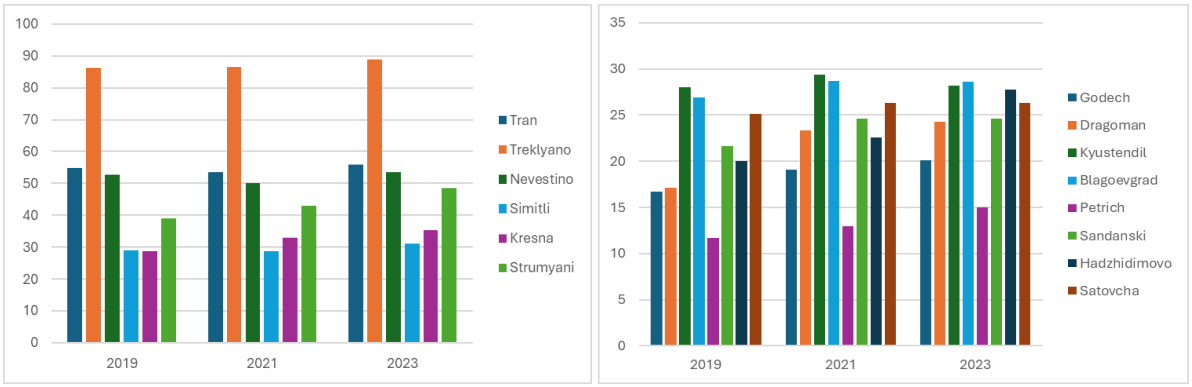


Fig. 3 and Fig. 4 Share of Employees in the Public Sector (in %)

In the first group, with high levels of public employment, the municipality of Treklyano clearly dominates. Throughout the entire period under review – 2019 to 2023 – more than 85% of employees in the municipality work in the public sector. In 2023, the share reaches almost 90%, leaving only about 10% for the private sector. This is a classic example of the so-called "budget economy" – a model in which state and municipal institutions, including administration, educational, and healthcare establishments, serve as the main (and often the only) source of employment. A similar situation is observed in the municipalities of Trŭn and Nevestino, where the public sector maintains a share between 50% and 55%, while the private sector ranges between 45% and 50%. This indicates that public employment plays a stabilizing role and is a key source of income for the population in conditions of limited economic initiative.

The municipalities of Strumyani and Kresna demonstrate a more moderate but stable dependence on public-sector employment. In Strumyani, an increasing trend is observed – from about 39% in 2019 to nearly 48% in 2023 – suggesting that the public sector continues to assume functions that the private sector is unable to fulfill. A similar, though less pronounced, trend is present in Kresna. In the municipality of Simitli, the share of public-sector employees remains relatively low – around 30%, indicating that the private sector maintains a stronger position, especially compared to the other municipalities in this group.

The second chart includes municipalities in which the public sector plays a secondary role in overall employment. These are larger, better connected, and economically more active territories where private initiative and business development play a dominant role. In the municipalities of Blagoevgrad, Kyustendil, and Sandanski, the share of employees in the public sector ranges between 26% and 30%, meaning that around 70–74% of the workforce is engaged in the private sector – in trade, services, tourism, manufacturing, and transport. This ratio is an indicator of a more robust economic structure, market mechanisms, and weaker dependence on state support.

The municipality of Petrich demonstrates an even stronger orientation toward the private economy. The share of public employment fluctuates between 12% and 15% during the observed period, meaning that the private sector provides over 85% of jobs. A similar situation exists in Godech, which, although smaller, shows a stable share of private employment – around 80% over the three years. This suggests the presence of local enterprises or a favorable proximity to economically active zones, including opportunities for labor migration to the capital. In the municipality of Hadzhidimovo, the share of public-sector employees increases to nearly 28% in 2023, but the private sector still retains a larger share. However, this may signal constraints on private initiative and compensation through public programs or budgetary spending.

**The analysis of the differences between public and private employment highlights the presence of two main types of border municipalities in Southwestern Bulgaria.** On the one hand

are the small, demographically vulnerable, and economically lagging territories with dominant budgetary employment, where the public sector acts as a stabilizing factor. On the other hand are the more urbanized, integrated, and economically active municipalities where the private sector is leading, while the public sector complements it through administrative and social functions. The balance between these two sectors not only outlines the structure of the local economy but also affects sustainability, quality of life, investment attractiveness, and the demographic prospects of each municipality.

**This indicator is crucial for analyzing socio-economic processes in border areas, where the effects of remoteness and demographic decline require targeted policies for economic diversification, promotion of entrepreneurship, and strengthening the capacity of the private sector to provide stable and sustainable employment.**

**Labor Migrants**

Within contemporary regional studies, labor mobility has become a key indicator of the degree of economic interconnectedness between individual territories. In the context of increasing spatial dynamics and growing municipal specialization, daily labor movements reflect the actual functional organization of regional space. In this regard, the analysis of the share of labor migrants who leave the municipality, as well as those who enter it from other territories, provides valuable information about the directions, intensity, and interdependencies of local labor markets. The data for 2021 make it possible to outline the characteristic patterns of labor mobility in the studied municipalities and to identify the leading centers of labor concentration.

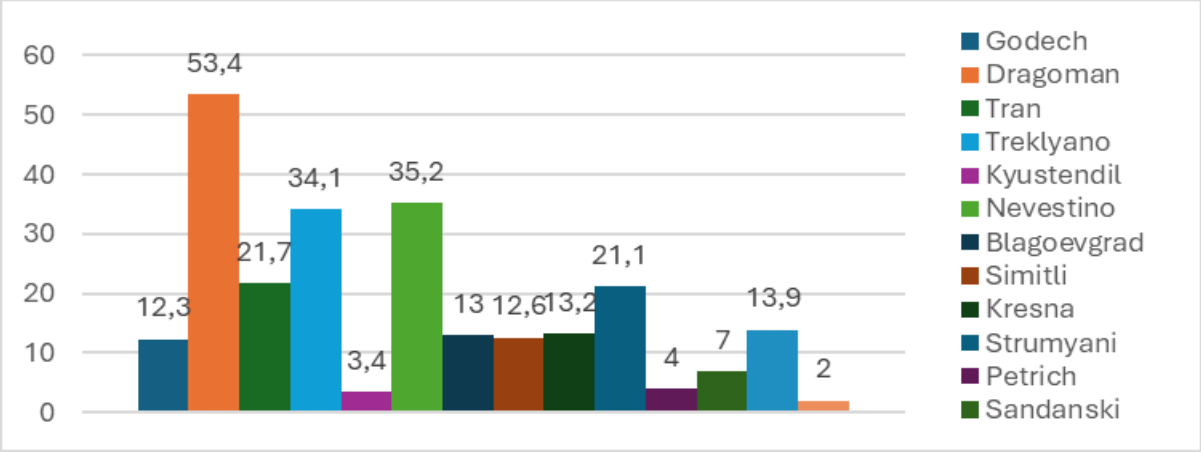


Figure 5: Share of daily labor migrants from other municipalities in %, 2021

Figure 5 traces the spatial differences in the share of daily labor migrants from other municipalities relative to the total number of employed persons in selected municipalities of Southwestern Bulgaria for 2021. The diagram reveals a clear heterogeneity between the municipalities, which suggests the need for a deeper analysis that takes into account the socio-economic, demographic, and infrastructural characteristics of the studied territory.

The municipality of Dragoman stands out most strikingly, with more than 53% of employed persons being daily labor migrants from other municipalities. This phenomenon should be interpreted as a result of its strategic location near Sofia – the leading economic and labor center of the country. It is highly likely that Dragoman functions as a logistic and transport zone serving the periphery of the capital. This generates a demand for labor that cannot be met solely by the local population, both due to demographic constraints and mismatches between available qualifications and employers' requirements. In this sense, the high share of incoming labor migrants is an indicator not only of economic activity but also of structural deficits in the local labor market.

A similar dynamic is observed in small and demographically vulnerable municipalities such as Nevestino (35.2%) and Treklyano (34.1%). In these cases, the high values of incoming labor

migration are not so much the result of intensive economic activity as of an extremely small and ageing local labor force. Even a limited number of incoming workers significantly increases their relative share of total employment in the municipality. These cases clearly illustrate the so-called "small-base effect" and should be interpreted with caution, especially when used for policy or strategic conclusions in regional development.

Municipalities such as Trŭn (21.7%) and Strumyani (21.1%) also register a high share of incoming labor migrants. In both cases, these are territories with limited local employment, where selective economic specialization is observed – for example in agriculture or extractive industries – which often rely on seasonal or external labor. Cross-border labor mobility may also play a role, particularly given the proximity to the Serbian and North Macedonian borders.

At the opposite end of the spectrum are municipalities such as Satovcha (2%), Petrich (4%), and Kyustendil (3.4%). Here, the share of incoming daily labor migration is extremely low, suggesting the presence of a relatively well-balanced local labor market. This may be due both to a comparatively stable demographic structure and to an economy that provides sufficient local employment opportunities. For example, Kyustendil is an administrative and cultural center with traditions in agriculture and services, which creates conditions for local employment without the need to import labor.

Sandanski (7%) and Simitli (12.6%) occupy an intermediate position, characterized by a moderate inflow of external labor migrants. This likely reflects regional mobility within agglomeration zones around larger cities (e.g. Blagoevgrad), while also indicating the presence of a relatively self-sufficient labor force.

Based on the above analysis, several main conclusions can be drawn. First, a high share of incoming daily labor migration is often an indicator of economic activity that exceeds the capacity of the local labor market.

Second, in small and demographically weakened municipalities, a high share may result not from economic attractiveness but from the low absolute number of employed persons, which distorts the relative values.

Third, a low share of labor migrants may signal both the stability of the local labor market and low economic attractiveness, necessitating a deeper contextual analysis.

Such an understanding of labor-migration dynamics is essential for designing territorially adapted policies in the fields of employment, infrastructural development, and demographic sustainability.

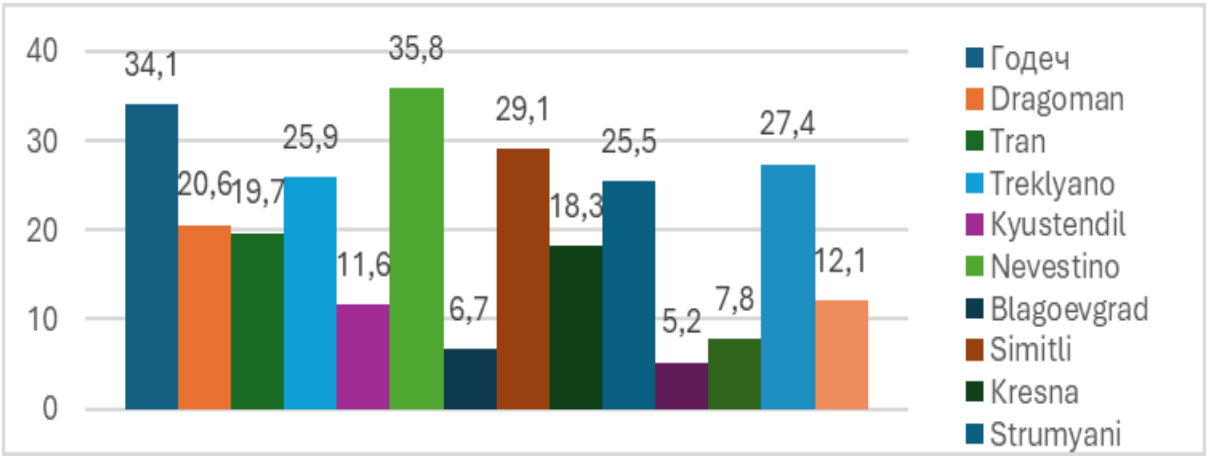


Figure 6: Share of daily labor migrants commuting to other municipalities in %, 2021

In 2021, the spatial distribution of daily labor migration in Southwestern Bulgaria (Fig. 6) reveals clearly expressed territorial disparities in the share of employed persons who leave their municipality

to work elsewhere. These differences reflect a complex spectrum of economic, demographic, and infrastructural factors that shape the socio-economic dynamics at the regional level.

The highest share of outbound labor migrants is observed in the municipality of Nevestino, where 35.8% of employed residents commute daily to other municipalities for work. This is indicative of an acute deficit of local employment opportunities and a limited economic base within the municipality itself. As a small and demographically vulnerable territory, Nevestino sends a substantial portion of its active population to larger and more economically developed centers, making mobility a necessary strategy for labor realization.

A similar tendency is present in Godech, where 34.1% of employed persons work in other municipalities. Godech's proximity to Sofia positions the capital's labor market as the primary attractor of workforce mobility. Here, the issue is not merely the lack of local opportunities but a structural dependence on a major economic pole, within whose orbit Godech functions as a periphery. This suggests the presence of adequate transport accessibility and daily connectivity with Sofia, facilitating labor migration.

High levels of outbound mobility are also recorded in Simitli (29.1%), Blagoevgrad (27.4%), Strumyani (25.5%), and Treklyano (25.9%). Although differing in scale and economic profile, these municipalities share a common characteristic: limited capacity to retain their workforce. Simitli and Strumyani are typical transit municipalities near larger cities such as Blagoevgrad and Sandanski, implying that residents travel daily to neighboring settlements offering better employment conditions. Blagoevgrad itself, despite its status as a regional center, registers a considerable share of outbound commuters, underscoring regional interconnectedness and the deep integration of municipalities within a broader functional urban zone.

At the opposite end of the spectrum are municipalities with low shares of daily outbound labor migration. Petrich reports only 5.2%, indicating a strong local labor market and a high degree of economic self-sufficiency. The town serves as a local hub, with a balanced employment structure and the presence of industrial, commercial, and tourism-related activities that satisfy the labor needs of its residents.

A similar case is observed in Kyustendil (11.6%), where outbound mobility is also low due to a stable economic structure. Dragoman likewise registers a relatively low share (20.6%) of workers commuting out of the municipality, aligning with data on its high inbound labor flow – a sign of economic activities capable of retaining workforce locally.

These observations highlight the existence of clear regional polarization – some municipalities function as sources of labor, while others emerge as centers of labor concentration. A high share of outbound daily migration should be interpreted not only as a deficit of local economic capacity but also as a sign of integration into broader labor systems, especially when supported by adequate transport accessibility.

In conclusion, the distribution of daily labor mobility towards other municipalities is the result of a complex interplay between available employment opportunities, geographical location, transport infrastructure, and regional economic dependencies. This process requires careful planning within the framework of regional policy, focusing on balanced territorial development, improving local labor markets, and strengthening integration between centers and peripheries.

**The "from–to" relationship**

A comparison of data on daily labor migration "from" and "to" other municipalities reveals deeper territorial dynamics that are essential for understanding regional labor markets in Southwestern Bulgaria. The two forms of mobility – inbound and outbound – follow different logics of movement but are closely interrelated, shaping the functional profile of each municipality according to its economic role within the broader regional context. The 2021 data outline a consistent, though not mechanical, correlation between the two types of migration, exhibiting both classical core–periphery models and more complex and unstable interdependencies between individual territories.

Municipalities with a high share of inbound labor migration typically display low or moderate levels of outbound migration. This inverse relationship is clearly visible in municipalities such as Dragoman, where more than half of the employed workforce consists of workers from other municipalities, while only about one-fifth of local employees commute outward daily. This model unmistakably indicates a concentration of economic activity and an accumulation of labor opportunities that not only satisfy local needs but also require additional human resources from outside. Dragoman, given its proximity to Sofia and the presence of logistics and industrial structures, functions as a labor-attracting center, albeit secondary in scale compared to the capital.

Conversely, Godech exhibits the opposite pattern: its outbound labor migration significantly exceeds inbound migration, positioning the municipality as a labor donor. Many local residents seek employment outside the municipality, mainly in Sofia, indicating a weak economic base, dependence on external labor markets, and likely an underdeveloped industrial or service infrastructure locally.

Particularly interesting are municipalities that register high levels of both inbound and outbound labor migration, such as Simitli. Here, both significant inflows of external workers and outflows of local residents are observed, implying a high degree of mobility and interconnectivity within the regional system. Simitli functions as an intermediate or transit zone, where labor flows converge and redistribute towards major urban centers such as Blagoevgrad. This configuration reflects the complex urbanized structure of the region, where municipal boundaries become blurred with respect to labor functions and economic dependencies. A similar, though less pronounced, dynamic can be observed in Trŭn and Kresna, both of which display a more balanced profile between inbound and outbound migration, pointing to a somewhat unstable but adaptive labor structure.

A more complex – even paradoxical – model is seen in Nevestino, where both inbound and outbound migration exceed 35%. For a small and demographically constrained municipality, such values likely reflect the small-base effect – even minimal absolute movements of the workforce translate into high relative shares. This emphasizes the need for careful interpretation of data and contextual understanding when analyzing mobility in sparsely populated territories. It is likely that a considerable portion of residents travel daily to Kyustendil or other nearby towns, while a small yet structurally significant number of incoming workers perform specific activities locally, such as administrative work.

At the opposite end are municipalities such as Petrich and Kyustendil, where both inbound and outbound migration are extremely low. This indicates strong internal labor consolidation and the presence of a relatively closed labor market that provides employment for the local population without the need for daily mobility. Petrich, in particular, stands out with a developed local economy, cross-border activity, and tourism potential, all of which create internally satisfied labor needs. Kyustendil, as a larger municipal and regional center, also demonstrates a high degree of labor self-sufficiency, albeit with some workforce outflows.

Overall, the analysis of both types of migration shows that an inverse correlation is observed in most cases – a high share of inbound mobility is accompanied by a low share of outbound mobility and vice versa. This confirms the classical model of regional cores and peripheries, whereby some municipalities act as centers of economic attraction and others as labor donors. Exceptions to this pattern reveal more complex regional interrelations characteristic of urbanized areas with high levels of integration and functional spillover across municipal boundaries. Such cases highlight the need for an interdisciplinary approach in the analysis of labor mobility and in the development of territorial policies that consider not only administrative boundaries but also the actual socio-economic flows between municipalities.

### Unemployment

Unemployment is one of the most significant socio-economic indicators, directly reflecting the condition of the labor market and the effectiveness of local economic structures. In the border municipalities of the Southwestern Region, it acquires particular importance, as it reflects the complex interaction between demographic processes, economic activity, the degree of urbanization, and access to labor markets. The dynamics of unemployment over the past decade show a clear territorial

differentiation and a distinct divide between municipalities operating in more favorable economic environments and those in which structural weaknesses and demographic erosion deepen social vulnerability.

**Dynamics of Overall Unemployment (2011–2022)**

The data presented in Figures 7 and 8 show that during the period 2011–2022, most border municipalities experienced a decline in unemployment rates, albeit with varying intensity and stability. The national average fell from around 11% in 2011 to below 5% in 2022, while in several border municipalities the values remained significantly higher.

In the first group of municipalities (Fig. 7), the highest unemployment levels in 2016 were recorded in Trŭn (over 35%) and Treklyano (over 20%), significantly exceeding national figures. These territories exemplify isolated and demographically severely affected areas, where the absence of an economic base and limited transport accessibility sustain high levels of structural unemployment. Although some improvement is observed by 2022, unemployment rates remain approximately twice the national average.

The municipalities of Kyustendil and Nevestino demonstrate relative stability and more favorable indicators – around 10–12% in 2022, which is close to the national average. Their comparatively lower unemployment is due to a combination of agricultural employment, seasonal activities, and proximity to urban labor markets. Godech and Dragoman also display moderate values (6–9%), reflecting the positive influence of labor migration towards Sofia and the presence of logistics and industrial zones.

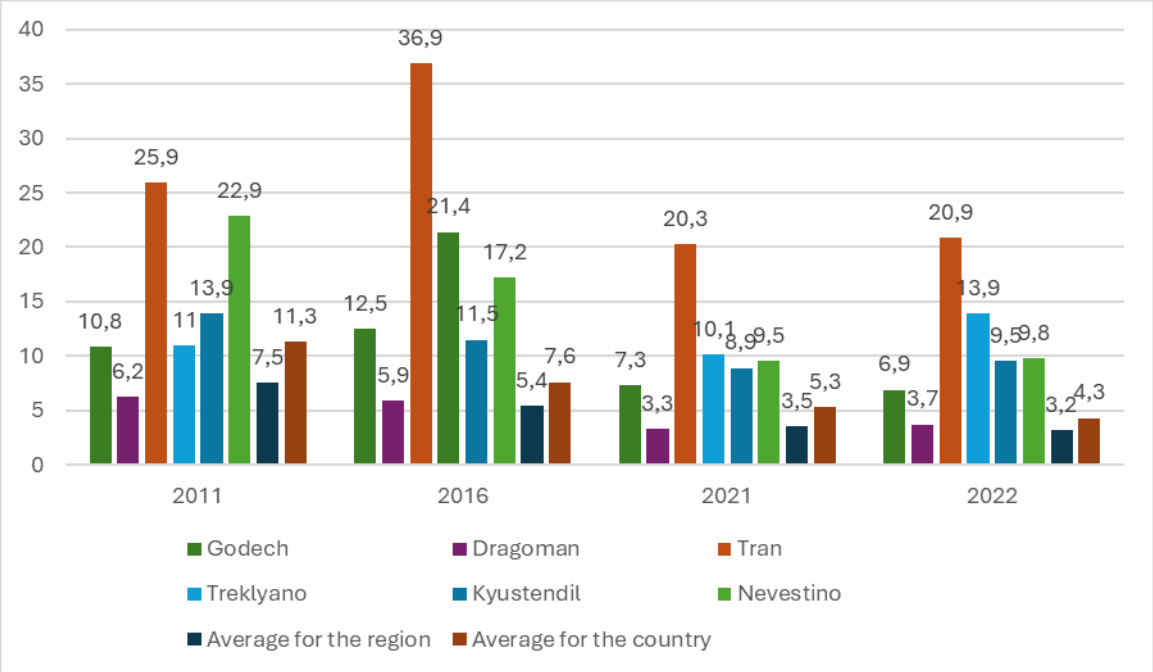


Figure 7: Unemployment Rate in the Western Border Municipalities of the Sofia, Pernik, and Kyustendil Provinces (in %)

In the second group of municipalities (Fig. 8), the variation is even more pronounced. Municipalities such as Strumyani and Satovcha maintain persistently high unemployment rates, reaching 20–25% in both 2016 and 2022, while Blagoevgrad, Petrich, and Sandanski remain below 8%. This territorial polarisation highlights a clear distinction between economically active urban centers and peripheral, agriculturally oriented territories. In Strumyani and Satovcha, high unemployment is driven by limited opportunities for permanent employment, the seasonal nature of available work, and the low qualification levels of the population.

The municipalities of Simitli and Kresna demonstrate moderate unemployment levels (10–14%), which indicates partial integration into regional labor networks and possibilities for labor mobility towards Blagoevgrad and Sandanski. Petrich and Sandanski exemplify economically resilient areas with a well-diversified economic structure – agriculture, tourism, trade, services – enabling them to maintain low unemployment levels even under conditions of demographic pressure.

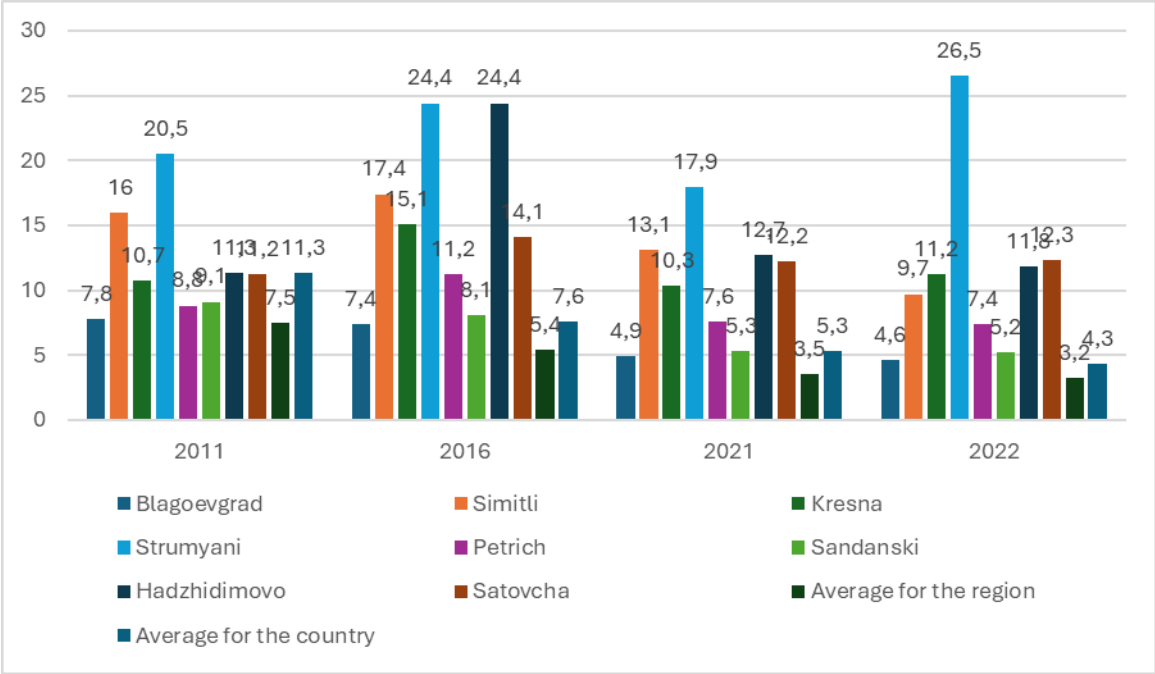


Figure 8: Unemployment Rate in the Western Border Municipalities of Blagoevgrad Province (in %)

**Long-Term Unemployment and Social Vulnerability**

Figure 9 illustrates the share of long-term unemployed among all unemployed persons in 2023 – an indicator of critical importance for assessing the social resilience and adaptability of local labor markets. The data reveal a troubling trend: in several municipalities, more than one-third of all unemployed individuals remain detached from the labor market on a long-term basis.

The highest shares are observed in Kyustendil (50%), Treklyano (45%), Trŭn (46%), and Strumyani (41%), which indicates structural unemployment and limited opportunities for reintegration into employment. These municipalities lack stable private investment, and the available jobs are predominantly in the public sector or in low-paid seasonal activities. The inability to secure permanent employment leads to social apathy, migration, and further deterioration of the demographic structure.

At the opposite end of the spectrum are municipalities such as Dragoman (8%), Sandanski (10%), and Hadzhidimovo (13%), where the share of long-term unemployed is significantly lower. This reflects a more flexible and adaptive labor market, greater opportunities for seasonal or temporary employment, and higher workforce mobility. Blagoevgrad, Simitli, and Kresna also show values below 15%, which is a positive signal for the resilience of the regional economic structure.

The pronounced divergence between municipalities with persistently high long-term unemployment and those with relatively low levels underscores the spatially uneven capacity of local economies to absorb and retain labor. In structurally weak territories, long-term unemployment becomes self-reinforcing: prolonged detachment from the labor market erodes skills, reduces motivation, and limits the effectiveness of active labor-market policies. Moreover, these municipalities often lack the institutional and business environment necessary to create sustainable jobs, which deepens dependence on social assistance and accelerates outward migration among the

working-age population. Conversely, municipalities with lower levels of long-term unemployment benefit from stronger private-sector activity, better connectivity to regional labor centers, and more diverse employment opportunities, making them more resilient to demographic and economic shocks. The contrast between these two groups highlights the need for territorially differentiated strategies aimed at reintegration, upskilling, and the creation of stable employment in vulnerable border areas.

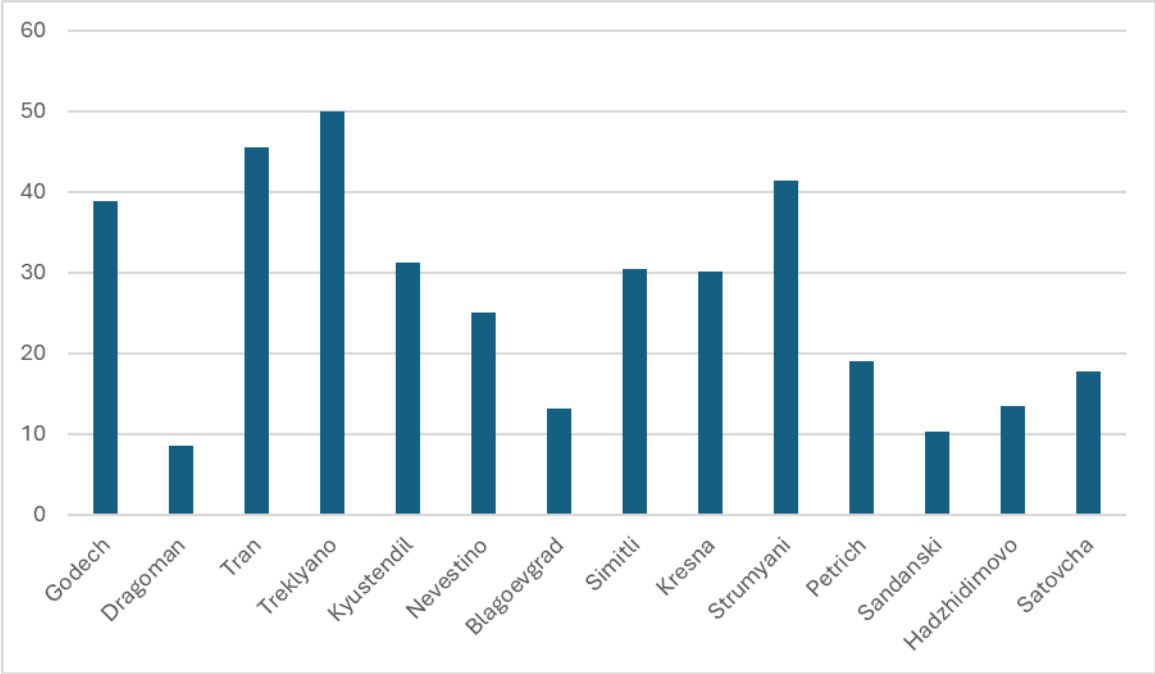


Fig. 9 Share of Long-Term Unemployed Among All Unemployed, 2023 (in %)

**Regional Interdependencies and Conclusions**

The analysis of unemployment in the border municipalities of the Southwestern Region highlights profound territorial contrasts between economically active urban cores and peripheral, mountainous territories. Municipalities with well-developed infrastructure and access to larger markets (Dragoman, Blagoevgrad, Sandanski, Petrich) demonstrate low unemployment levels and higher social resilience.

In contrast, sparsely populated and isolated municipalities such as Treklyano, Trŭn, Strumyani, and Satovcha remain "zones of chronic unemployment," where the lack of economic alternatives fosters dependence on social assistance and leads to long-term emigration.

There is also a direct relationship between the high share of long-term unemployed and the degree of depopulation – the longer the population remains detached from the labor market, the greater the likelihood of migration or social exclusion. In this context, national and regional policy should focus on:

- stimulating local entrepreneurship and microbusiness development
- expanding social and seasonal employment opportunities
- programs for retraining and digital skills acquisition
- improving transport accessibility and connections to labor centers

In conclusion, unemployment in the border municipalities of the Southwestern Region is not merely an economic indicator but an expression of deeper social and spatial inequalities.

Overcoming it requires an integrated approach combining economic diversification, infrastructural improvement, and an active employment policy tailored to the local specificities and potentials of each municipality.

### Wages

In 2023, the average gross monthly wage in Bulgaria reached 2,077 BGN in the public sector and 1,990 BGN in the private sector, reflecting the sustained growth of the national economy and the strengthening of income levels in the country. Against this backdrop, the border municipalities of the Southwestern Region emerge as territories with a clearly expressed economic peripherality, where wages remain below the national averages and indicate limited economic activity and a relatively weak potential for the development of local labor markets.

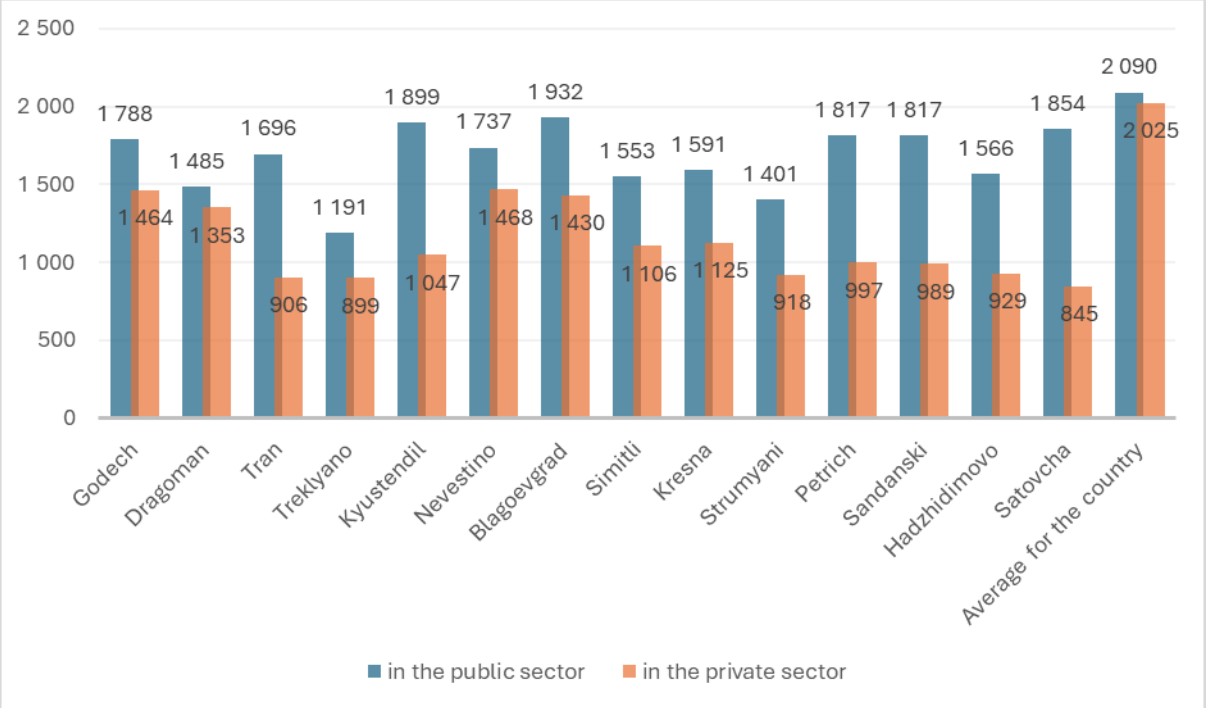


Fig. 10 Average Gross Monthly Wage in the Public and Private Sectors in 2023 (in BGN)

### General Trends and Regional Differences

In more developed and territorially accessible municipalities such as Blagoevgrad, Kyustendil, Petrich, and Sandanski, higher levels of public-sector wages are observed. This can be explained by the concentration of institutional functions as well as the presence of a broader range of state and municipal services. These municipalities act as regional hubs where public-sector employment is stable and well-structured, while the presence of universities, cultural institutions, and hospitals contributes to higher average wages.

In the private sector, the highest remuneration is recorded in Godech, Dragoman, Nevestino, and Blagoevgrad. These values stem from the diversity of economic activities and the proximity of Godech and Dragoman to Sofia, which functions as a powerful economic core and attracts labor flows from peripheral territories. This pattern confirms the influence of major centers on peripheral municipalities and demonstrates how spatial connectivity and regional integration raise income levels.

At the opposite end of the spectrum are small, mountainous, and demographically vulnerable municipalities such as Treklyano, Strumyani, Hadzhidimovo, and Satovcha. In these territories, economic activity is limited to low-paid, low–value-added sectors – traditional agriculture, seasonal employment, small-scale entrepreneurship, and basic services. The private sector in these municipalities is weak and underdeveloped, resulting in considerably lower average wages. At the same time, the public sector in some of these municipalities maintains relatively higher salaries due to nationally determined standards.

This is particularly evident in Satovcha, where the high share of public-sector employment compensates for weaknesses in local production but also increases economic dependence on state funding. Thus, income disparities reflect not only the current economic situation but also a broader pattern of structural peripherality shaped by geographical, demographic, and infrastructural factors.

**Relationship between the Public and Private Sectors**

The analysis of wage differentials between the public and private sectors reveals one of the most persistent and stable characteristics of labor markets in the border municipalities. In all of them, the public sector offers higher wages than the private sector – an indicator of the limited economic base and low productivity of local enterprises. This disproportionality appears at varying scales, and in some municipalities – such as Satovcha, Petrich, and Sandanski – the difference reaches 800–1000 BGN, highlighting the dominant role of the budgetary economy in maintaining local living standards. Here, the public sector serves as the main generator of stable income, while the private sector is heavily constrained by the small local market, lack of investment, and shortage of skilled labor.

In other municipalities, such as Godech, Nevestino, and Blagoevgrad, the differences between the two sectors are smaller – an indicator of higher economic dynamism, a more active labor market, and greater opportunities for private-sector development. In these cases, the private sector operates more flexibly and offers remuneration closer to that in the public sphere. The reasons lie in better transport connectivity, access to external labor markets, higher economic diversification, and a more substantial presence of commercial and industrial activities.

Particularly noteworthy are Petrich and Sandanski, where the large gap between the two sectors is not due to a weak private sector but to relatively higher wages in the public sphere and the specific economic profile of these municipalities, oriented toward tourism, trade, and cross-border interactions. This shows that sectoral wage differences must be analyzed not only quantitatively but also qualitatively – through the lens of local economic functions and their role within the regional system.

Additionally, in several agrarian areas of Southwestern Bulgaria, including Sandanski and Petrich, the influence of the informal agricultural sector must be taken into account. Unregistered seasonal work, characteristic of fruit and vegetable production, leads to an underestimation of actual income and distorts comparisons between the two sectors, as part of labor remuneration remains outside official statistics. This phenomenon not only lowers recorded wage levels in the private sector but also reinforces the image of local economies as dependent on low-paid, unstable, and often informal employment, further complicating the assessment of real economic activity in the region.

**Spatial Dependencies and Conclusions**

The spatial distribution of wages in the border municipalities reveals a complex model of interaction between geography, infrastructure, demography, and economic activity. Municipalities located near major economic centers exhibit significantly higher wage levels compared to remote and mountainous territories. The presence of transport corridors, access to road and rail networks, proximity to large labor markets, and access to cross-border routes all stimulate private-sector development and help maintain higher remuneration.

In contrast, municipalities suffering from demographic ageing, outmigration of the working-age population, and limited infrastructural connectivity display low wage levels and strong dependence on public-sector employment. This model reinforces peripherality and deepens socio-economic disparities across the region. Low private-sector income results in limited consumption, low levels of entrepreneurship, and an inability to achieve sustainable development, which in turn accelerates migration processes and contributes to demographic decline.

Of particular importance is the persistent mismatch between average wage levels and the actual socio-economic needs of the population across almost all peripheral territories. Although the cost of living is lower in small municipalities, low income levels weaken access to quality education, healthcare, transport, and other essential services. In this context, economic disparities translate into social ones, increasing the risk of further regional imbalance.

The analysis of average wages in the border municipalities of the Southwestern Region outlines a clearly structured and persistently reproduced economic polarization. Municipalities with favorable geographical location, strong transport connectivity, and functional integration with major labor markets achieve higher wages and more competitive economic environments. In contrast, mountainous, ageing, and remote municipalities remain heavily dependent on the public sector and exhibit low private-sector dynamism, low income levels, and limited economic diversification.

Overcoming this structural unevenness requires targeted regional policies aimed at stimulating investment, increasing workforce skills, improving transport accessibility, and building a sustainable local economic environment. Equally important is systematic action to combat the informal sector, which in many border municipalities – particularly in agriculture – limits development potential, distorts labor statistics, and undermines the competitiveness of officially operating enterprises. The presence of unregulated employment not only lowers recorded income levels but also results in loss of social rights, public revenue, and investment security, further complicating socio-economic stabilization in peripheral territories.

Without such interventions, disparities between central and peripheral municipalities will continue to deepen, with long-term consequences for both demographic sustainability and socio-economic cohesion in the region.

## CONCLUSION

The analysis of the labor market in the border municipalities of Southwestern Bulgaria reveals a deeply rooted and structurally reproduced pattern of socio-economic peripherality that continues to shape the development trajectories of these territories.

By integrating statistical data, comparative territorial analysis and document-based interpretation, the study demonstrates that the border zone remains characterized by persistent demographic decline, weakened local economies, limited employment opportunities and strong dependence on public-sector structures. Despite the potential for cross-border cooperation, tourism expansion and agricultural specialization, the majority of municipalities continue to function as marginal spaces within regional labor systems.

The employment analysis highlights a sharply differentiated territorial structure. Municipalities such as Dragoman, Godech, Blagoevgrad, Petrich, Sandanski and Kyustendil possess relatively higher employment rates and more diversified economic profiles, benefiting from better transport accessibility, proximity to regional centres and integration into broader labor markets. In contrast, small and mountainous municipalities such as Treklyano, Trŭn, Satovcha, Strumyani and Hadzhidimovo demonstrate chronically low employment levels, reflecting limited economic bases, demographic shrinkage and insufficient private-sector development.

These territories display features typical of “silent depopulation zones,” where an ageing population, reduced economic activity and insufficient infrastructure reinforce peripheral status.

The structure of employment between the public and private sectors further deepens this divide. In a significant part of the border municipalities, the public sector dominates, functioning as a stabilizing mechanism in the absence of private enterprises able to generate sustainable employment. In places such as Treklyano, Trŭn and Nevestino, public employment accounts for more than half of the workforce, indicating structural dependence on state-funded jobs. Conversely, municipalities closer to economic centres or located along major corridors – Godech, Dragoman, Petrich and Blagoevgrad – exhibit stronger private-sector participation, suggesting higher economic dynamism and a more favourable business environment. New regional-development paradigms increasingly emphasize cross-border functional linkages and labour-market restructuring as key mechanisms for overcoming peripherality (Pugalis & Gray, 2016; Copus & de Lima, 2015)

Labor mobility reveals crucial functional dependencies within the region. Municipalities such as Dragoman, Simitli, Godech and Blagoevgrad act as nodes of labor concentration or transit zones, attracting or redistributing workforce flows. Others – Nevestino, Strumyani, and Treklyano – serve

predominantly as labor donors, with large shares of residents commuting daily to seek employment elsewhere. The correlation between inbound and outbound migration patterns confirms the presence of a clear core–periphery structure, shaped by geographical accessibility, infrastructural capacity and economic attractiveness. Importantly, mobility also reveals the inability of certain municipalities to retain their workforce due to the lack of competitive job opportunities.

Unemployment trends reinforce the structural vulnerabilities of the region. Although national unemployment rates have decreased significantly over the last decade, the border municipalities continue to exhibit values far exceeding national and regional averages. In some areas, long-term unemployment affects more than 40% of all unemployed individuals, indicating deep labor-market detachment and limited reintegration potential.

These patterns reflect accumulated structural disadvantages – insufficient investment, low educational attainment, narrow employment specialization and demographic ageing. At the same time, municipalities with stronger economic structures – Dragoman, Sandanski, Blagoevgrad and Petrich – show comparatively low unemployment and better social resilience.

Wage analysis confirms the broader polarization of the region. Municipalities integrated into larger economic systems exhibit higher average wages, especially in the private sector, benefiting from spatial proximity to Sofia or to major regional centres. Meanwhile, remote and mountainous municipalities remain characterized by low private-sector income, limited consumption potential and strong reliance on public-sector salaries. This disparity not only limits local economic growth but also reinforces outward migration and demographic erosion.

Taken together, the results demonstrate that the labor market in the border municipalities of Southwestern Bulgaria is shaped by a combination of structural, geographic, demographic and institutional factors. The border location itself is not the primary barrier; rather, it is the interaction between peripherality, limited connectivity, demographic collapse and weak economic diversification that produces persistent inequalities. Overcoming these challenges requires a coordinated, territorially tailored policy approach that moves beyond uniform national strategies.

In this context, several strategic directions emerge:

1. **Diversification of local economies**, especially in municipalities where agriculture or budgetary employment dominate, through the promotion of microbusiness, family enterprises and value-added production.

2. **Investments in human capital**, including vocational training, digital skills programmes and adult education, aimed at increasing labor-market adaptability.

3. **Strengthening transport and digital infrastructure**, enabling functional integration with regional centres and facilitating employment access.

4. **Encouraging cross-border economic cooperation**, particularly with North Macedonia and Serbia, through joint labor-market initiatives, cluster development and cross-border commuting frameworks.

5. **Targeted support for private-sector development**, especially through incentives for SMEs, social enterprises and seasonal employment schemes.

6. **Measures to reduce informal employment**, especially in agriculture, which obscures real income levels and limits local tax capacity.

Looking ahead, the future of the border municipalities will depend on their ability to integrate into broader economic networks while developing internal capacities. If current trends persist – low private-sector wages, demographic decline and dependence on public employment – several municipalities risk further depopulation and functional collapse.

Conversely, with adequate policy intervention and efficient use of EU and national instruments, border regions can transform from peripheral spaces into active participants in regional development.

Ultimately, the findings of this study underscore the need for a spatially sensitive, multi-level governance model that aligns national, regional and local efforts. Only through such an integrated approach can the labor markets of Southwestern Bulgaria's border municipalities achieve sustainable development and contribute to the socio-economic cohesion of the region.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

## REFERENCES

Buturac, G., Mikulić, D., & Palić, P. (2019). Sources of export growth and development of manufacturing industry: empirical evidence from Croatia. Economic Research-Ekonomska Istraživanja, 32(1), 101–127. https://doi.org/10.1080/1331677X.2018.1550003

Copus, A., & de Lima, P. (2015). Territorial Cohesion in Rural Europe: The Relational Turn in Rural Development. Routledge. https://doi.org/10.4324/9781315773061

Corcoran, J., & Faggian, A. (2017). Commuting, migration, and labour market outcomes. Journal of Economic Geography, 17(4), 759–783. https://doi.org/10.1093/jeg/lbx01

Employment Agency (2011–2023). *Annual Reports on the State of the Labor Market and Unemployment Rates by Municipalities.*

ESPON. (2020). ESPON 2020 Atlas: Territorial Evidence and Policy Insights. Luxembourg: ESPON EGTC. https://doi.org/10.28071/ES-ESPON-ATLAS-2020

European Commission (2017). *Boosting Growth and Cohesion in EU Border Regions.* COM(2017) 534 final.

European Court of Auditors (2021). *Special Report – Interreg Cooperation: The Potential of Cross-Border Regions Has Not Yet Been Fully Unlocked.* Publications Office of the EU.

Eurostat (2022–2024). *Regional Labor Market Statistics* and *Commuting between Regions* – employment, unemployment and labor mobility data in EU border regions.

Filatova, E., & Patarchanova, E. (2025). Geographical Studies of Urbanization Processes and Their Spatial Organization in Bulgaria. International Journal of Digital Research, 1(3), 97–109. https://doi.org/10.63711/ijdr.net20250308

Fratesi, U., & Wishlade, F. (2017). The impact of EU cohesion policy on regional growth and labour markets. Regional Studies, 51(8), 1196–1207. https://doi.org/10.1080/00343404.2016.1255321

Geshev, G. (1998). *Opportunities for Cross-border Cooperation for Sustainable Development of Border Regions. – Problems of Geography*, No. 3–4, 173–183.

INNOBUS Project (2021). *Analysis of Business Clusters in the Cross-Border Region Greece–Bulgaria (INTERREG V-A): Opportunities for Strengthening Competitiveness in Border Regions.*

Karadzhov, V. (2024). Aspects of social vulnerability after retirement among the Mohammedan population in Bulgaria: A pilot study. *Economics and Management*, 21(1), 150–167. https://doi.org/10.37708/em.swu.v21i2.10

Karadzhov, V., Patarchanova, E., & Kyupriyska, I. (2024). Development of specialized types of tourism in small Bulgarian municipalities: The case of Yablanitsa, Lukovit and Teteven. Yearbook of the College of Tourism – Blagoevgrad, 3(1), 57–82. https://doi.org/10.5281/zenodo.14711127

Lang, T., & Görmar, F. (2019). Shrinking peripheral regions in Europe: Towards a socially just regional development. Springer. https://doi.org/10.1007/978-3-030-03386-6

Ministry of Regional Development and Public Works (MRDPW) (2021). *Socio-Economic Analysis of NUTS 2 Regions in Bulgaria for the Period 2014–2020 (Southwestern Region).*

National Statistical Institute (NSI) (2023). *Labor Resources, Employment and Unemployment.* Official statistical publications and databases (Labor Market section).

National Statistical Institute (NSI) (2023–2024). *Average Gross Monthly Wages – Annual and Quarterly Data by Regions and Municipalities.*

National Statistical Institute (NSI) (2023). *Census 2021 – Population and Demographic Processes; Specialised Tables on Daily Labor Migration and Place of Work.*

Nestorov, L., & Petrović, M. (2022). Labor-market restructuring in rural and border regions of the Western Balkans. Zbornik Matice Srpske, 172(1), 115–130. https://doi.org/10.2298/ZMSDN2272115N

OECD. (2019). Regions in Industrial Transition. OECD Publishing. https://doi.org/10.1787/c76d5d48-en

Partridge, M. D., & Rickman, D. S. (2008). Distance from urban agglomeration economies and rural poverty. Journal of Regional Science, 48(2), 285–310. https://doi.org/10.1111/j.1467-9787.2008.00554.x

Patarchanova, E. (2019). Geodemographic Processes and Their Effects in Blagoevgrad Municipality. Journal of Settlements and Spatial Planning, 10(2), 95–108.

Pugalis, L., & Gray, N. (2016). New regional development paradigms: Rethinking the geography of place and labour markets. Local Economy, 31(1–2), 67–85. https://doi.org/10.1177/0269094215623729

Ravnachka, A. (2021). *Demographic Situation and Labor Market in Blagoevgrad and Kyustendil Provinces.* Sofia: National Publishing House for Education and Science "Az-buki".

Ravnachka, A. (2015). *Territorial Features of the Natural Population Change in the Mountainous Areas of Bulgaria during the Period 2001–2013.* – In: *Yearbook of Sofia University "St. Kliment Ohridski", Faculty of Geology and Geography, Geography Series.*

Rodríguez-Pose, A., & Ketterer, T. (2020). Institutional change and the development of lagging regions in Europe. Regional Studies, 54(9), 1264–1279. https://doi.org/10.1080/00343404.2019.1608356

Sustainable Youth Integration Project (2022). *Analysis of Youth Employment and Structural Unemployment in the Peripheral and Border Regions of Bulgaria.*

Veselinova, N. (2017). *Geography of Population and Settlements in the World.* Sofia: Paradigma Publishing.

Zelenogorski, G. (2020). *Geo-economic Preconditions for the Development of New Transport Corridors in the Border Areas of Bulgaria. – Geopolitics.*

**How to cite this article:**

Pandurski, V. (2025). Labor Market in the Border Municipalities of Southwestern Bulgaria - Challenges and Trends. *International Journal of Digital Research*. E-ISSN: 3033-179X, Vol. *1* (4): P.p. 59-77. *https://doi.org/10.63711/ijdr.net20250404*

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Research Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 78-91*

# An Analysis of Students' Motivation and Satisfaction in Higher Education

**Ani Atanasova[1], Viktoriya Kalaydzhieva[2], Radostina Yuleva-Chuchulayna[3] Kalina Durova-Angelova[4]**

[1, 2, 3] Chief Assistant Professor, PhD in the Department of "Business management and marketing", [4] Chief Assistant Professor, PhD in the Department of "Finance and accounting"
[1,2,3,4] South-West University "Neofit Rilski", Blagoevgrad, Bulgaria, Faculty of Economics.
ORCID ID: [1] 0000-0003-2926-5654, [2] 0000-0002-1825-2228, [3] 0000-0002-0755-5776, [4] 0000-0001-8051-1342

Corresponding Author: Radostina Yuleva-Chuchulayna, E-mail: radostina_yuleva@swu.bg

https://doi.org/10.63711/ijdr.net20250405

## ABSTRACT

In the modern educational environment, the quality of higher education is increasingly viewed not only through the prism of academic achievements but also through students' personal experience and satisfaction. At the same time, the level of satisfaction with education is an indicator of the effectiveness of the educational services provided and the ability of the institution to meet the needs and expectations of students. This article analyses the interrelationships between motivation and student satisfaction with higher education, focusing on factors such as teaching approaches, learning environments, opportunities for personal development, and professional development.

***Keywords:*** *Higher education, Students, Motive, Satisfaction, Motivation*



## INTRODUCTION

Living in an era of dynamic changes, intensive improvement and constant search for effective solutions leads to an overall improvement in quality of life. In this context, higher education is established as a fundamental element in the development of modern societies. However, students face a number of challenges that affect their motivation and satisfaction. Among them are the economic uncertainty caused by global events such as the Covid-19 pandemic, the high degree of complexity of curricula, the lack of time, as well as the need to balance education, employment and personal commitments. Effectively dealing with these difficulties largely depends on the level of internal motivation and the degree of satisfaction with the educational process, which are crucial for the academic and personal success of students.

The analysis of student motivation and satisfaction with higher education at the Faculty of Economics of the South-West University "Neofit Rilski" is carried out with several key goals and reasons. The first, more important, is to identify the need to improve the quality of education through

the analysis of student motivation and satisfaction. By studying the level of student motivation and satisfaction, the faculty can identify the strengths and weaknesses in the learning process and the organization of training. This provides a basis for introducing targeted improvements in curricula, teaching methods and student support. This will affect the increase in academic engagement, as motivated students are more likely to participate actively in the learning process, achieve better results and be successful in their professional lives.

The analysis helps to understand the factors that stimulate or hinder this engagement. Secondly, the study can also identify ways to adapt to the needs of students. In the modern competitive education market, universities must offer education that meets the real expectations and needs of students. This has changed mainly due to the epidemiological situation surrounding Covid-19, through the introduction of online learning, the digitalization of the educational process and part of the administrative requirements, as well as the introduction of artificial intelligence, etc. The analysis provides information on the extent to which students are satisfied with the chosen specialty, the conditions of study and future opportunities for realization.

Establishing the motivation and satisfaction of students will help to strengthen the reputation of the faculty. High satisfaction and motivation of students are also directly related to the good image of the institution. This is an important factor for attracting new students and increasing public trust in the Faculty of Economics and South-West University "Neofit Rilski" as a whole. The results of the analysis and the data from the conducted survey can lead to the formation of management decisions aimed at sustainable development and innovation in educational activities. Also, the analysis is an important tool for understanding and optimizing the student experience and engagement, with the long-term goal being to increase the efficiency and competitiveness of higher education at the Faculty of Economics.

## LITERATURE REVIEW

The level of motivation and satisfaction with the academic life of students influences the development of potential, achievement of success and increase of the intelligence of the personality. This fact not only leads to a calmer and more positive behavior among students, but also contributes to an increased sense of belonging and well-being.

The idea of increasing motivation and satisfaction among students has always been and will be an emphasis, as this will improve universities as a whole and the desire of young people to develop their abilities. (Jedvaj & Skrbinjek, 2022) describe that the central figure in the higher education system is the student, therefore it is extremely important for higher education institutions to maintain high motivation, which consists of "motivation for work and learning, a sense of challenge in activities, a sense of value from performing activities and ultimately satisfaction during and after training." Their concept is a continuation of the scientific researches of (Alves & Raposo, 2006), who mention that student satisfaction plays an important role for two main reasons. Firstly, is by contributing to a positive perception of the university, which encourages future student enrollment or re-enrollment. Secondly, is by motivating students to "continue their academic career or help apply existing knowledge to new students or develop new skills."

Dissatisfied students, according to the authors, are much more likely to drop out or change their "course" of study, while also spreading negative criticism of the educational institution and the course of study. (Alves and Raposo, 2006, pp.1-2). In other words, if students feel dissatisfied, this would lead to a decrease in their motivation and turn into "demotivation". Motivation is defined as a "psychological process", as described in the work of (Kobal & Musek, 2009) indicating that this process refers to students' behavior and emotions, their thoughts, attitudes and perceptions, beliefs and other psychological contents. "Here, educators are primarily interested in the causes and intentions of student behavior. Therefore, motivation is a psychological process that motivates and directs student behavior." (Kobal & Musek, 2009, p. 15). An important part of student satisfaction is their sense of belonging, which influences their academic success.

In his scientific researches (Dimitrov, 2025) concludes that the factors in the university environment that most strongly motivate students and would attract young people are the opportunities for development and growth, an interesting and meaningful learning environment. Accordingly, this also has an impact on their future professional realization. For the purposes of the study, it is also necessary to pay attention to (Semerdzhieva & Naydenova, 2019), who examine academic motivation as a criterion for the quality of the educational product. As competition between higher education institutions becomes greater, the practical implementation of a marketing concept in the Bulgarian higher education system is increasingly urgent.

The quality of higher education is very important for the motivation of students and their choice of a higher education institution. It directly affects the success of industry and business, and is of key importance for the prosperity of a nation. According to (Georgiev et al., 2015), the quality of higher education in Bulgaria can be improved by adopting globally recognized excellence models and quality management standards and by strengthening student motivation.

Motivation is the basis of the academic process and a factor significantly influencing the academic success, personal self-improvement and professional realization of students. It can be considered as internal (related to personal interest, curiosity and the pursuit of knowledge) and external (related to grades, scholarships and future career).

The COVID-19 pandemic has profoundly changed the educational environment and put student motivation in a new context, subjecting it to serious tests. Before 2020, student motivation was mainly related to academic traditions and personal goals. Internal motivation was expressed through a desire for self-improvement, learning new knowledge and building a professional identity. External motivation was related to the expectation of better realization in the labor market, as well as academic awards (scholarships, plaques of distinction, diplomas and certificates, etc.). Face-to-face learning facilitates the building of social connections and creates a sense of belonging, which also helps maintain high motivation.

During the Covid-19 pandemic, with the transition to a distance learning form, a serious change occurred in the conditions that shape student motivation. For some students, this period was associated with increased independence, development of digital skills and the opportunity for flexible time management, which maintains or even strengthens their intrinsic motivation. For others, however, the lack of social interaction, uncertainty about the future and difficulties in adapting to the online environment cause a decline in motivation. In the context of distance learning, extrinsic motivation turns out to be particularly vulnerable, as students sometimes encounter difficulties in understanding the interrelationship of the educational process and future career realization.

In the post-pandemic period, an interesting double effect is observed. On the one hand, the return to face-to-face learning has restored some aspects of the social support and academic engagement, despite the initial challenges and adjustment back to lecture halls. On the other hand, the new hybrid educational environment offers opportunities for more individualized approaches to learning, which stimulates intrinsic motivation in many students. Extrinsic motivation has also been strengthened through the resumption of career initiatives, internships and practical activities, improved digital skills in lecturers and lecture halls, improved university applications and new methods of working and communicating between students and lecturers.

The three periods "before – during – after" the Covid-19 pandemic can be compared, which shows that student motivation is strongly dependent on the social and institutional context. Before the pandemic, it was mainly supported by traditional academic and professional factors. During the pandemic, the intrinsic motivation of some students was reduced by social isolation and digital challenges. After the pandemic, motivation is developing in a new direction – hybrid, flexible and more closely linked to the digital environment, which suggests a need to adapt university strategies for supporting and stimulating students.

The reviewed literature provides a clear and accurate picture of the way to motivate students and the motivation factors that universities can maintain in order to have the necessary number of students. Since the university system in Bulgaria is highly fragmented, i.e. the country has a large

number of universities, colleges and specialized higher education institutions, relative to the population (European Commission, 2018, p.8), universities need to "fight" for students due to the decline in the population.

Table 1. Comparison of enrolled students and higher education institutions by region in Bulgaria for 2019 and 2025 (in numbers). *Source: Adapted by the authors, based on National Statistical Institute data. Available at: https://www.nsi.bg/statistical-data/188/587*

| | **2019** | | | **2025** | | |
|---|---|---|---|---|---|---|
| **Region** | *Number of students / bachelor and master/* | *Number of universities* | *Average number of students per University* | *Number of students /bachelor and master/* | *Number of universities* | *Average number of students per University* |
| Northwest | 5339 | 1 | 5,339.0 | 5471 | 2 | 2,735.5 |
| North central | 26,925 | 5 | 5,385.0 | 23,238 | 5 | 4,647.6 |
| Northeastern | 31,193 | 7 | 4,456.1 | 28,907 | 7 | 4,129.6 |
| Southeast | 13 133 | 3 | 4,377.7 | 14,633 | 3 | 4,877.7 |
| Southwestern | 105,845 | 29 | 3,649.8 | 95,279 | 27 | 3,528.9 |
| South Central | 37,733 | 9 | 4,192.6 | 35,989 | 7 | 5,141.3 |
| **Total** | **220 168** | **51** | **4,317.0** | **203,517** | **51** | **3,990.5** |

The total number of enrolled students in Bulgaria in 2025 shows a decrease of about 7.6% compared to the data in 2019. During this period, a relatively constant number of higher education institutions was observed, which does not apply to the average number of students per institution. The decrease from 4317.0 in 2019 to 3990.5 in 2025 can be explained by the concentration of students in a smaller number of universities or by the optimization of the educational infrastructure.

On the other hand, the overall decrease in students (by about 7.6%) reflects the challenges facing student motivation in Bulgaria as a whole. Some young people are demotivated by the limited career prospects in the country and prefer to study abroad.

At the same time, the importance of internal motivation is growing - students who remain in Bulgarian universities increasingly choose programs that match their personal interests and desires for development.

Regional differences in the number of students in 2019 and 2025 can be seen not only as demographic and institutional trends, but also as a reflection of the level of motivation of young people for higher education. Universities that manage to adapt their programs, ensure a connection with the labor market and create a socially supportive environment show growth or stability in enrolment. At the same time, where such incentives are lacking, motivation weakens and the number of students decreases.

## METHODS OF RESEARCH

In the following sections, we will present a detailed overview of the context and theoretical framework of the study, describe in detail the research design and methodological approaches used, outline the procedures for collecting and processing the empirical data, and explain the analytical strategies through which the obtained results are interpreted.

The main research methods used in the article are content analysis, analysis and synthesis method, an intuitive and systematic approach, and a questionnaire survey.

## RESULTS

### Study of student motivation and satisfaction.

In the period March - April 2025, an anonymous survey was conducted within the Faculty of Economics of the South-West University "Neofit Rilski". The participating students are distributed by number in three main professional fields – Professional Field 3.7. Administration and Management are attended by 72 respondents, Professional Field 3.8. Economics are 159 participants and Professional Field 3.9. Tourism has 79 surveyed students. The total number of surveyed students is 310.

The student motivation and satisfaction survey was carried out with several main objectives. The first and perhaps most important is to improve the quality of education by identifying the factors that influence their motivation and satisfaction. The second objective is to assess the learning environment by identifying the relationships between teachers and students, administrative support, access to resources, etc.

The third objective is to identify students' desire for the so-called "student participation", by including students in the evaluation of their education, thus strengthening their sense of belonging and commitment to the institution.

Another important objective is to track changes in students' attitudes and satisfaction over time, as regular surveys allow for the analysis of trends and the effectiveness of the measures taken in the long term. Such surveys are a feedback tool that help higher education institutions to be more efficient, responsible and student-oriented.

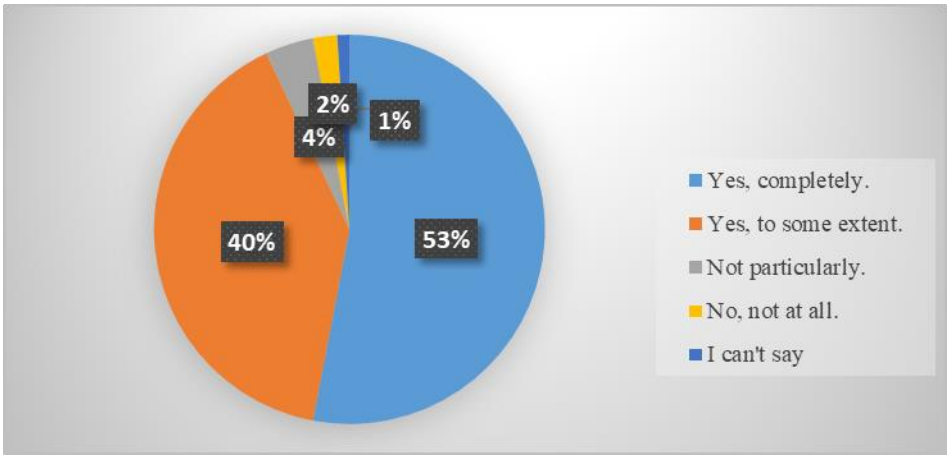


Figure 1. Degree of satisfaction with the studied specialty among the surveyed students (in %).
*Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

The data recorded in Figure 1 shows that the satisfaction of students with the major they are studying is very high. In a correlation relationship, the high values of their willingness to recommend their major should also be added. If 93% are the positive results of the satisfaction survey with the major they are studying, then 90% of the students participating in the survey would recommend the major they are studying to other prospective students (Table 2).

The values presented in Figure 1 and Table 2 indicate a high degree of satisfaction and confidence among students that the specialty they are studying has value that they would recommend to others.

Table 2. Share of students willing to recommend their major (%). *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

| Degree | % |
|---|---|
| **Yes, completely.** | 57.10% |
| **Yes, to some extent.** | 32.90% |
| **Not particularly.** | 5.81% |
| **No, not at all.** | 1.94% |
| **I can't say.** | 2.26% |

These results not only confirm the quality of the educational process in the programs under consideration, but also serve as an important indicator of the positive image of the specialties among current students, which is essential for future admission and the development of the academic environment. We can assume that in this way, students will be able to more easily establish themselves in the labor market and their knowledge will be evaluated.

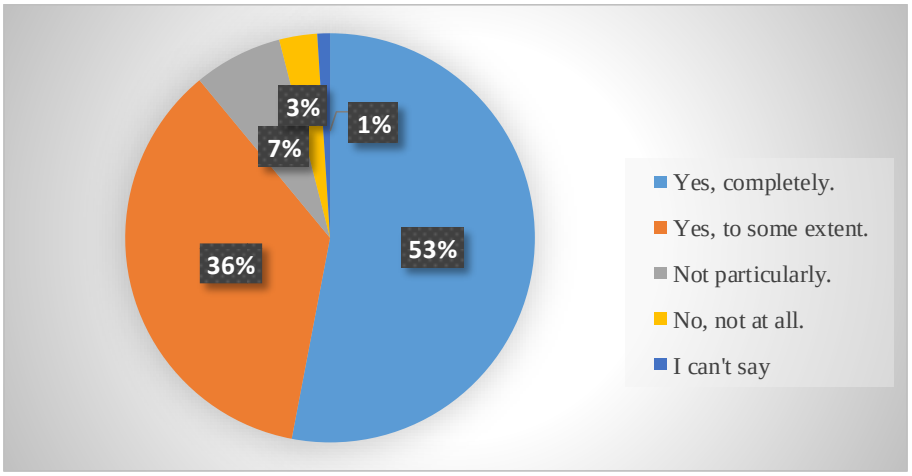


Figure 2. Degree of satisfaction with the organization of the learning process (in %). *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

The data recorded in Figure 2 shows that the surveyed students have a very high level of satisfaction with the organization of the educational process in the three professional fields. Accordingly, 163 answers were registered for the answer "Yes, completely", which is 52.58%. The answer "Yes, to some extent" was given by 111 respondents (35.81%). The answer "Not particularly" was indicated by 7.42 % of the respondents (23 respondents).

Only 9 (2.9%) of the surveyed students responded that they were not at all satisfied with the organization of the educational process in the faculty and only 4 respondents indicated the answer "I can't say" (1.29%).

The conclusion is that satisfaction with the organization of the educational process is high. This may include factors such as clarity of the curriculum, access to teachers, teaching materials,

administrative support and effectiveness of communication with teachers and administrative staff. The data speak of a stable and well-structured educational environment that meets students' expectations. The responses recorded to this question confirm the overall positive perception of the learning process by students in all areas.

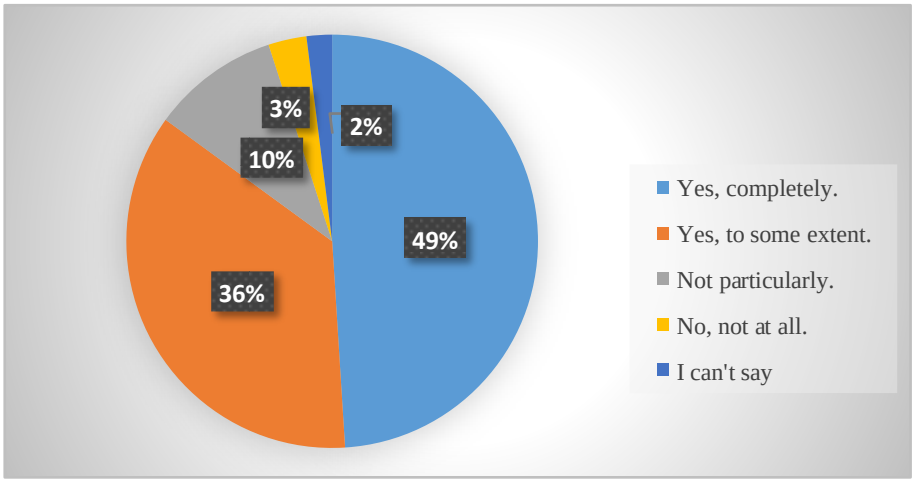


Figure 3. Degree of satisfaction with the available material and technical base and the materials provided for preparation in the disciplines in the studied specialty. (in %). *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski"*

The data in Figure 3 are again positive, with few negative responses. 153 respondents (49.35%) were completely satisfied with the material and technical base provided to them and materials for preparation in the disciplines in their major. In second place were students who indicated that they were satisfied to some extent – 35.48% (110 respondents).

The answer "No, particularly" was given by 30 respondents (9.68%). In penultimate place was the answer "No, not at all" with 3.23% (10 respondents). In last place was the answer "I cannot judge" indicated by 7 students (2.26%).

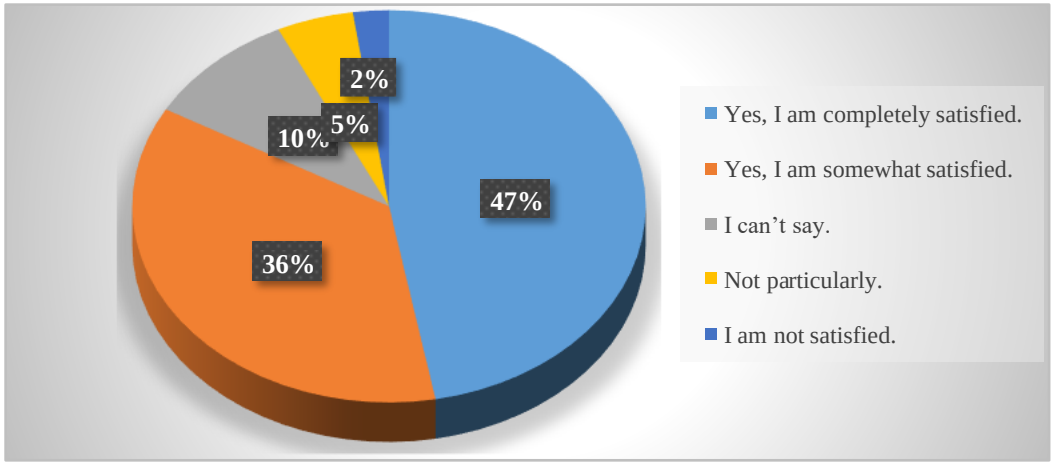


Figure 4. Degree of satisfaction with the acquired knowledge (in %). *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski"*

From Figure 4 it can be seen that the level of satisfaction with the acquired knowledge among the surveyed students is high - 47.10% of the respondents are completely satisfied with the acquired knowledge (146 students), and 36.13% indicate that they are satisfied to some extent, i.e. 112 of the surveyed students.

If all positive answers are taken - 258 respondents, they amount to 83.23%. The students who indicated the answer "I can't say" are 30, which represents 9.68% of the surveyed.

The students who are not particularly satisfied with the acquired knowledge are 15, i.e. about 4.84%, and the students who are not satisfied at all are 7 - 2.26%. Negative answers are indicated by 22 respondents (7.1%). These results show that the students generally perceive the learning process as effective and useful for their academic and professional development.

The analysis shows a high level of satisfaction among the students with the acquired knowledge. Most of them give a positive assessment, with a significant part being completely satisfied, and another part being partially satisfied. Negative opinions are few in number and do not significantly affect the overall picture. The share of those who hesitate is also low, which further suggests that the educational process meets the expectations of the majority of respondents.

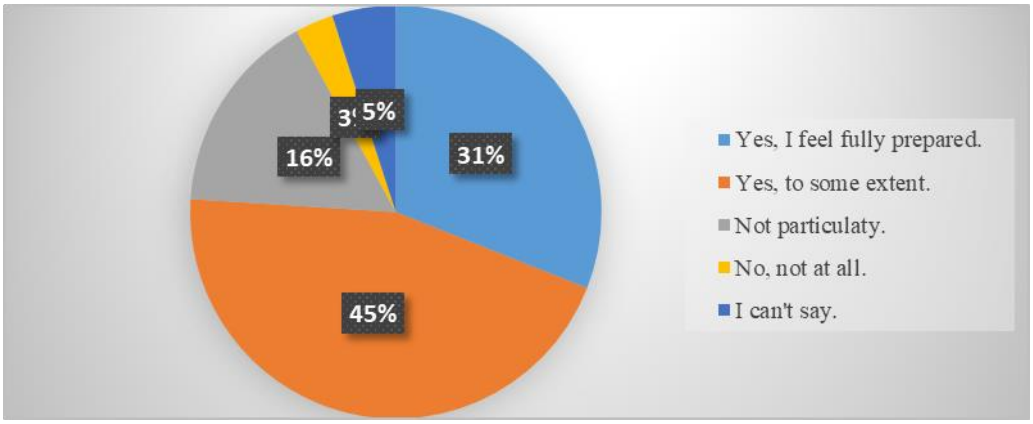


Figure 5. Presence of change in self-confidence and attitudes towards real work in practice among respondents. (in %). *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski"*

The data in Figure 5 shows a change in self-confidence and attitude towards real work in practice among the surveyed students. The highest results are for the answer "Yes, to some extent" – 45.16% of the respondents (140 answers). The answer "Yes, completely" was registered by 95 respondents (30.65%). These results show that the majority of students feel a positive change in themselves, moving from partial to full confidence in their own abilities.

The answers show that the educational environment successfully stimulates personal and professional development, but also reveal the need for even more widespread practice and contact with a real work environment. The presence of this positive change in attitudes and self-confidence is a valuable indicator of the effectiveness of the curricula and their role in building professional confidence in future specialists.

At the same time, the prevalence of the intermediate answer ("Yes, to some extent") shows that there is potential for even more targeted development of the practical components in training – internships, case studies, simulations and work on real projects.

The answer "Not particularly" was indicated by 48 of the respondents, which represents 15.48%. The number of negative answers is again low, with "No, not at all" indicated by 10 respondents (3.23%). The answer "I can't say" was indicated by 17 respondents, i.e. 5.48%.

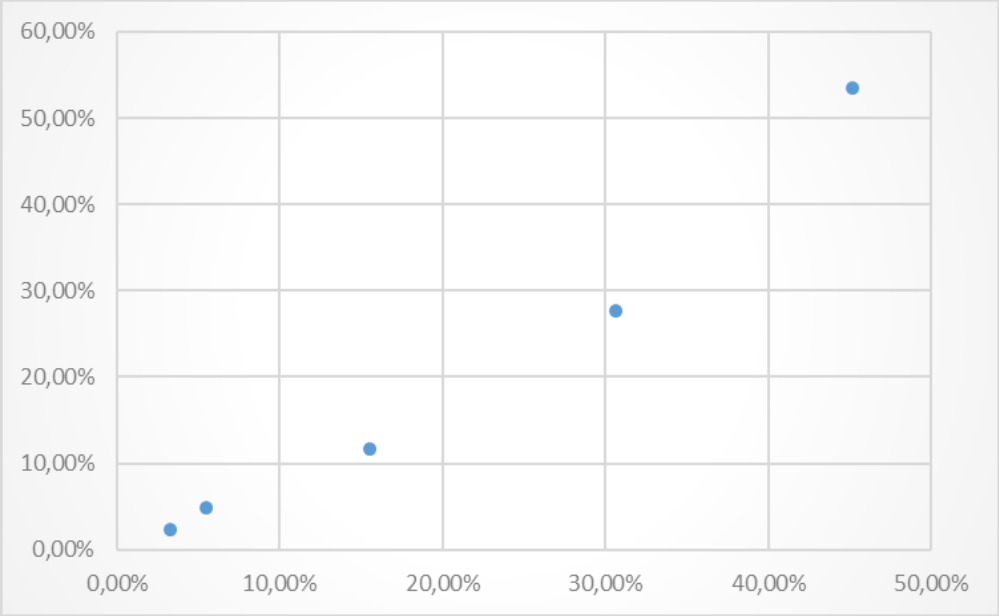


Figure 6. Dot plot of the strength of the correlation between the ability to apply the acquired knowledge and the change in self-esteem and attitudes towards real work in students. *Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

In connection with the analysis of the level of student motivation and satisfaction with higher education, it is essential to present the strength of the correlation relationship and dependence between the ability to apply the acquired knowledge and the change in self-esteem and attitudes towards real work among students. A scatter diagram (Figure 6) displays the results of the calculation of the correlation relationship between the two phenomena. The correlation coefficient is equal to 0.98446, which reveals the strong dependence between the studied quantities.

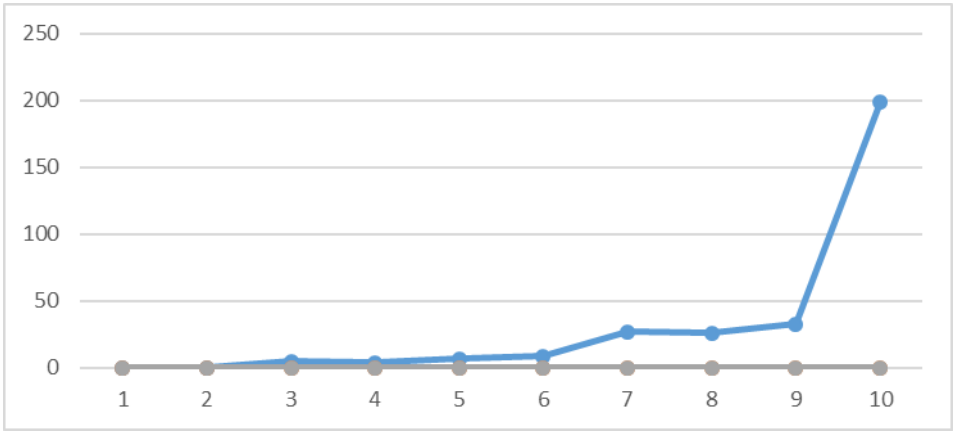


Figure 7. Degree of motivation for successful completion of studies among students (in numbers/scale from 1 – extremely weak to 10 – extremely strong).

*Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

The data in Figure 7 shows clearly the presence of high motivation among the surveyed students for successful completion of the studied specialty. Almost all respondents chose values in the upper

range of the scale (scores from 7 to 10). The largest number of answers 198 (63.87%) were given for the highest level – 10, which indicates extremely strong motivation, i.e. 63.87%. In addition, a large number of respondents rated their motivation for completing their higher education with 9 on a ten-point scale (33 answers), which is 10.65%. A score of 8 was indicated by 26 respondents, i.e. about 8.39% and a score of 7 was chosen by 27 surveyed students – 8.71%.

The average values of the scale (5 and 6) were chosen by a smaller number of participants, and the number of respondents who indicated values below 5 was negligible, a total of 10 answers (3.22%). This is a clear indicator of extremely high personal commitment and strong internal motivation for successful graduation.

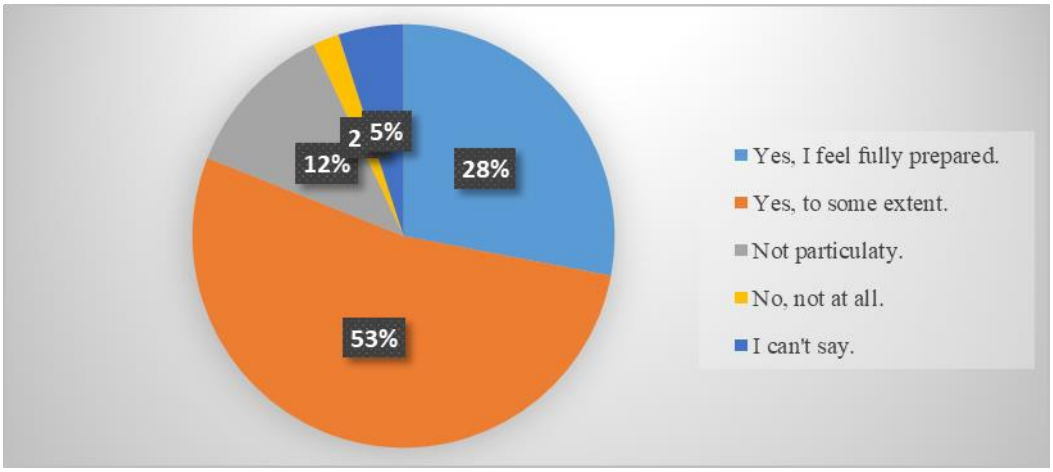


Figure 8. Assessment of the ability to apply the knowledge gained at the university in practice (in %).

*Source: Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""*

The results show a positive general attitude among the respondents regarding their ability to apply the acquired academic knowledge in a practical environment. The largest share of students - 53.55% indicated that they feel prepared to some extent, which indicates moderate but realistic confidence (166 respondents).

This can be interpreted as a signal that students appreciate the connection between theory and practice, but are aware of the need for more experience. Additionally, 27.74% (86 respondents) stated that they feel fully prepared. This is an indicator of the effectiveness of the learning process and that a significant part of the students is convinced that they will successfully apply their knowledge in real situations. Negative assessments - "not particularly" by 11.61% (36 respondents) and "No, not at all" by 2.26% (7 respondents) - represent a relatively small part of the respondents.

This indicates that there is a limited but existing group of students who do not feel confident enough to apply the acquired knowledge and skills in practice. The remaining 15 respondents (4.84%) indicated that they could not say, which may indicate a lack of sufficient practical experience or hesitation in self-assessment. Most students feel prepared to apply their knowledge in practice, with over a quarter stating complete confidence.

The data indicate that university education succeeds in creating a solid foundation for professional development, although there remains a small group of students who need additional practical guidance and support.

## DISCUSSION

Based on the survey conducted among students from the Faculty of Economics of the South-West University "Neofit Rilski", the following main conclusions can be formulated:

High level of satisfaction with the educational process. Most of the surveyed students express full or partial satisfaction with their studies, the chosen specialty, the organization of the educational process, the resources provided and the material and technical base. This shows that the university environment successfully meets the expectations and needs of students and creates conditions for their development. On the one hand, high satisfaction indicates that the content of the curricula is adequate, practically applicable and up-to-date.

On the other hand, positive assessments of the organization of the learning process indicate the presence of good coordination between teachers, administration and students – including timely information, accessibility of teachers and effective communication. High assessments of the material and technical base complement the positive picture, emphasizing that students have appropriate conditions for learning – libraries, halls, electronic resources and other accompanying tools that facilitate the learning process. The combination of all these factors creates an academic atmosphere that not only supports the acquisition of knowledge, but also motivates students, creates a sense of support and increases their commitment to the learning process. This is of key importance for achieving high academic results and for their future successful professional realization.

Strong internal motivation to complete their studies. The registered results indicate that students are highly motivated to complete their higher education. The majority of respondents chose the highest values on the motivation scale, which reflects commitment, ambition and purposefulness. This strong motivation speaks not only of individual goals and ambitions, but also of a positive image of the university and its role as a driver of personal and professional development.

Motivation is an important indicator of long-term commitment to the specialty and is often directly related to academic success, participation in additional initiatives and willingness to take responsibility in the learning process. In addition, the motivation to complete can be seen as a result of the overall student environment - the support of teachers, access to resources, the clarity of the curricula and the prospects for professional development.

When these factors function effectively, they strengthen students' confidence in the meaning and benefits of education. In this context, strong intrinsic motivation is not just a personal characteristic, but also reflects the quality of the learning and institutional environment. This creates a good foundation for higher academic activity, initiative, and resilience in dealing with difficulties during the course of study.

High trust in the quality of education and willingness to recommend. A large proportion of student's state that they would recommend their major to future prospective students. This is an indicator not only of personal satisfaction, but also of a positive image of the majors, which has the potential to attract new students and strengthen the academic authority of the faculty. Such recommendations play an important role in building a positive reputation for the faculty and the university as a whole. When current students recommend their major to others, it is a form of "organic advertising" that is based on real experience and emotional connection with the environment. This trust contributes to strengthening academic identity and creates a sense of belonging, which is a key factor for the sustainable development of the university community.

In addition, the willingness to recommend can be interpreted as an indirect assessment of the effectiveness of educational programs – the more students see real value and application of the knowledge they receive, the stronger their willingness to engage with the institution and recommend it to others. This is especially important in the context of competition between higher education institutions and their pursuit of greater visibility and attractiveness. The recommendation can also be seen as a manifestation of confidence in future professional development – when a student believes

that the education received will provide him with good opportunities in the labor market, he is more inclined to recommend it as a valuable and reliable choice.

Confidence in the applicability of knowledge with opportunities for upgrading. The survey data show that most students feel prepared to apply the knowledge acquired at the university in a real professional environment. This is a positive sign of the effectiveness of the academic content and its compatibility with the requirements of practice. A significant part of the respondents declares full or partial confidence in their ability to transform theoretical knowledge into practical actions. However, there is also a smaller but significant group of students who express uncertainty or moderate self-confidence regarding the practical application of knowledge.

This suggests that there are areas in which training can be further improved by including more practical elements. Measures that could increase student confidence are the introduction and expansion of internship programs, student participation in real business projects, work on case studies from practice, i.e. on an actual case, organization of simulations and practical seminars, as well as active partnerships with business and the state. Such initiatives will not only improve the preparation of students, but also facilitate their transition to the real work environment by developing practical skills, adaptability and professional self-confidence.

Providing opportunities for practical application of knowledge during training is a key factor for successful professional realization. In this sense, the university has an important role not only to provide knowledge, but also to create conditions for it to be exercised, tested and further developed in a real context. This builds not only confidence in students, but also skills that meet the dynamics and requirements of the labor market.

Based on the analysis and conclusions drawn, the following recommendations can be offered to improve the educational process and strengthen the connection between theory and practice:

Expanding the practical components in training, as the need for stronger confidence in applying knowledge in practice indicates a need to introduce or expand internship programs, work on real business cases, simulations and practical projects within the academic disciplines.

Maintaining and upgrading the already established good practices, because the high levels of satisfaction with the specialty, the organization of the learning process and the acquired knowledge speak of a well-established academic foundation. It is recommended that current practices be established, but also regularly updated in accordance with the dynamics of the labor market and the development of the relevant professional fields.

Strengthening student participation and feedback, as student engagement with institutional life can be improved through more frequent and structured feedback, inclusion in councils, committees or focus groups related to improving the learning process and program content.

Improving awareness of career opportunities through career forums, employer meetings, consultations and mentoring programs. This will give students a clearer picture of the application of knowledge in a real work environment and strengthen their professional orientation.

## CONCLUSION

This article analyzes the interrelationships between student motivation and satisfaction with higher education, examining these factors in the context of the modern educational environment, including the impact of the COVID-19 pandemic. Both the sources of student motivation and the challenges that lead to a decline in their engagement are studied, in order to establish the need to improve the quality of education. The literature reviewed on the topic and the conducted survey confirm that student motivation and satisfaction are interrelated and determining factors for the effectiveness of higher education. The analysis of the surveys and the recorded data show high levels of satisfaction with the chosen specialty, the organization of the educational process, the material and technical base and the acquired knowledge.

These results testify to a qualitatively structured educational environment that meets the expectations of students and contributes to the formation of a positive academic identity at the Faculty of Economics of the South-West University "Neofit Rilski". The high degree of internal motivation to complete the training is an indicator of commitment and confidence in the benefits of education, which creates prerequisites for successful professional realization.

At the same time, the study also highlights areas for improvement in the faculty, especially in the context of practical training. Although the majority of students feel confident in their ability to apply their knowledge, a portion of them express uncertainty or moderate self-confidence in a real professional environment. This indicates a need to strengthen the practical components through internships, simulations, real-life case studies and closer cooperation with employers at the Faculty of Economics of the South-West University "Neofit Rilski". Such initiatives would allow for a more successful transformation of theoretical knowledge into practical skills, which would strengthen the connection between higher education and the labor market.

In conclusion, the results of the study emphasize the importance of sustainable development of student motivation and satisfaction as a strategic priority of higher education institutions and in particular of South-West University "Neofit Rilski". Maintaining high standards in the organization of the educational process, regular feedback with students and updating the curricula in accordance with the dynamics of modern society and economy are key conditions for improving the quality of education at the Faculty of Economics.

Universities that succeed in combining academic tradition with innovation and practical orientation will strengthen their competitiveness, strengthen public trust and contribute to the more successful realization of young specialists. The article emphasizes that effective higher education not only provides knowledge, but also creates conditions for its exercise, building professional confidence and adaptability in accordance with the dynamics of the labor market.

***Declaration by Authors***

**Ethical Approval:** Approved

**Acknowledgement:** None

**Source of Funding:** Authors' study based on the results of project RP-B1/25 on the topic "Research on the professional opportunities for students graduating from the Faculty of Economics of the South-West University "Neofit Rilski""

**Conflict of Interest:** The authors declare no conflict of interests.

## REFERENCES

Alves, H. & Raposo, M. (2006). Conceptual model of student satisfaction in higher education. *Total quality management.* pp. 1261-1278.

Dimitrov, Y. (2025). Pokolenie "Z" – izsledvane na vashata motivatsiya i tsennosti vŭv vrŭzka s realizatsiyata im na pazara na truda, *University of Finance, Visshe uchilishte po zastrakhovane i finansi,* pp. 66-97. Available at: https://www.researchgate.net/publication/392263211_Pokolenie_Z_-_izsledvane_na_tahnata_motivacia_i_cennosti_vv_vrzka_s_realizaciata_im_na_pazara_na_truda

European Commission. (2018). The research evaluation and performance-based funding system in Bulgaria. *Monitor*. Available at: https://rio.jrc.ec.europa.eu/en/file/12400/download?token=wcgzyidE and ET Monitor, Bulgaria, p. 8. Available also at: https://www.eufunds.bg/sites/default/files/uploads/opseig/docs/2021-08/BG_HE_June_22.pdf

Georgiev, Ts., Sakakushev, B. & Georgieva, D. (2015), Analiz na vliyanieto na konteksta na vissheto uchilishte vŭrkhu kachestvo na vissheto obrazovanie. *Nauchni Trudove na Rusenskiya Universitet*, 54(9), pp. 80-87. Available at: https://conf.uni-ruse.bg/bg/docs/cp15/9/9-12.pdf

Jedvaj, K. & Skrbinjek, V. (2022). Student motivation and satisfaction with their studies. Management, *Knowledge and Learning International Conference*, Available at: https://toknowpress.net/ISBN/978-961-6914-29-1/122.pdf

Kobal, G., D. & Musek, J. (2009). *Perspective motivation Ljubljana*. Slovenija: Znanstvena book of Ljubljana.

National Statistics Institute (NSI). (2025) *Higher schools, students enrolled and graduates by statistical zones, statistical regions and districts*. Available data at: https://www.nsi.bg/en/statistical-data/188/587

Semerdzhieva, E., & Naydenova,V. (2019). Academic motivation as a criterion for the quality of the educational product. N*auchni trudove na SUB ot Natsionalna nauchna konferentsiya s mezhdunarodno uchastie Nauka i obshtestvo*, 7. pp. 448-454, ISSN 1314-3425. Available at: https://www.academia.edu/41604021/АКАДЕМИЧНАТА_МОТИВАЦИЯ_КАТО_КРИТЕРИЙ_ЗА_КАЧЕСТВОТО_НА_ОБРАЗОВАТЕЛНИЯ_ПРОДУКТ

**How to cite this article:**

Atanasova, A., Kalaydzhieva, V., Yuleva-Chuchulayna, R., & Durova-Angelova, K. (2025). An Analysis of Students' Motivation and Satisfaction in Higher Education. *International Journal of Digital Research*. E-ISSN 3033-179X, Vol. *1*(4): P.p. 78-91. *https://doi.org/10.63711/ijdr.net20250405*

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Review Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 92-105*

# Policies at the European, National and Regional Levels Aimed at the Development of Border Regions

**Vasil Pandurski**

PhD student (Economic and Social Geography)
Department of Geography, Ecology and Environmental Protection
Faculty of Mathematics and Natural Sciences
South-West University "Neofit Rilski", Blagoevgrad, Bulgaria
ORCID ID: 0009-0001-4005-4113

Corresponding Author: Vasil Pandurski, E-mail: vpandurski@swu.bg

**https://doi.org/10.63711/ijdr.net20250406**

## ABSTRACT

The present publication examines the development of border municipalities in the Southwestern region of Bulgaria through a historical, institutional, and financial analysis of policies at the European, national, and regional levels. It outlines the stages of transformation of border regions – from strictly controlled peripheral zones with security functions during the period of centralized governance to territories integrated into contemporary concepts of regional development and territorial cohesion. The analysis of key financial indicators such as the share of own-source revenues, local tax collection rates, equalization and capital subsidies, and EU funds absorbed per capita reveals significant intra-regional disparities shaped by demographic, economic, and institutional factors. The results demonstrate that the most vulnerable border municipalities remain highly dependent on state transfers and have limited access to investment resources, whereas larger and administratively stronger municipalities absorb substantially more national and European funding. The study highlights the need for territorially sensitive policies, a differentiated approach, and strengthened administrative capacity as essential prerequisites for reducing regional inequalities and ensuring sustainable development in border areas.

***Keywords:*** *Border regions, Regional policy, Territorial cohesion, Fiscal decentralization, Cross-border cooperation*



## INTRODUCTION

Regional policy in Bulgaria from the 1950s to the late 1970s with regard to border territories is characterized by specific measures aimed at reinforcing political and military stability. Border regions were perceived primarily as a "protective belt" and a zone of control rather than as areas designated for development (Geshov, 1999; Boyadzhiev, 2005; Lichev, 2019). Similar characteristics of border territories are identified in Patarchanov's (2000) analysis of the regional aspects of cross-border cooperation between Bulgaria and Macedonia, where border zones are described as peripheral spaces

with high dependence on central authority and severely limited endogenous resources. Large-scale collectivization and industrialization led to the relocation of population from villages and small towns to major industrial centres in the country's interior – a process described as a specific form of "point urbanization" (Geshov, 1992; Goodall, 1987; Galabinova, 2015). The establishment of Agricultural and Industrial Complexes (APC) in larger cities deprived villages of their role in agricultural management (Geshov, 1999), while the lack of major urban centres in close proximity to national borders deepened the spatial and social isolation of border regions.

This isolation was further reinforced by the fact that border zones were subject to restricted accessibility from the rest of the country – access was regulated and subordinated to security considerations (Geshov, 1995; Lichev, 2023). The infrastructure built during these decades, especially the road network, was primarily oriented toward military defense and border patrolling, rather than toward integrating peripheral territories into the national economic system (Todorova, 2014; Maucorps, 2023). Combined with the semi-mountainous and mountainous relief found in many border areas of the Southwestern region, these conditions predetermined an early manifestation of negative demographic and economic trends, similar to those observed in other peripheral areas across the EU (Copus, 1999; Luukkonen, 2010).

Throughout the 1950s–1970s, state policy toward border territories was driven predominantly by security and control. Legislation did not provide decentralized mechanisms for development; instead, it relied on centralized planning, restricted access to the border zone, and mass collectivization (Geshov, 1999; Stoyanova, 2019). The population of border municipalities – particularly those in rural and mountainous areas of Southwestern Bulgaria – began to decline under the influence of industrialization and the policy of point urbanization, which concentrated functions and investments only in selected centres (Geography of Bulgaria, 2002; Lichev, 2019).

During the 1980s, the first more substantial attempts were made to stimulate development in these isolated regions by relocating state enterprises and creating new production facilities. To a large extent, this policy failed. The main reasons include the uncontrolled relocation of enterprises to border regions without consideration of local resource potential, the lack of entrepreneurship based on local raw materials, and direct state financing without adequate monitoring of effectiveness (Geshov, 1999; Dokova et al., 2018; Lichev, 2023).

After 1989, efforts were made to eliminate the so-called "point concentration" and introduce the principles of modern regional policy. Gradually, ideas such as integration of social, economic, and environmental policies, improvement of multi-level governance, and strengthening the role of local authorities became established (Boyadzhiev, 2005; Galabinova, 2011; Shah, 2004). In this context, Patarchanov and Patarchanova (2014) emphasize the importance of the partnership principle and multi-level governance for mobilizing local communities in peripheral regions and overcoming the passivity of local authorities. A more active coordination between various state institutions emerged, accompanied by an emphasis on democratization, decentralization, and participation of local communities.

The development of border territories in Bulgaria, particularly in the Southwestern region, is strongly influenced by the normative framework shaped at both European and national levels. This framework has undergone significant transformation from the mid-20th century to the present, with its main objectives gradually shifting from military and security functions toward territorial cohesion, economic activation, and socio-demographic stabilization of peripheral areas (Luukkonen, 2010; Zillmer et al., 2021; Maucorps, 2023).

With the democratic transition and the shift toward a market economy, the normative and institutional framework underwent a fundamental change. The main objective became the integration of border regions into the national and European space through decentralization, local self-government, regional programming, and cross-border cooperation (Todorova, 2014; Jakubowski, 2024; Dentinho, 2020). Contemporary research by Patarchanova (2012) on rural and peripheral areas in Bulgaria further emphasizes the need for regional policy to account for territorial potential and the functional role of these spaces, including border municipalities.

## LITERATURE REVIEW

Research on border and peripheral regions has evolved along several main directions: spatial peripherality and regional inequalities, the European policy for territorial cohesion, cross-border cooperation, and decentralization and local finance. In the classical works of Copus (1999), Goodall (1987), and Partridge & Rickman (2008), border territories are conceptualized as specific types of peripheries characterized by limited accessibility, small markets, and demographic decline. These concepts are reflected in the Bulgarian context as well – studies by Geshov (1992; 1995; 1999) and Boyadzhiev (2005) outline the historical evolution of regional policy, emphasizing the role of industrialization, collectivization, and centralized planning in deepening territorial disparities. Studies of regional investment environments in Bulgaria also demonstrate significant spatial disparities, showing that institutional readiness and local economic structures substantially influence the ability of municipalities to attract external resources (Gavrilova, 2025).

After 2010, the focus in European literature shifts towards territorial cohesion as an integrative framework of regional policy. Luukkonen (2010) defines territorial cohesion as a concept building upon economic and social cohesion by emphasizing spatial justice and access to services. Medeiros, Zaucha, and Ciołek (2023) empirically demonstrate that the dynamics of cohesion policy remain uneven between central and peripheral regions, while Chamusca (2024) and Maucorps (2023) highlight that border areas often remain in structural "imbalance" despite long-term INTERREG funding and other instruments.

Cross-border cooperation (CBC) represents a separate line of research. Classical analyses of INTERREG (Wassenberg et al., 2015; Medeiros, 2018) show that these programs have positive effects on regional connectivity, yet their actual impact depends on the administrative capacity and institutional maturity of participating partners. More recent studies by Basboga (2020) and Nagy (2020) find that participation in CBC correlates positively with regional growth, although effects are weaker in depopulated and remote municipalities.

Batyk & Rzeczkowski (2020) add that the external borders of the EU – including the Balkan Peninsula – are particularly sensitive to political shifts and differences in administrative systems. In the Bulgarian context, Galabinova (2011) and Dokova (2018) examine CBC as a tool for partially compensating peripheral status, but note the limitations stemming from the resource and managerial capacity of small municipalities. The regional aspects of cross-border cooperation between Bulgaria and its western neighbours are more deeply analyzed by Patarchanov (2000; 2023), who outlines both the potential and the barriers to the development of border municipalities within the framework of EU policies.

Another important research stream concerns decentralization and local finance. Bird & Vaillancourt (2006), Shah (2004), and Shah & Shah (2006) lay the foundations of the theory of fiscal autonomy and the role of local revenues in effective governance. In Bulgaria, the issue is examined by Galabinova (2011), Lichev (2019; 2023), and Veleva (2023), who emphasize that despite political decentralization, fiscal decentralization remains limited. World Bank reports (2022; 2023; 2025) reveal substantial differences among municipalities in terms of own-source revenues, tax collection, and dependence on equalization transfers. These disparities are particularly pronounced in mountainous and border municipalities, where a weak economic base and demographic depopulation constrain fiscal sustainability.

The absorption of European funds has become an increasingly prominent topic. Territorial Cohesion Policy in Europe (2010), Dentinho (2020), and Zillmer et al. (2021) highlight that although EU policy aims to reduce regional disparities, actual funding flows depend heavily on local administrative capacity. As a result, larger or better-organized municipalities absorb significantly more funds than weaker ones, including those in border regions.

Overall, the literature demonstrates that border municipalities are strongly influenced by a combination of structural (demographic, geographic), institutional (capacity, governance), and financial (local revenues, transfers, EU funds) factors. Despite the availability of cohesion and cross-

border cooperation instruments, their impact is limited when resources and administrative readiness are insufficient. Recent Bulgarian research further highlights how digitalization, demographic vulnerability, and social inequalities shape development potential in rural and peripheral regions, reinforcing the uneven capacity of local communities to participate in modernization processes (Lendzhova, 2025). The present study fits within this scientific framework by combining historical, institutional, and financial approaches to assess the development of border municipalities in the Southwestern region of Bulgaria.

## MATERIALS & METHODS

The study focuses on the border municipalities of the Southwestern region of Bulgaria, defined as Godech, Dragoman, Tran, Treklyano, Kyustendil, Nevestino, Blagoevgrad, Simitli, Kresna, Strumyani, Petrich, Sandanski, Hadzhidimovo, and Satovcha. These municipalities form a contiguous belt along the state border and combine pronounced peripheral characteristics with varying degrees of functional integration into the national and regional urban system.

The research is based on a combination of historical–institutional and quantitative financial analysis. The historical and policy-oriented part of the study draws on secondary sources, including monographs and articles on regional policy, border peripheries and territorial cohesion, as well as key national strategic and legal documents (Regional Development Act, National Concept for Spatial Development, National Strategy for Regional Development, National Strategy for Demographic Development, and EU regulations on cohesion and territorial cooperation). These materials are used to reconstruct the evolution of state and European approaches to border territories from the 1950s to the present and to situate the Southwestern border municipalities within broader conceptual and policy frameworks.

The empirical analysis employs comparable municipal-level data for several key financial indicators. The share of own-source revenues in total municipal income (2024) and the amount of equalization and capital subsidies (2024) are used as proxies for fiscal autonomy and the degree of dependence on central government transfers. The property tax (PT) collection rate (2022) serves as an indicator of local fiscal effort and administrative capacity, while EU funds disbursed per capita over the period 2007–2024 capture the ability of municipalities to access and utilize cohesion policy resources. The data are derived from official national statistics and institutional sources (Ministry of Finance, National Statistical Institute, public finance and municipal finance reports of the World Bank, and operational programme monitoring systems), harmonized where necessary to ensure comparability across municipalities and years.

The methodological approach combines descriptive statistics, comparative regional analysis, and simple correlation analysis between the four core financial indicators (share of own-source revenues, equalization subsidies, capital subsidies, and EU funds per capita). Municipalities are grouped into categories (high, medium, and low financial autonomy or performance) based on threshold values of the respective indicators, which allows for the identification of distinct territorial patterns and clusters. The results are visualized through figures presenting the distribution of indicators across municipalities, facilitating the interpretation of spatial disparities. The quantitative findings are then interpreted in conjunction with the historical and institutional context in order to derive more nuanced conclusions about the functioning of decentralization, cohesion policy, and territorial development mechanisms in border regions.

## RESULTS AND DISCUSSION

### Financial Autonomy of Border Municipalities

The financial autonomy of local government is a fundamental component of decentralization and a prerequisite for sustainable regional development (Shah, 2004; World Bank, 2023; Council of

Europe/World Bank, 2022). One of the main indicators of this autonomy is the share of own-source revenues – that is, the funds generated by municipalities through local taxes, fees, fines, rents, concessions, and economic activities – relative to total budget revenues, which also include state subsidies, targeted transfers, and external funding (Galabinova, 2011; World Bank, 2025).

Data for 2024 concerning the border municipalities of the Southwestern region show clearly pronounced territorial disparities in the degree of financial autonomy, measured as the share of own-source revenues. These differences result from the combined influence of economic, demographic, spatial, and institutional factors, which form identifiable patterns (Lichev, 2023; World Bank, 2025).

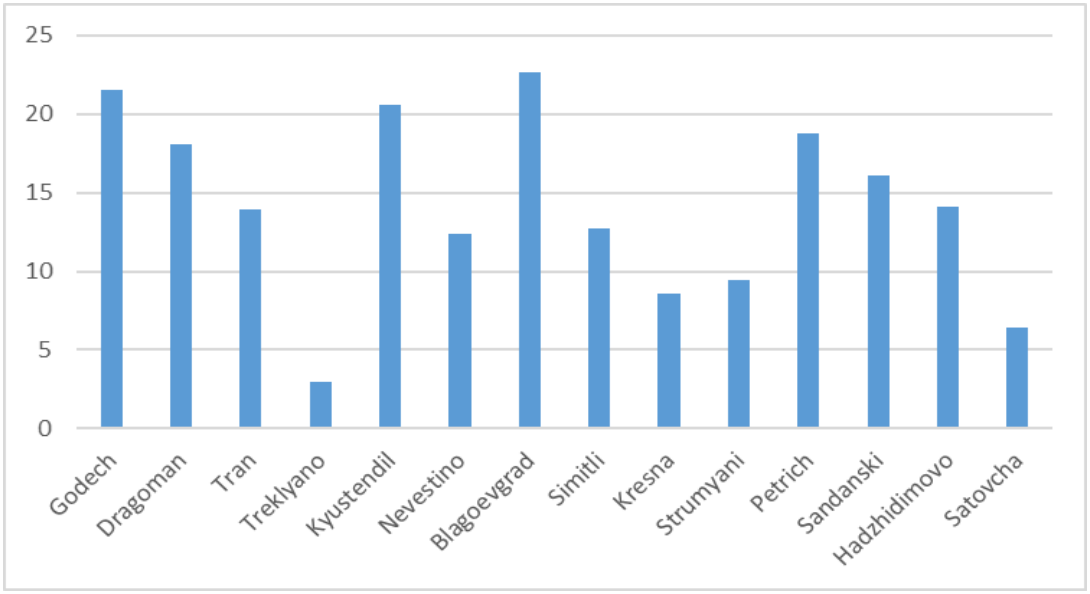


Fig. 1 Share of own-source revenues in total municipal income (%), 2024

**Municipalities with a High Degree of Financial Autonomy**

At the top in terms of the share of own-source revenues are the municipalities of Simitli (over 23%), Godech (around 21.5%), Kyustendil (21%), Nevestino (around 20.5%), and Dragoman (18.5%).

– Simitli benefits from its strategic location along the main transport axis of Southwestern Bulgaria (Corridor No. 4) and develops a diversified economy based on transport, construction, and local business.

– Godech and Dragoman, although border municipalities with relatively small populations, capitalize on their proximity to Sofia and the Kalotina border crossing through industrial zones and logistics functions.

– Kyustendil, as a regional centre, concentrates administrative functions, education, healthcare, and commercial infrastructure – an archetypal example of a "functional centre" that generates revenue across a territory larger than its own administrative unit.

– Nevestino stands out with a high share of own-source revenues despite its small size and population, likely due to effective financial discipline and active management of municipal assets.

Middle Group: Stable but Limited Capacity

Municipalities such as Petrich (18.8%), Sandanski (16%), Hadzhidimovo (14.2%), Tran (13.8%), Blagoevgrad (12.5%), and others show a moderate level of financial autonomy. The economies of Petrich and Sandanski are relatively well developed – with agriculture, balneological and SPA tourism, and cross-border trade – but high expenditures related to delegated state activities and social policy increase total revenues and reduce the relative share of own-source income. Blagoevgrad, despite its economic significance, also shows a relatively low share due to large volumes of transfers for the university, hospital, cultural institutions, and infrastructure projects.

Municipalities with a Low Degree of Financial Autonomy

At the opposite end of the spectrum are Treklyano (3%), Satovcha (6.5%), Kresna (8.7%), and Strumyani (9%), where the structure of budget revenues is dominated by state subsidies and the share of own-source revenues is low. Treklyano, as the smallest and most depopulated municipality in the country, practically lacks a significant tax base, while Satovcha and Kresna are strongly dependent on transfer financing due to demographic and geographic constraints.

The analysis of own-source revenue shares reveals a close relationship between economic activity, demographic structure, administrative capacity, and the geographic position of municipalities – a relationship confirmed in the international literature on fiscal decentralization (Shah, 2004; Bird & Vaillancourt, 2006; World Bank, 2023).

**Property Tax Collection**

The collection rate of local taxes, particularly the property tax (PT), is a key indicator of fiscal stability and the administrative capacity of each municipality (Galabinova, 2011; World Bank, 2010). In the context of demographic depopulation, economic peripherality, and structural inequalities characteristic of border territories, the analysis of PT collection becomes especially significant.

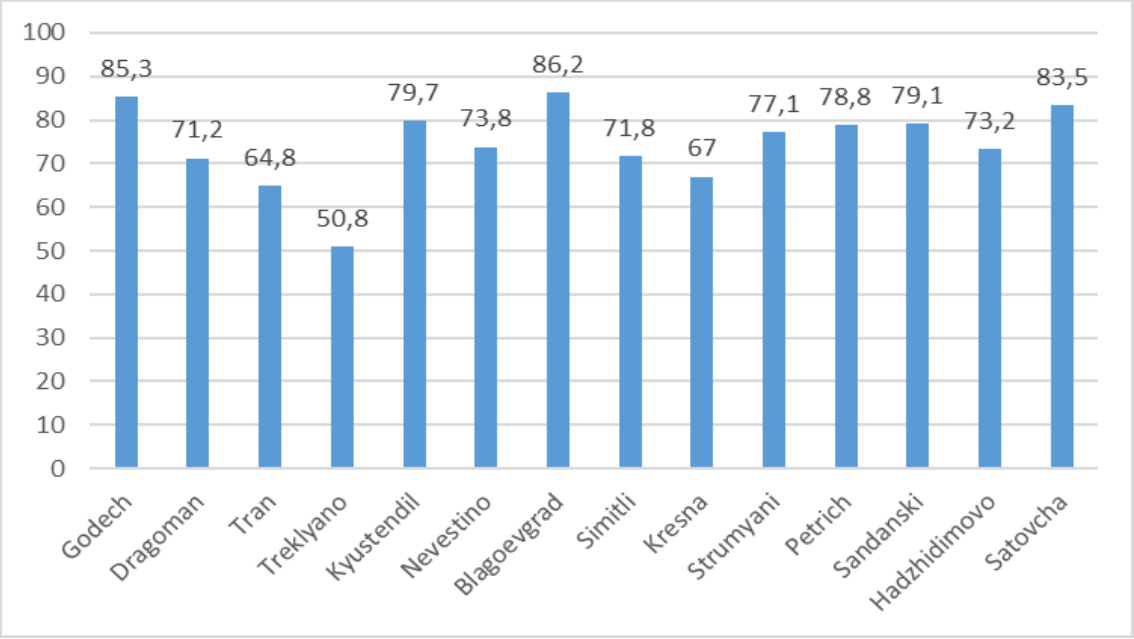


Fig. 2 Property tax collection rate, 2022

The collection of local taxes, particularly the property tax (PT), is a key indicator of the fiscal stability and administrative capacity of any municipality. In the context of demographic depopulation, economic peripherality, and structural inequalities characteristic of Bulgaria's border territories, the analysis of PT collection acquires particular significance. The data for 2022, visualized in the comparative chart provided, reveal a clearly pronounced territorial differentiation among the border municipalities in the Southwestern region, ranging from over 85% in Blagoevgrad Municipality to below 60% in Treklyano.

Against the backdrop of the relatively high national average PT collection rate (over 75%), only part of the border municipalities exceed this value. The leader is Blagoevgrad (over 85%), followed by Godech, Satovcha, Kyustendil, and Sandanski – all with results above 80%. At the opposite end of the spectrum are Treklyano, Tran, Kresna, and Dragoman, where collection rates do not exceed 65%, and in Treklyano fall around or below 60%.

This heterogeneity cannot be explained solely through administrative efficiency. A range of demographic, economic, infrastructural, and institutional factors must be accounted for, as they jointly determine a municipality's capacity to realize revenue from local taxes.

A clear correlation is observed between the level of urbanization and PT collection. Municipalities with larger and more stable urban centres – such as Blagoevgrad, Kyustendil, and Sandanski – demonstrate higher fiscal discipline and activity. These municipalities feature a larger population concentration, greater public awareness, and a more substantial presence of legal entities, which are major contributors to this tax.

Conversely, in municipalities such as Treklyano, Tran, and Strumyani, where the population is significantly reduced and aging, demographic and social disintegration hampers effective tax administration. A large share of properties is owned by individuals residing outside the municipality – often in major cities or abroad – which leads to complications in notification, collection, and enforcement.

Economic activity in a municipality directly affects tax collection. Municipalities with well-developed trade, tourism, or industry (e.g., Sandanski, Petrich, Blagoevgrad) demonstrate higher financial culture and activity, while those with low economic potential (Treklyano, Tran, Kresna) exhibit reduced collection.

Not least, the administrative capacity of municipal structures plays a crucial role – availability of up-to-date property registers, modernized electronic notification systems, effective communication with debtors, and consistent application of sanctions and incentives. The development of e-governance in municipalities such as Blagoevgrad and Kyustendil likely contributes to more rigorous fiscal control. In contrast, underfunded municipalities like Treklyano and Dragoman lack the resources for such digitalization and institutional activity.

The analysis of PT collection in the context of border municipalities allows conclusions regarding deeper spatial-functional dependencies. At the regional level, it is evident that:

• Municipalities occupying central positions in the regional hierarchy (Blagoevgrad, Kyustendil) demonstrate the highest collection rates;

• Mountainous and peripheral municipalities with pronounced depopulation (Treklyano, Tran) face structural difficulties in exercising fiscal control;

• Some rural municipalities with compact populations and limited out-migration (Satovcha) show relatively good collection levels, indicating the importance of social structure and municipal policy.

In conclusion, differences in property tax collection among the border municipalities of the Southwestern region result from a combination of demographic, economic, administrative, and cultural factors. High collection rates are typical of urbanized, economically active, and institutionally stable municipalities. Conversely, low collection is a symptom of territorial decline, social marginalization, and administrative weakness.

The issue should not be viewed solely through a fiscal lens, but rather as an indicator of spatial inequality and uneven development – requiring an integrated approach involving improved administrative registers, e-governance, regional policies supporting small municipalities, and the promotion of tax culture through transparency and accountability (Karadzhov, 2016).

**Equalization and Capital Subsidies**

In Bulgaria's local self-government system, fiscal decentralization is a core principle, but in practice it unfolds under conditions of significant territorial disparities in the municipalities' capacity to generate their own revenues (World Bank, 2025; Lichev, 2019; Galabinova, 2011). This necessitates the application of compensatory mechanisms by the state, the main ones being the equalization subsidy and the capital subsidy.

In 2024, the border municipalities of the Southwestern region of Bulgaria demonstrate significant differences both in the absolute size and in the ratio between equalization and capital subsidies, reflecting a complex picture of the territorial-financial structure and the effectiveness of public policy.

The highest absolute values of the equalization subsidy are received by Kyustendil (3.72 million BGN), Blagoevgrad (2.93 million BGN), and Petrich (1.94 million BGN). These are territories with large populations and substantial engagement in state-delegated activities – particularly in education, healthcare, and culture. At the same time, their relative financial autonomy (measured as the share of own-source revenues) is moderate, meaning that the subsidy plays a balancing rather than a primary role. In smaller border municipalities such as Godech (0.71 million BGN), Dragoman (0.62 million BGN), Tran (0.72 million BGN), and especially Treklyano (0.45 million BGN), the equalization subsidy often represents the main source of revenue through which minimal administrative and communal functioning is maintained. This clearly demonstrates the dependence of peripheral territories on central government and their inability to ensure independent fiscal sustainability.

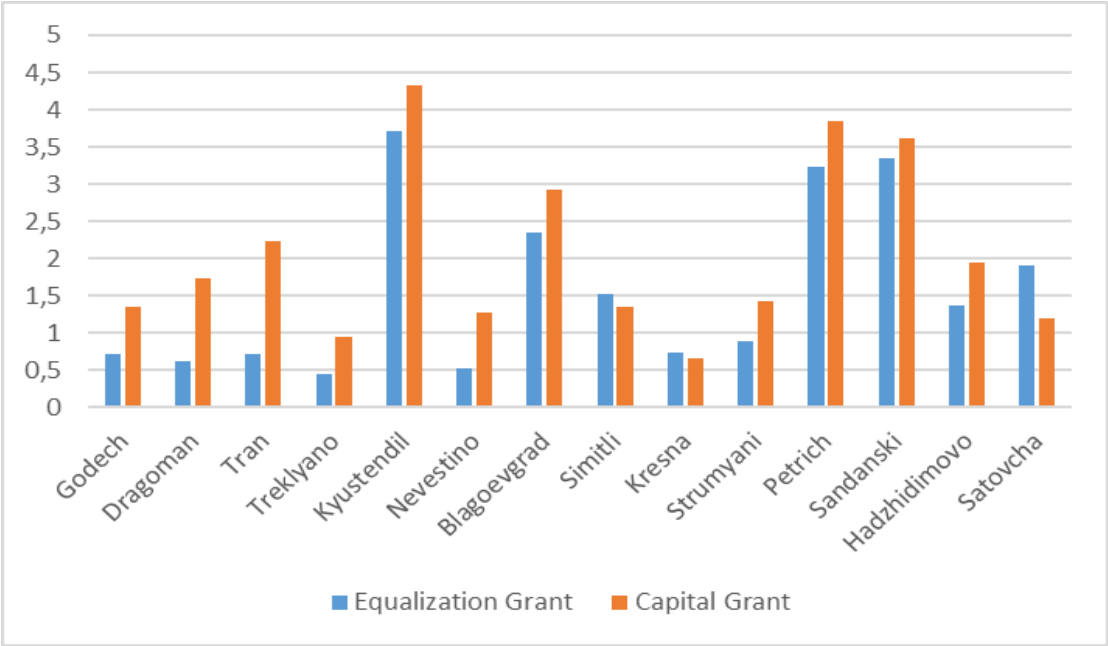


Fig. 3 Equalization and capital subsidies (in million BGN), 2024

Meanwhile, the distribution of capital subsidies – which are targeted and intended for investments – offers a different perspective on state intervention. The largest capital transfers in 2024 are again directed to Kyustendil (4.33 million BGN), Blagoevgrad (3.84 million BGN), Petrich (3.62 million BGN), and Tran (2.24 million BGN). For the larger municipalities, this reflects administrative readiness, project capacity, and the ability to implement large-scale infrastructure activities. In the case of Tran, however, the high value of capital subsidies (over 2 million BGN) is due to targeted state support for infrastructure and environmental improvements – often in the context of cross-border cooperation and local tourism.

A similar situation is observed in Dragoman (1.73 million BGN), where the geostrategic location and proximity to Corridor No. 4 facilitate investments in logistics and transport connectivity.

At the opposite end of the spectrum are municipalities such as Satovcha (1.20 million BGN), Strumyani (1.28 million BGN), and Hadzhidimovo (1.42 million BGN), which – despite economic challenges and social vulnerability – receive relatively modest capital funding. This raises questions about the effectiveness of the distribution mechanism, particularly in the context of territorial cohesion policies. It is evident that the most disadvantaged territories do not always receive priority

support – factors such as administrative activity, project maturity, and political attention play a significant role in resource allocation.

Comparing equalization and capital subsidies reveals several dependencies. First, municipalities with the lowest fiscal capacity (Treklyano, Strumyani, Satovcha) are highly dependent on the equalization subsidy but often lack the capacity to implement capital projects – resulting in a vicious cycle of dependence and stagnation. Second, large municipalities with developed administrative capacity (Kyustendil, Blagoevgrad, Petrich) successfully combine both types of subsidies, using the equalization subsidy for current expenditures and the capital subsidy for strategic investments – a model that ensures sustainable development. Third, there is a group of border municipalities that successfully absorb capital funds despite limited resources (e.g., Tran, Dragoman), demonstrating that targeted project work and cross-sector partnerships can compensate for territorial limitations.

In conclusion, equalization and capital subsidies are not merely financing tools but a mirror of the state's territorial policy. They reveal both its ability to balance regional development and the uneven distribution of administrative capacity, political attention, and project activity. For the border municipalities of the Southwestern region, these subsidies remain a crucial resource; however, they must be complemented by structural measures aimed at enhancing local autonomy, stimulating economic activity, and building long-term institutional capacity.

**European Funds and Cohesion Policy**

One of the key indicators of the effectiveness of European and national territorial development policy is the degree of absorption of European funds at the local level (EC, 2013; Zillmer et al., 2021; Jakubowski, 2024). The data on EU funds disbursed per capita in the period 2007–2024 in the border municipalities of the Southwestern region clearly demonstrate spatial differences in access to financing.

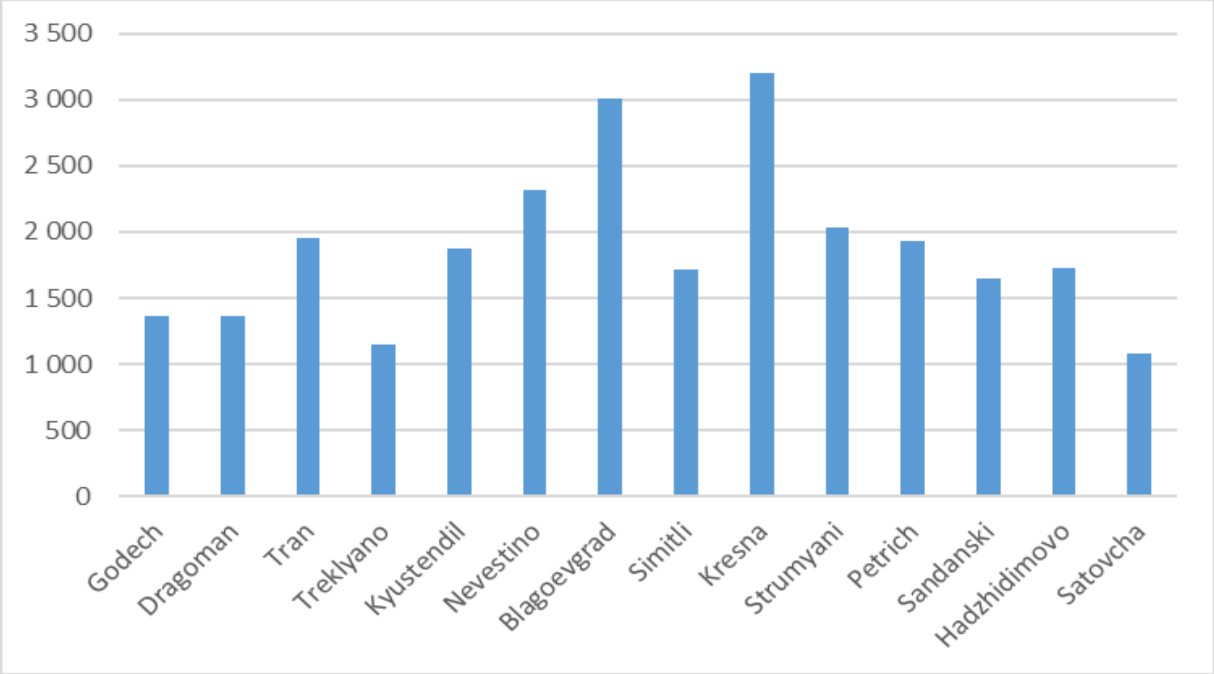


Fig. 4 EU funds disbursed per capita, 2007–2024

Kresna is the clear leader, with absorption levels exceeding 3,200 BGN per capita – a result of active project development, good transport accessibility (Corridor No. 4), and targeted investments in infrastructure and environmental protection. Blagoevgrad – the largest city in the region – also demonstrates high absorption, owing to its expert capacity and diverse project initiatives. Of particular

interest is the municipality of Nevestino, which, despite its small size, shows a high level of absorption. This is likely due to implemented projects under the Rural Development Programme and cross-border cooperation, as well as active policies in infrastructure and public services.

A group of municipalities – including Strumyani, Tran, Petrich, Kyustendil, Hadzhidimovo, Simitli, and Sandanski – forms a middle tier with absorption levels between 1,700 and 2,300 BGN per capita. In the larger municipalities (Petrich, Kyustendil, Sandanski), the lower value of the indicator is due to the higher population size, which distributes the total volume of funding, whereas in smaller municipalities it results from limited project activity.

At the bottom of the ranking are the municipalities of Godech, Dragoman, Treklyano, and Satovcha, all with absorption below 1,500 BGN per capita, with Satovcha occupying the last place at around 1,200 BGN. Possible reasons include limited administrative capacity, weak project activity, demographic depopulation, low interest in EU programmes, and a lack of strategic project initiatives. Particularly concerning is the case of Treklyano, which – despite being one of the smallest and most socially vulnerable municipalities – fails to attract substantial EU funding.

The emerging territorial disparities in EU fund absorption raise questions about the effectiveness of the territorial cohesion policy. Although some of the most disadvantaged municipalities fall within priority categories under national and EU regional policy, actual financing favours better-organized, more accessible, and institutionally prepared municipalities. This pattern confirms existing observations that EU funds are not distributed automatically based on need, but rather according to administrative capacity, project activity, and strategic planning (Territorial Cohesion Policy…, 2010; Maucorps, 2023; Dentinho, 2020). Similar patterns are identified in national studies on EU-funded development in rural Bulgaria, where the impact of European programmes strongly depends on institutional capacity and the ability of municipalities to formulate and implement mature project proposals (Shlyakov, 2025). Recent methodological research also underscores the importance of structured external-environment analysis for strengthening municipal strategic planning, especially in territories facing demographic decline and administrative limitations (Karadzhov & Patarchanova, 2025).

**Interrelationships between Key Financial Parameters and Conclusion**

A quantitative analysis of four interrelated indicators – the share of own-source revenues, the size of equalization and capital subsidies, and EU funds absorbed per capita – allows for a more detailed assessment of the functioning of the mechanisms of fiscal decentralization, subsidization, and external investment in vulnerable territories.

• A strong positive relationship between equalization and capital subsidies indicates that the same municipalities concentrate both current and investment support – a consolidated compensatory approach that may reflect targeted cohesion policy, but may also reinforce structural dependency (Lichev, 2019).
• A negative and weak correlation between the share of own-source revenues and the equalization subsidy confirms the theoretical purpose of the subsidy – to support municipalities with a low tax base – but also suggests that formula-based mechanisms do not always reflect real territorial deficits (Galabinova, 2011; Bird & Vaillancourt, 2006).
• A moderate positive correlation between EU funding and state subsidies, contrasted with a weak correlation with the share of own revenues, shows that EU funds depend more on administrative capacity and project culture than on objective need (Jakubowski, 2024; Zillmer et al., 2021; Maucorps, 2023).

The analysis of the interrelationships between the key financial parameters of border municipalities demonstrates that fiscal autonomy and access to investment (national and European) depend not only on the objective needs of the territories, but also on their institutional capacity, project culture, and administrative effectiveness. This necessitates a shift from a formal to a functional model of territorial financing, in which national and European policies are based on development potential and real constraints rather than solely on statistical indicators and mechanical formulas.

Only such a differentiated and territorially sensitive approach can ensure genuine cohesion and sustainable development in the country's border, mountainous, and vulnerable regions.

## CONCLUSION

The analysis of European, national, and regional policies aimed at the development of border areas demonstrates that the transformation from a "security buffer zone" into a space for integration and development remains a long, complex, and still incomplete process. The historical overview reveals strongly centralized, security-oriented approaches during the second half of the 20th century, within which the border territories of the Southwestern region functioned primarily as peripheral and controlled zones. This has resulted in long-lasting peripheralization, demographic decline, and lagging social and infrastructural development.

The contemporary normative and strategic framework – including the Regional Development Act, the National Concept for Spatial Development, the National Strategy for Regional Development, the Demographic Development Strategy, and the European regulations on cohesion and territorial cooperation – formally places border and peripheral regions among national priorities. Instruments such as Integrated Territorial Investments, the territorial approach, cross-border programmes, and targeted demographic measures reflect a shift toward multi-level governance and territorially oriented planning.

However, the quantitative analysis of financial parameters reveals significant intra-regional disparities. The share of own-source revenues, the effectiveness of local tax collection, the volume of equalization and capital subsidies, and the level of EU fund absorption all illustrate the uneven development of border municipalities. Some of them – such as Blagoevgrad, Kyustendil, Petrich, Sandanski, Simitli, Godech, and Dragoman – manage to utilise their advantageous location and administrative capacity to achieve relatively high financial autonomy and project activity.

In contrast, small, mountainous, and depopulated municipalities such as Treklyano, Satovcha, Kresna, and Strumyani remain structurally dependent on state transfers and have limited access to investment resources.

The empirical findings indicate that fiscal autonomy and effective participation in cohesion policy depend not only on territorial needs, but also on institutional capacity, project culture, and the quality of local governance. This creates a risk of reproducing a "double periphery," in which the most vulnerable border municipalities remain insufficiently represented in national and European investment streams.

In summary, there is a clear discrepancy between the declared goals of territorial cohesion and the actual outcomes achieved. A transition toward a functionally oriented, adaptive, and territorially sensitive policy model is required – one that acknowledges the specific characteristics, potential, and constraints of each border municipality in the Southwestern region. Only such an approach can ensure sustainability, socio-demographic stabilization, and meaningful integration of these critical territories into the national and European space.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interests.

REFERENCES

Dentinho, T. (2020). Cross-border cooperation and regional cohesion. *Regional Science Policy & Practice*, 12(6), 1031–1046. https://doi.org/10.1111/rsp3.12376

Başboğa, K. (2020). The role of open borders and cross-border cooperation in regional growth across Europe. Regional Studies, Regional Science, 7(1), 532–549. https://doi.org/10.1080/21681376.2020.1842800

Basboga, K. (2020). Cross-border cooperation and regional growth. *Regional Studies, Regional Science*, 7(1). https://doi.org/10.1080/21681376.2020.1842800

Batyk, I., & Rzeczkowski, D. (2020). Cross-border cooperation at the EU external border. https://doi.org/10.24136/eq.2020.036

Chamusca, P. (2024). Territorial cooperation dynamics. *Social Sciences*, 13(2). https://doi.org/10.3390/socsci13020108

Chirodea, F., Soproni, L., & Marian, M. (2024). European Union Tools for the Sustainable Development of Border Regions. Sustainability, 16(1), 388. https://doi.org/10.3390/su16010388

Demeterova, B., Goodwin-Hawkins, B., & Fischer, T. (2020). Conceptualisations of territorial cohesion in Central European border regions. European Planning Studies, 28(12), 2287–2306. https://doi.org/10.1080/09654313.2020.1716692

EU. (2013). *Regulation (EU) No 1303/2013 laying down common provisions for ERDF/CF.* https://eur-lex.europa.eu

European Commission, DG REGIO. (2021). *Border regions for the European Green Deal: Obstacles and solutions to cross-border cooperation in the EU.* Luxembourg: Publications Office of the European Union. https://data.europa.eu/doi/10.2776/305111

Gavrilova, O. (2025). Foreign Direct Investments in Trakia Economic Zone: Models and Economic Effects. *International Journal of Digital Research*, ISSN: 3033-179X. Vol. *1*(3), 21–34. https://doi.org/10.63711/ijdr.net20250302

Karadzhov, V. (2016). "Swot Analysis of The International Seasonal Labor Migrations of Bulgarian Students," Economics and Management, Faculty of Economics, SOUTH-WEST UNIVERSITY "NEOFIT RILSKI", BLAGOEVGRAD, Vol. 12(2), pages 183-196.

Karadzhov, V., & Patarchanova, E. (2025). How to Create the Best PESTEL Analysis. International Journal of Digital Research, ISSN: 3033-179X. Vol. *1*(3), 8–20. https://doi.org/10.63711/ijdr.net20250301

Lendzhova, V. (2025). Bridging the Divide: Digitalization and Young Rural Women in Bulgaria. *International Journal of Digital Research*, ISSN: 3033-179X. Vol. *1*(2), 25–39. https://doi.org/10.63711/ijdr.net20250203

Lichev, R. (2019) The need for changes in the administrative-territorial division in the Republic of Bulgaria in the context of its membership in the European Union. https://jbgs.arphahub.com/article/32296/

Lichev, R. (2023). Modern dimensions of the regional development of the Republic of Bulgaria https://science.uard.bg/index.php/regions/article/view/961

Lina, D. M., & Bedrule-Grigorută, M. V. (2009). Cross-Border Cooperation – A Tool for Regional Development in Europe. SSRN Electronic Journal.: http://dx.doi.org/10.2139/ssrn.1351728

Luukkonen, J. (2010). Territorial cohesion as a policy concept. *European Urban and Regional Studies*, 17(4), 387–400. https://doi.org/10.1177/0969776409350789

Maucorps, P. (2023). *Do borders still matter?* WIIW Policy Notes

Martín-Uceda, J., & Vicente Rufí, J. (2021). Territorial Development and Cross-Border Cooperation: A Review of the Consequences of European INTERREG Policies on the Spanish–French Border (2007–2020). Sustainability, 13(21), 12017. https://doi.org/10.3390/su132112017

Medeiros, E., Guillermo Ramírez, M., Dellagiacoma, C., & Brustia, G. (2021). Will reducing border barriers via the EU's b-solutions lead towards greater European territorial integration? Regional Studies, 56(4), 504–517. https://doi.org/10.1080/09654313.2022.2093606

Medeiros, E., Zaucha, J., & Ciołek, D. (2023). Measuring territorial cohesion trends. *European Planning Studies.* https://doi.org/10.1080/09654313.2022.2143713

Nagy, I. (2020). Cross-border cooperation on the external borders of the EU and the impact of the received EU CBC funds on AP Vojvodina/Serbia. Belgeo, 2020(2). https://doi.org/10.4000/belgeo.38732

Partridge, M. D., & Rickman, D. S. (2008). Distance from urban agglomeration economies and rural poverty. Journal of Regional Science, 48(2), 285–310. https://doi.org/10.1111/j.1467-9787.2008.00554.x

Patarchanova, E. (2012). *Socio-Economic Patterns and Trends in Rural Development in EU. Journal of Settlements and Spatial Planning*, Vol. 3, No. 2, pp. 151–155. http://geografie.ubbcluj.ro/ccau/jssp/arhiva_2_2012/11JSSP022012.pdf

Patarchanov, P., Patarchanova, E. (2014). *Contemporary Theory and Methodology in Studies and Development Models of Peripheral Areas. Journal of Settlements and Spatial Planning*, Special Issue No. 3, pp. 95–100. https://geografie.ubbcluj.ro/ccau/jssp/arhiva_si3_2014/13JSSPSI032014.pdf

Rehm, M., Schröder, M., & Wenzelburger, G. (2025). Border regions as nuclei of European integration? Evidence from Germany. Journal of Common Market Studies, 63(2), 485–506. https://doi.org/10.1111/jcms.13607

Shah, A. (2004). *Fiscal decentralization in transition economies.* World Bank Policy Research Working Paper 3314. https://doi.org/10.1596/1813-9450-3314

Shlyakov, V. (2025). European Programmes as a Factor for the Ecological Development of Rural Areas in Bulgaria. International Journal of Digital Research, ISSN: 3033-179X. Vol. *1*(4), 44–58. https://doi.org/10.63711/ijdr.net20250403

Territorial Cohesion Policy in Europe. (2010). *Journal of European Planning.* https://doi.org/10.1080/09654313.2010.504345

Topaloglou, L., Kallioras, D., Manetos, P., & Petrakos, G. (2005). A Border Regions Typology in the Enlarged European Union. Journal of Borderlands Studies, 20(2), 67–89. https://doi.org/10.1080/08865655.2005.9695644

Veleva, R. (2023). Local government and decentralization in Bulgaria. https://doi.org/10.37075/JOMSA.2023.1.04

Бояджиев, К. (2005). *Регионално развитие и регионална политика.* София: УИ „Св. Климент Охридски".

МРРБ. (2013-2025). Национална концепция за пространствено развитие 2013–2025. https://www.mrrb.bg/static/media/ups/articles/attachments/d747ca682ac1a70380428fd1dc664fb3.pdf

МРРБ. (2020). Национална стратегия за регионално развитие 2012–2022 (Актуализация). https://www.strategy.bg

Министерство на труда и социалната политика. (2012). Национална стратегия за демографско развитие 2012–2030. https://www.mlsp.government.bg

Закон за регионалното развитие: https://lex.bg/bg/laws/ldoc/2135589285

Закон за местното самоуправление и местната администрация. https://lex.bg/bg/laws/ldoc/2132580865

Колектив. (2018). *Регионални дисбаланси и демографски предизвикателства в България.* София: ИМИ-БАН https://tjs.trakia-uni.bg/index.php/tjs/article/view/209

**How to cite this article:**

Pandurski, V. (2025). Policies at the European, National and Regional Levels Aimed at the Development of Border Regions. *International Journal of Digital Research*. E-ISSN: 3033-179X. Vol. *1*(4): P.p. 92-105. *https://doi.org/10.63711/ijdr.net20250406*

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Short Communication*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 120-124*

# Evaluation of Physical Exercises on Gymnastic Boys in Shkoder, Albania

**Benjamin Naku[1], Migena Plasa[2]**

[1]Department of Physical Education and Sports, Faculty of Educational Sciences, University "L. Gurakuqi", Shkoder, Albania
[2]Department of Sports Performance, Scientific Research Institute of Sports, University of Sports of Tirana, Albania
ORCID IDs: [2]0009-0007-1453-925X

Corresponding Author: Migena Plasa E-mail: mplasa@ust.edu.al

https://doi.org/10.63711/ijdr.net20250408

## ABSTRACT

Gymnastics training may be beneficial for improving selected aspects of physical function in children over a relatively short period of time. The present study aimed to evaluate the effects of a basic gymnastics training program, conducted for one hour per week over ten weeks, on several physical function variables in boys aged 6–8 years from the city of Shkoder, Albania. A total of twelve male children participating in gymnastics were assessed before and after the ten-week training program. The intervention focused on fundamental movement patterns, including landing, static control, and jumping. Physical function was evaluated using standardized tests of abdominal strength, flexibility, balance, sprint speed, coordination, and lower limb power. Post-intervention results demonstrated improvements in several physical function components. Notable increases were observed in abdominal strength (30-s sit-up test; +16%), flexibility of the waist and thigh muscles (sit-and-reach test; +5.4%), and lower limb power (vertical jump test; +3.6%). Smaller improvements were observed in sprint speed and coordination, while balance performance showed high variability. The findings suggest that a short-term gymnastics training program may represent a potentially effective approach for enhancing selected components of physical function in boys aged 6–8 years. The exploratory age-specific normative range tables derived from baseline testing may be useful to practitioners conducting similar physical function assessments in young children.

***Keywords:*** *Gymnastics, Physical fitness, Motor development, Children aged 6–8 years, Physical education.*



## INTRODUCTION

Establishing normative ranges for these physical function tests in children will be valuable to practitioners conducting similar physical function tests in the future, both for identifying talents and for

early identification of children in need of improvement. Physical fitness in children and adolescents has also been associated with positive health outcomes in adults (Kvaavik, Klepp, Tell, Meyer, & Batty, 2008). Encouraging motor skill development and fitness in young children is likely to have significant benefits on health outcomes and potentially on subsequent athletic success in children.

Physical fitness, physical activity behaviour, and motor skill development are important components of physical education curricula and are potential indicators of children's health (Lloyd, Colley, & Tremblay, 2010). Furthermore, motor skills can be used to identify talent to predict athletic success in children (Grice, 2003). Previous research has demonstrated the positive effects of a four-week after-school program that addresses motor skills and fitness in young children (Matvienko & Iradge, 2009).

Understanding the benefits of participating in gymnastics training would provide important information for this field. The purpose of this study was to evaluate the effects of one hour per week for ten weeks of basic movement skills training in gymnastics on several components of physical function in children.

## MATERIALS & METHODS

A total of 12 children aged 6-8 years (7.4 ±1.3 years; 1.24 ±0.9 m; 31.9 ±3.9 kg) enrolled in the sport of general gymnastics. The children participated in one hour per week of general gymnastics training that included activities based on basic movement skills. The program focused on the development of 3 main movement patterns: landing, statics, jumping. Data were collected during the sessions, before and after the 10-week gymnastics training program. Body mass and height were measured, along with physical function variables of sprint speed (20 m), balance (stork balance test) (Johnson & Nelson, 1979).

The procedure was explained to all children practicing the sport of gymnastics who agreed to participate in the study, and all participants and their parents/coaches signed a written informed consent, in accordance with the ethical standards of the Declaration of Helsinki.

These tests were chosen because they have been clearly defined and validated in other studies (Beurden et al., 2003; Espana-Romero et al., 2010; Fjortoft, 2000), are easy to administer and time-efficient, and they cover a range of skill components. Performance changes for each test were calculated and expressed as percentages, with 90% confidence limits (90% CL) to indicate the possible range of the true value. Means and standard deviations from baseline testing were used to define performance categories.

Table 1: Categories and definitions of performance based on mean and standard deviations.

| Category | Definition |
|---|---|
| Excellent | More than three standard deviations above mean performance. |
| Good | Between two and three standard deviations above mean performance. |
| Above average | Between one and two standard deviations above mean performance. |
| Average | Within one standard deviation of mean performance. |
| Below average | Between one and two standard deviations below mean performance. |
| Poor | Between two and three standard deviations below mean performance. |
| Very poor | More than three standard deviations below mean performance. |

## RESULTS

Normative ranges for each component of physical function were calculated based on data from children who participated in the first testing session (see Tables 2). Change scores (expressed as percentages with 90% CL) were calculated for children who completed the testing before and after the intervention.

Table 2: Categories of performance on each physical function test for boys aged 6-8 years.

| | 20-m sprint | 30 s sit- up | Stork test | Sit and reach | Vertical jump |
|---|---|---|---|---|---|
| **Boys (n=12)** | **5.52 ±0.51** | **8.3 ±5.4** | **1.93 ±1.57** | **29.5 ±4.2** | **19.2 ±4.9** |
| very poor | > 7.04 | 0* | < 0.50* | < 15.5 | < 4.4 |
| poor | 6.55 - 7.04 | 1 - 2* | 0.50 - 0.92* | 15.5 - 19.5 | 4.4 - 9.2 |
| below average | 6.04 - 6.54 | 3 - 4* | 0.93 - 1.35 | 20.0 - 24.5 | 9.3 - 14.2 |
| average | 5.02 - 6.03 | 5-14 | 1.36 - 3.15 | 25.0 - 34.5 | 14.3 - 24.1 |
| above average | 4.51 - 5.01 | 15 – 19 | 3.16 - 6.37 | 35.0 - 39.0 | 24.2 - 29.1 |
| good | 4.00- 4.50 | 20 – 24 | 6.38 - 8.54 | 39.5 - 43.5 | 29.2 - 34.0 |
| excellent | < 4.00 | > 24 | > 8.54 | > 43.5 | > 34.0 |

*These ranges were selected by the authors, as they could not be defined by the data.

Normative values are exploratory and based on baseline testing only. Normative ranges were derived exclusively from baseline measurements and are intended as exploratory reference values.

## DISCUSSION

There was a small improvement in 20-meter sprint time, although the true effect size is likely to be insignificant. There was a significant improvement in the 30-second sit-up test, with a 17% increase in the average number of sit-ups that children were able to complete in 30 seconds. This was likely a beneficial effect.

There was a small decline in performance on the stork balance test. However, the large variability in the observed value suggests that the test was not an appropriate measure for this age group. A variant of this test, the flamingo balance test, may be more suitable for future testing (Adam et al., 1988). Significant improvements were seen for the sit-and-reach test, with a mean improvement of 6.4% on baseline scores. This is likely a beneficial effect. Thus, aerobic training probably has a beneficial effect on hip and lower back muscle flexibility in children. There was a mean decrease of 1.3 s (i.e., a small improvement) in the time required to complete the limb speed and coordination test, with an average improvement of $-1.79 \pm 4.52$ s observed in the present sample. Several activities within the gymnastics training program, such as swinging and jumping jacks, may have contributed to this small 5.8% improvement in limb speed and coordination, both of which are important components of motor function.

There was a small but significant improvement (4.6%) in the vertical jump height test for lower limb strength and power. Jumps are a key part of the training program, and thus the improvements

observed are likely the result of practicing and learning such movements. The baseline test results will help determine normative ranges for children completing these physical function tests. The sample size does not allow us to generalize the results to other active children in this age range with a good degree of confidence. These data will be valuable to practitioners conducting similar physical function tests in the future, both for identifying talents and for early identification of children who need improvement. These physical attributes form the basis of other athletic activities (e.g., track and field, diving).

Beyond its role as a competitive sport, gymnastics may be conceptualized as a transferable motor foundation that develops fundamental movement competencies such as strength, coordination, flexibility, and postural control. These capacities are broadly applicable across multiple physical activities and sports, supporting long-term physical literacy rather than sport-specific specialization.

## CONCLUSION

The findings of this study indicate that a short-term gymnastics training program can produce measurable improvements in selected components of physical function among boys aged 6–8 years. Following approximately ten weeks of structured gymnastics practice, positive changes were observed primarily in abdominal strength, flexibility, coordination, and lower limb power. These outcomes support the role of gymnastics as an effective foundational activity for promoting motor development during early childhood.

Although improvements in sprint performance and balance were modest and, in some cases, inconsistent, the overall pattern of results suggests that regular exposure to fundamental movement patterns – such as jumping, landing, and static control – contributes positively to physical fitness development in young children. The limited response observed in balance performance highlights the importance of selecting age-appropriate testing instruments and suggests that alternative balance assessments may be more suitable for this population in future research.

The normative range tables generated in this study provide preliminary reference values for practitioners and coaches conducting physical function assessments in children aged 6–8 years. While these reference values should be interpreted with caution due to the small sample size, they may nonetheless assist in early talent identification, monitoring physical development, and identifying children who may benefit from targeted intervention.

Several limitations must be acknowledged. The small sample size and lack of a control group restrict the generalizability of the findings, and the results should therefore be considered exploratory. Future studies should employ larger samples, include both sexes, apply longer intervention periods, and incorporate comparative or randomized designs to strengthen causal inference.

In conclusion, the present study contributes practical evidence supporting the inclusion of gymnastics-based activities in early childhood physical education programs. Gymnastics training appears to be a valuable tool for enhancing fundamental physical capacities that underpin later athletic performance and long-term physical activity participation.

### *Declaration by Authors*

**Ethical Approval:** Approved
**Acknowledgement:** We thank the children and their parents who made this process possible.
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interests.

## REFERENCES

Adam, C., Klissouras, V., Ravazzolo, M., Renson, R., & Tuxworth, W. (1988). Eurofit: European Test of Physical Fitness Council of Europe. Committee for the Development of Sport Rome.

Beurden, E., Barnett, L., Zask, A., Dietrich, U., Brooks, L., Beard, J. (2003). Can we skill and activate children through primary school physical education lessons? "move it groove it" - a collaborative health promotion intervention. *Preventive Medicine*, *36*(4), 493–501. https://doi.org/10.1016/s0091-7435(02)00044-0

España-Romero, V., Artero, E. G., Jimenez-Pavón, D., Cuenca-Garcia, M., Ortega, F. B., Castro-Piñero, J., Sjöstrom, M., Castillo-Garzon, M. J., Ruiz, J. R. (2010). Assessing Health-Related Fitness Tests in the school setting: Reliability, Feasibility and Safety; the ALPHA Study. *International Journal of Sports Medicine*, *31*(07), 490–497. https://doi.org/10.1055/s-0030-1251990

Fjørtoft, I. (2000). Motor Fitness in Pre-Primary School Children: The EUROFIT Motor Fitness Test explored on 5–7-Year-Old children. *Pediatric Exercise Science*, *12*(4), 424–436. https://doi.org/10.1123/pes.12.4.424

Johnson, B. L., & Nelson, J. K. (1979). *Practical measurements for evaluation in physical Education.* https://eric.ed.gov/?id=ED048380

Kvaavik, E., Klepp, K., Tell, G. S., Meyer, H. E., & Batty, G. D. (2008). Physical fitness and physical activity at age 13 years as predictors of cardiovascular disease Risk factors at ages 15, 25, 33, and 40 years: Extended follow-up of the Oslo Youth Study. *PEDIATRICS*, *123*(1), e80–e86. https://doi.org/10.1542/peds.2008-1118

Lloyd, M., Colley, R. C., & Tremblay, M. S. (2010). Advancing the debate on 'Fitness testing' for children: Perhaps we're riding the wrong animal. *Pediatric Exercise Science*, *22*(2), 176–182. https://doi.org/10.1123/pes.22.2.176

Matvienko, O., Ahrabi-Fard, I. (2010). The effects of a 4-Week After-School program on motor skills and fitness of kindergarten and First-Grade students. *American Journal of Health Promotion*, *24*(5), 299–303. https://doi.org/10.4278/ajhp.08050146

Susanto, E., Indonesia,. Bayok, M., Indonesia,., Satriawan, R., Indonesia. N. T., Festiawan, R., Indonesia,. Kurniawan, D. D., Indonesia., Putra, F. (2023). Talent Identification Predicting in Athletics: a case study in Indonesia. *Annals of Applied Sport Science*, *11*(1), 0. https://doi.org/10.52547/aassjournal.1102

**How to cite this article:**

Naku, B., & Plasa, M. (2025). Evaluation of physical exercises on gymnastic boys in Shkoder, Albania. *International Journal of Digital Research*, E-ISSN: 3033-179X, Vol. 1 (4): 120–124. https://doi.org/10.63711/ijdr.net20250408

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Research Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 125-142*

# Remote Sensing Technique For Temporal and Spatial Mapping of the LST and Surface Urban Heat Island (SUHI) Development Between 1990–2025 in Plovdiv, Bulgaria

**Miroslav Ivanov[1], Vladimir Karadzhov[2], Emilia Patarchanova[3], Veselina Dalgacheva[4]**

[1,2,3,4] Department of Geography, Ecology, and Environmental Protection, Faculty of Mathematics and Natural Sciences, South-West University "Neofit Rilski" – Blagoevgrad

ORCID IDs: [1] 0000-0002-2347-8029, [2] 0000-0002-7514-5517, [3] 0000-0002-1806-557X, [4] 0000-0002-1976-5367

Corresponding Author: Miroslav Ivanov, m_ivanov@swu.bg

https://doi.org/10.63711/ijdr.net20250409

## ABSTRACT

The main objective of this study is to map the temporal and spatial development of land surface temperature (LST) and surface urban heat island (SUHI) within the city of Plovdiv, Bulgaria, for the period between 1990 and 2025. The analysis is based on satellite imagery and remote sensing techniques, using Landsat data processed through Google Earth Engine and geographic information system software. Average summer LST and the normalized difference vegetation index (NDVI) were calculated for selected reference years in order to assess long-term trends in urban heat accumulation and their relationship with land cover characteristics. The results indicate a clear increase in LST over the studied period, with the highest values observed in densely built-up areas, industrial zones, and large open surfaces with limited or no vegetation. In contrast, areas with well-developed green infrastructure, including urban parks and the Maritsa River corridor, exhibit lower surface temperatures and a mitigating effect on urban heat intensity. The analysis also reveals the gradual formation of a surface urban heat island belt surrounding the city core, as well as the emergence of localized micro-scale heat islands in newly urbanized peripheral areas. These patterns reflect the combined effects of urban expansion, land-use change, and regional climate warming. The study confirms the reliability of satellite-based remote sensing for assessing urban thermal environments and highlights its practical relevance for sustainable urban planning, climate adaptation measures, and smart city development.

***Keywords:*** *Remote sensing, Land surface temperature, Surface urban heat island, NDVI, LST, Landsat satellites, Urban climate, Plovdiv, Bulgaria*

## INTRODUCTION

Climate change has led to a noticeable increase in the frequency and duration of heat waves across Europe, significantly impacting urban areas. Rapid population growth in cities, coupled with large areas of unvegetated land, makes urban environments particularly susceptible to rising land surface temperatures (LST). Elevated LST poses health risks, especially for vulnerable groups within the urban population, creating a pressing need for innovative urban development practices to mitigate the effects of heat waves. The urban heat island effect, characterized by higher temperatures in urban areas compared to their rural surroundings (Decheng et al., 2018), further compounds these challenges. This phenomenon results from varying land cover types and the presence or absence of vegetation and water bodies within the city.

The connection between urbanization patterns and surface urban heat island (SUHI) has been investigated in numerous scientific studies. Dimitrov et al. (2024) applied thermal photogrammetry using unmanned aerial systems (UAS), combined with geographic information systems (GIS), to analyse surface urban heat island intensity at a local level for the largest housing complex in Bulgaria – the Lyulin district of Sofia. Dimitrov et al. (2024) found a temperature difference of 16.5 °C between locations affected by surface urban heat islands and peripheral non-built or natural land cover types within the urbanized area. In similar research, Dimitrov et al. (2023) used thermal photogrammetry carried out by an unmanned aerial system to determine local climate zones (LCZ) in the city of Burgas, Bulgaria. Sarafova et al. (2025) investigated the urban heat island phenomenon in Bulgaria during the extreme heatwave event of July 2024, using high-resolution ECOSTRESS satellite data from the International Space Station. In their research, Sarafova et al. (2025) mapped and visualized temperature variations across major urban centres in the country. The data cover 26 of the 27 regional capitals, highlighting the pronounced urban heat island effect in densely populated and industrial areas. Spasova et al. (2021; 2024) also investigated the connection between urban heat islands and renewable energy sources in different planning regions of Bulgaria.

Elevated temperatures not only deteriorate the quality of life for residents but also lead to increased energy consumption and higher greenhouse gas emissions. Therefore, mapping areas with elevated LST is a crucial tool for effective urban planning and an integral part of the smart city concept, aimed at enhancing urban sustainability and resilience. Advances in remote sensing in recent decades, together with the large number of available satellite instruments, have significantly improved techniques for mapping surface urban heat islands.

Based on the above, the main goal of this research is to map surface urban heat islands within the city of Plovdiv, Bulgaria, using satellite data, remote sensing techniques, the Google Earth Engine Code Editor, and ArcGIS Pro for result interpretation. Plovdiv is one of Bulgaria's oldest cities, renowned for its rich history and vibrant culture. Situated in the south-central part of the country, it features a unique blend of ancient and modern influences, including well-preserved Roman ruins, such as the Ancient Theatre and Stadium, alongside Ottoman-era buildings and contemporary urban areas. The city is built on seven hills, offering picturesque views and favourable conditions for urban green spaces.

In recent years, the city has experienced significant economic development, and the presence of several industrial zones has attracted both local and foreign investment. As a result of this industrial expansion, Plovdiv has experienced gradual population growth, reflecting positive trends in migration and urbanization. The population of Plovdiv municipality was 329,489 inhabitants in 2024, with a positive net migration of 4,887 people during the same year (www.nsi.bg). This positive migration trend has led to a significant rise in construction activity and rapid urbanization of the city outskirts. The city's

rapid growth has resulted in the replacement of natural landscapes with concrete and asphalt surfaces, contributing to the surface urban heat island effect, where built environments absorb and retain heat, leading to higher temperatures compared to surrounding green areas.

Although the city maintains a relatively well-developed green infrastructure, many urban areas lack sufficient vegetation, which reduces the natural cooling effects provided by trees and plants. High building density and the expansion of large industrial infrastructures also lead to increased land surface temperatures, forming distinct surface urban heat islands in certain parts of the city. The geographical characteristics of Plovdiv, including its valley location and surrounding hills, may further influence local climate conditions, limiting air circulation and contributing to heat accumulation during summer periods.

## MATERIALS AND METHODS

The area of interest is the city of Plovdiv, Bulgaria (Fig. 2). The city is situated in the south-central part of the country. Plovdiv is the second largest and one of the most significant cities in the Republic of Bulgaria. It is located on both banks of the Maritsa River in the Upper Thracian Plain, at a latitude of 42° 9′ N and a longitude of 24° 45′ E, with its lowest point at 160 meters above sea level. The city covers an area of 101.981 square kilometers, and its population is approximately 338,153 people (www.plovdiv.bg).

Plovdiv is a strategically important industrial, commercial, scientific, cultural, and transportation hub in the Balkans. It is internationally known for the International Fair, whose spring and autumn exhibitions, along with numerous specialized events, make it a center for commerce and business. The city is a key railway junction, and Plovdiv Airport has recently established itself as an alternative to Sofia Airport (www.plovdiv.bg).

Important international highways pass through the city, historically connecting the Orient with Europe, the Baltic Sea with the Mediterranean, and the Black Sea with the Adriatic. Its unique location at an ancient crossroads has contributed to strong cultural and political influences from both Eastern and Western civilizations, while maintaining an exceptional cultural identity. The six granite hills give the city a distinctive and picturesque character and, as protected areas, preserve a significant number of rare plant species. Together with the Maritsa River basin, the green-covered hills create specific climatic conditions – relatively mild winters and hot, humid summers. The favorable climate and geographical position of Plovdiv have supported its continuous development throughout all historical periods.

The city of Plovdiv is located within the transitional continental climate zone of Eastern Central Bulgaria. This region encompasses most of the lowlands along the Maritsa and Tundzha rivers and borders the Continental-Mediterranean climatic region to the southeast (Velev, 2010). ERA5-Land data provide evidence of a warming trend, as historical records for Plovdiv show a clear upward shift. The 40-year average temperature is approximately 12.36 °C, while the average for the most recent 20 years has risen to approximately 13.10 °C and to 13.53 °C for the last 10 years. In addition, significant seasonal shifts are observed: ERA5-Land data for Plovdiv indicate that summer temperatures have increased markedly (by nearly 2 °C) over the last 30 years, whereas winter temperatures have risen more modestly (by about 0.5 °C). ERA5-Land data have a spatial resolution of 9 km, making them highly suitable for identifying regional climate trends compared to standard global climate models. This conclusion is further supported by average annual temperature data for the period 1986–2025, which show a clear positive trend (Fig. 1).

Similar conclusions are reported by Stoyanov et al. (2025), who identified a gradual but consistent increase in mean annual temperature starting around 2005 and accelerating after 2015. As a result, mean annual temperatures reached values between 14.5 and 15 °C during the period 2022–2024, representing a substantial increase compared to the 12–13 °C range observed between 1977 and 2000. Overall, the data indicate a sustained upward trend in mean annual temperatures in Plovdiv for the period 1977–2024 (Stoyanov et al., 2025).

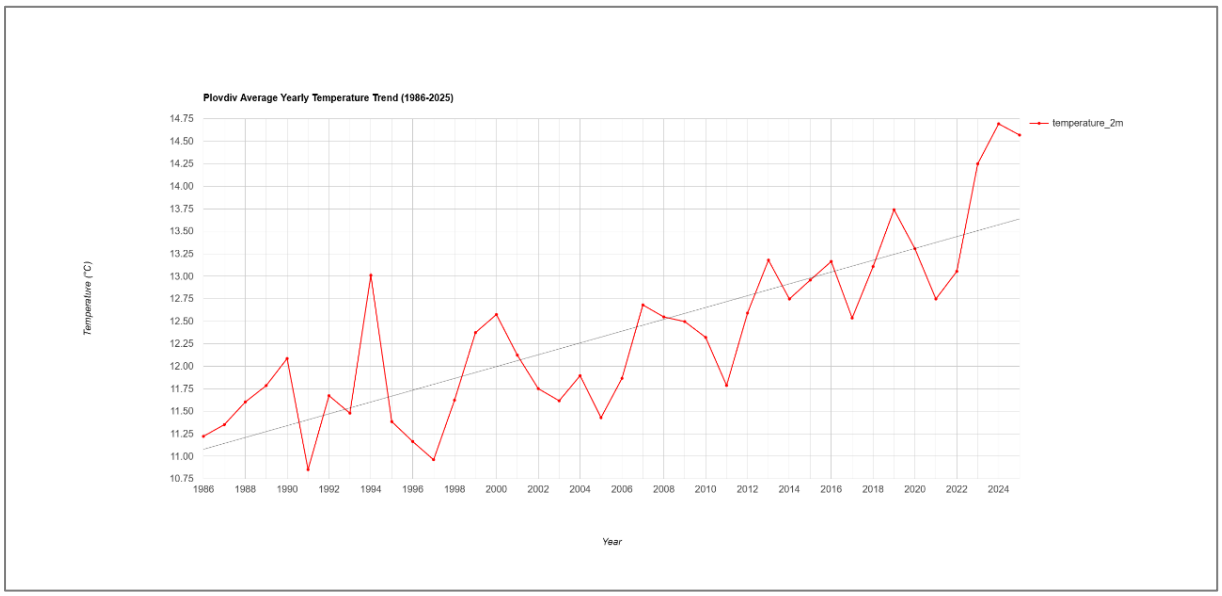


Fig. 1. Monthly temperature trend for Plovdiv (1986–2025), based on ERA5 data with 9 km spatial resolution.

The city has experienced significant economic development in recent years, and the presence of several industrial zones has attracted both local and foreign investment. As a result of the recent boom in industrial activity, Plovdiv has undergone a gradual increase in population, reflecting a positive trend in migration and urbanization. This positive net migration trend has also led to a significant expansion of the construction industry and rapid urbanization of the city outskirts.

Plovdiv's urban development has changed considerably over time, reflecting its rich historical heritage while accommodating modern needs. The city places strong emphasis on preserving its cultural and historical sites, ensuring that areas such as the Old Town retain their unique architectural style and historical character, which also contributes to the promotion of tourism.

In terms of infrastructure, Plovdiv has seen substantial investments in transportation systems, road networks, and utilities. Improvements in public transport and road infrastructure have increased connectivity both within the city and with nearby regions. In addition, efforts are being made to develop and enhance public spaces, making them more accessible and attractive for residents and visitors. These initiatives include the expansion of parks, pedestrian zones, and recreational areas, thereby improving the overall quality of life.

Plovdiv is also focusing on sustainable urban practices, such as eco-friendly building initiatives and the expansion of green spaces. The city is working to incorporate renewable energy solutions and to promote cycling and walking as alternative modes of transport. Furthermore, Plovdiv is exploring smart city initiatives by integrating digital technologies into urban services in order to enhance efficiency and citizen engagement.

Finally, the growing demand for housing has resulted in increased residential development, with new apartment complexes and mixed-use buildings being constructed to meet the needs of the expanding population.

Due to rapid economic and urban development, Plovdiv, like many urban areas, is highly vulnerable to elevated land surface temperatures (LST). The city's rapid growth has led to extensive construction, replacing natural landscapes with concrete and asphalt surfaces. This urban expansion contributes to the Surface Urban Heat Island (SUHI) effect, in which built-up environments absorb and retain heat, resulting in higher temperatures compared to surrounding green areas. Although Plovdiv maintains relatively well-developed green infrastructure, many urban zones still lack sufficient vegetation, which reduces the natural cooling effects provided by trees and plants. High building density and the development of large industrial infrastructures further contribute to increased land surface temperatures, forming a clearly distinguishable surface urban heat island in certain parts of the city (Ivanov et al., 2024).

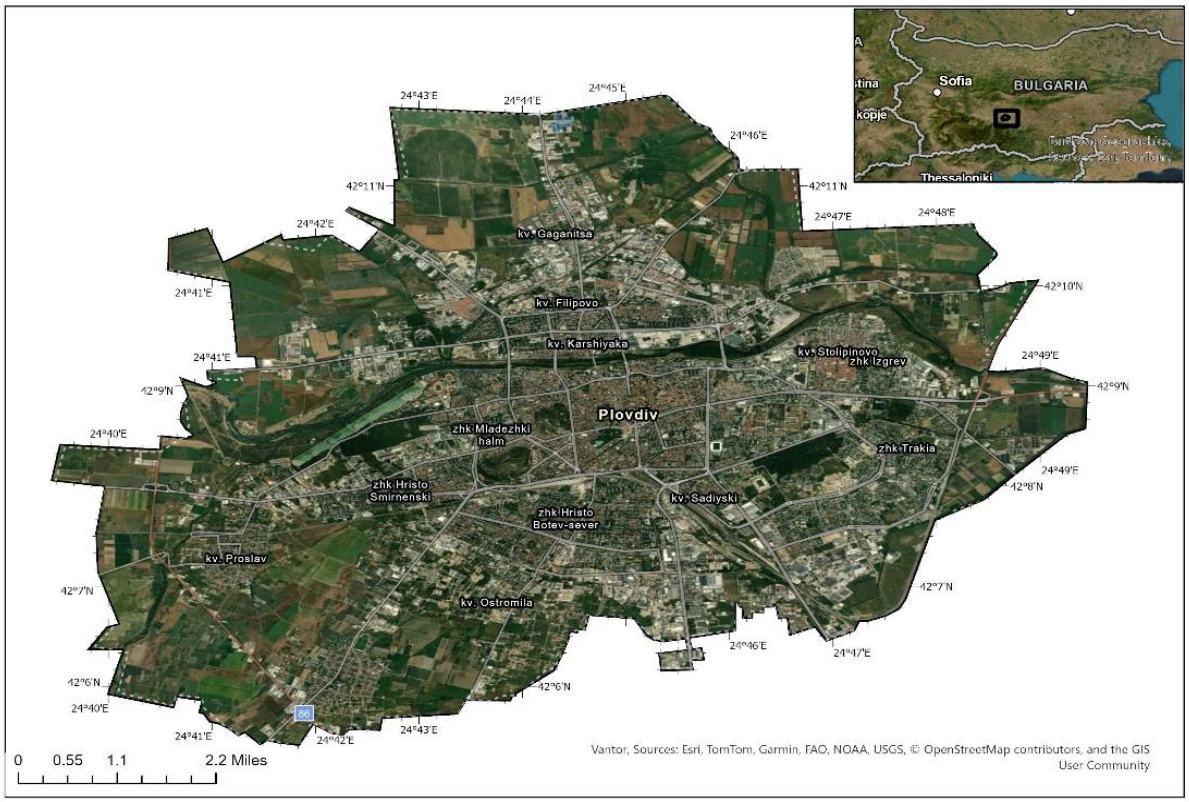


Fig. 2. Seasonal temperature variability for Plovdiv (1986–2025), based on ERA5 data with 9 km spatial resolution.

The geographical characteristics of Plovdiv, including its valley location and surrounding hills, can also influence local climatic conditions by limiting airflow and contributing to heat accumulation during summer periods, as well as temperature inversions in colder months. These inversions are often accompanied by fog formation and elevated concentrations of fine particulate matter. In addition, increasing traffic volumes and frequent traffic congestion contribute to environmental pressures within the city.

To analyze the temporal dynamics and spatial distribution of land surface temperatures within the city of Plovdiv, a series of satellite images captured during the summer period – from 1 June to 31 August – were used for the years 2025, 2015, 2005, 1995, and 1990. The year 1990 was selected as a reference point because, following the political changes in Bulgaria in 1989, the country underwent a transition to a new economic model, which substantially altered the patterns of urban and economic development in Plovdiv, as well as nationwide.

The satellite images used in this research were acquired by the Landsat 8 and Landsat 5 satellites, operated by NASA. The primary instruments onboard Landsat 8 are the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The OLI collects data in the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum (VNIR, NIR, and SWIR). The TIRS measures land surface temperature using two thermal bands and employs advanced sensor technology for heat detection.

Landsat 8 imagery provides a spatial resolution of 15 meters for the panchromatic band and 30 meters for multispectral bands, with a swath width of 185 km (115 mi) (www.usgs.gov). The spectral resolution of Landsat 8 imagery is presented in Table 1.

Table 1 – Spectral resolution of Landsat 8 (source www.usgs.gov)

| Operational Land Imager (OLI) | Thermal Infrared Sensor (TIRS) |
|---|---|
| • Nine spectral bands, including a pan band:<br>◦ Band 1 Coastal Aerosol (0.43 - 0.45 µm) 30 m<br>◦ Band 2 Blue (0.450 - 0.51 µm) 30 m<br>◦ Band 3 Green (0.53 - 0.59 µm) 30 m<br>◦ Band 4 Red (0.64 - 0.67 µm) 30 m<br>◦ Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m<br>◦ Band 6 SWIR 1(1.57 - 1.65 µm) 30 m<br>◦ Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m<br>◦ Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m<br>◦ Band 9 Cirrus (1.36 - 1.38 µm) 30 m | • Two spectral bands:<br>◦ Band 10 TIRS 1 (10.6 - 11.19 µm) 100 m<br>◦ Band 11 TIRS 2 (11.5 - 12.51 µm) 100 m |

To determine the temporal development and spatial distribution of the Surface Urban Heat Island (SUHI) in the city of Plovdiv, remote sensing techniques, the Google Earth Engine Code Editor, and GIS analyses using ArcGIS Pro software were applied to calculate the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST).

Because the temporal resolution of Landsat satellites is 16 days, average LST values for the summer period – from 1 June to 31 August – were calculated for the years 2025, 2015, 2005, 1995, and 1990. The code used for satellite image processing is presented in Fig. 3.

In addition, both the code and the corresponding results are accessible via the following links:

For Landsat 8: https://code.earthengine.google.com/4aa4b9a70f570cba0e5dc6a7c1f048b3

For Landsat 5: https://code.earthengine.google.com/b249b6b1dab291a094a9fd1686f2fe2b

To visualize the data for different years, the date range specified in the command .filterDate ('2025-06-01', '2025-08-31') can be modified to match the desired time period.

```
/**
 * Average Summer LST & NDVI - Plovdiv 2025
 * Sensor: Landsat 8 OLI/TIRS Collection 2 Level 2
 */

// 1. Define Area of Interest (AOI) - Plovdiv
var p_lat = 42.1354;
var p_lon = 24.7453;
var aoi = ee.Geometry.Point([p_lon, p_lat]).buffer(7000).bounds();

// 2. Load Landsat 8 Collection 2 Level 2 for Summer 2025 (June - August)
var summer2025 = ee.ImageCollection("LANDSAT/LC08/C02/T1_L2")
    .filterBounds(aoi)
    .filterDate('2025-06-01', '2025-08-31')
    .filter(ee.Filter.lt('CLOUD_COVER', 40));

// 3. Define Processing Function
var processImage = function(image) {
  // Scaling Factors for Collection 2
  var thermal = image.select('ST_B10').multiply(0.00341802).add(149.0); // Kelvin
  var optical = image.select('SR_B.').multiply(0.0000275).add(-0.2);

  // NDVI Calculation (NIR=B5, Red=B4)
  var ndvi = optical.normalizedDifference(['SR_B5', 'SR_B4']).rename('NDVI');

  // Emissivity based on NDVI
  var pv = ndvi.expression('((ndvi - 0.2) / (0.5 - 0.2))**2', {'ndvi': ndvi});
  var emissivity = pv.multiply(0.004).add(0.986);

  // LST Calculation (Celsius)
  var lst = thermal.expression(
    '(TB / (1 + (0.00115 * (TB / 1.438)) * log(em))) - 273.15', {
      'TB': thermal,
      'em': emissivity
    }).rename('LST');

  return image.addBands([lst, ndvi]);
};

// 4. Map Function and Calculate Mean
var processedCollection = summer2025.map(processImage);
var averageSummer2025 = processedCollection.mean().clip(aoi);

// 5. Visualizations
Map.centerObject(aoi, 12);

// LST Layer
var lstVis = {
  min: 25,
  max: 45,
  palette: ['blue', 'green', 'yellow', 'orange', 'red']
};
Map.addLayer(averageSummer2025.select('LST'), lstVis, 'Avg Summer LST 2025');

// NDVI Layer
var ndviVis = {
  min: 0,
  max: 0.8,
  palette: ['#FFFFFF', '#CE7E45', '#F1B555', '#66A000', '#012E01']
};
Map.addLayer(averageSummer2025.select('NDVI'), ndviVis, 'Avg Summer NDVI 2025');

// 6. EXPORTS (Check "Tasks" tab to Run)
Export.image.toDrive({
  image: averageSummer2025.select('LST'),
  description: 'Plovdiv_Summer_LST_2025',
  scale: 30,
  region: aoi,
  fileFormat: 'GeoTIFF'
});

Export.image.toDrive({
  image: averageSummer2025.select('NDVI'),
  description: 'Plovdiv_Summer_NDVI_2025',
  scale: 30,
  region: aoi,
  fileFormat: 'GeoTIFF'
});

print('Images used for average:', processedCollection.size());
```

Fig. 3. Methodology for calculating urban heat islands (Opong J., 2021)

The calculation of the Normalized Difference Vegetation Index (NDVI) was performed using the Google Earth Engine Code Editor with Java-based coding (Fig. 2). The generated raster data were extracted and analyzed in ArcGIS Pro, where classified raster images representing NDVI values and average seasonal Land Surface Temperature (LST) were produced.

The resulting images were clipped to the boundaries of the Urban Development Master Plan of the Plovdiv Municipality, which encompass not only the urban areas of the municipality but also agricultural lands and natural habitats.

## RESULTS

The values of the Normalized Difference Vegetation Index (NDVI) for the periods 1990–1995 (Fig. 4), 2005–2015 (Fig. 4), and for the year 2025 within the study area indicate that vegetation cover and green spaces are relatively well distributed both around the city and within its administrative boundaries. In 1990, the city was surrounded by well-defined agricultural lands and open spaces. However, NDVI values were generally lower in agricultural areas and along the green zones within the city, with prevailing values between 0.20 and 0.40. This can be attributed to dry climatic conditions observed in Bulgaria during the 1990s, as well as to agricultural activities such as crop harvesting or ploughing.

From a temporal perspective, the main components of green infrastructure within the central parts of the city of Plovdiv have remained largely intact throughout the study period. Nevertheless, after 2005, rapid urbanization became evident in the peripheral zones of the city, particularly in the southern, northern, and western districts, as well as within the northern, southern, and western industrial zones. This process has been accompanied by an increase in building density and a reduction of green areas within some high-density residential neighbourhoods that were planned and constructed prior to 1989.

The results further indicate that vegetation presence is less pronounced in the city centre. At the same time, some green areas located within older high-rise residential neighbourhoods, developed before 1989, remain partially preserved, although they are often inadequately maintained.

The analysis of Land Surface Temperature (LST) for the period 1990–2025 (Fig. 7, Fig. 8, Fig. 9) across the territory of the city of Plovdiv shows that areas with higher temperatures strongly overlap with zones lacking vegetation or characterized by sparse vegetation cover. Elevated temperatures are also observed in the historic city center and within industrial areas located around the city.

A clear increasing trend in LST is identified over the study period. The minimum average summer LST values increased from approximately 24 °C in 1990 to around 30 °C in 2025. A similar trend is observed for maximum LST values, which rose from 54.89 °C in 1990 to 56.31 °C in 2025.

This increase can be attributed to rapid urbanization in certain parts of the city and the expansion of industrial infrastructure, as well as to the overall warming trend of the regional climate, as Plovdiv has experienced a substantial temperature increase of approximately +1.5 to 2 °C since the 1970s (Stoyanov et al., 2025).

The temporal analysis of LST in Plovdiv between 1990 and 2025 reveals a gradual formation of a new heat island belt surrounding the urban core (Fig. 10), along with the development of localized micro heat islands within the most densely built-up areas of the city.

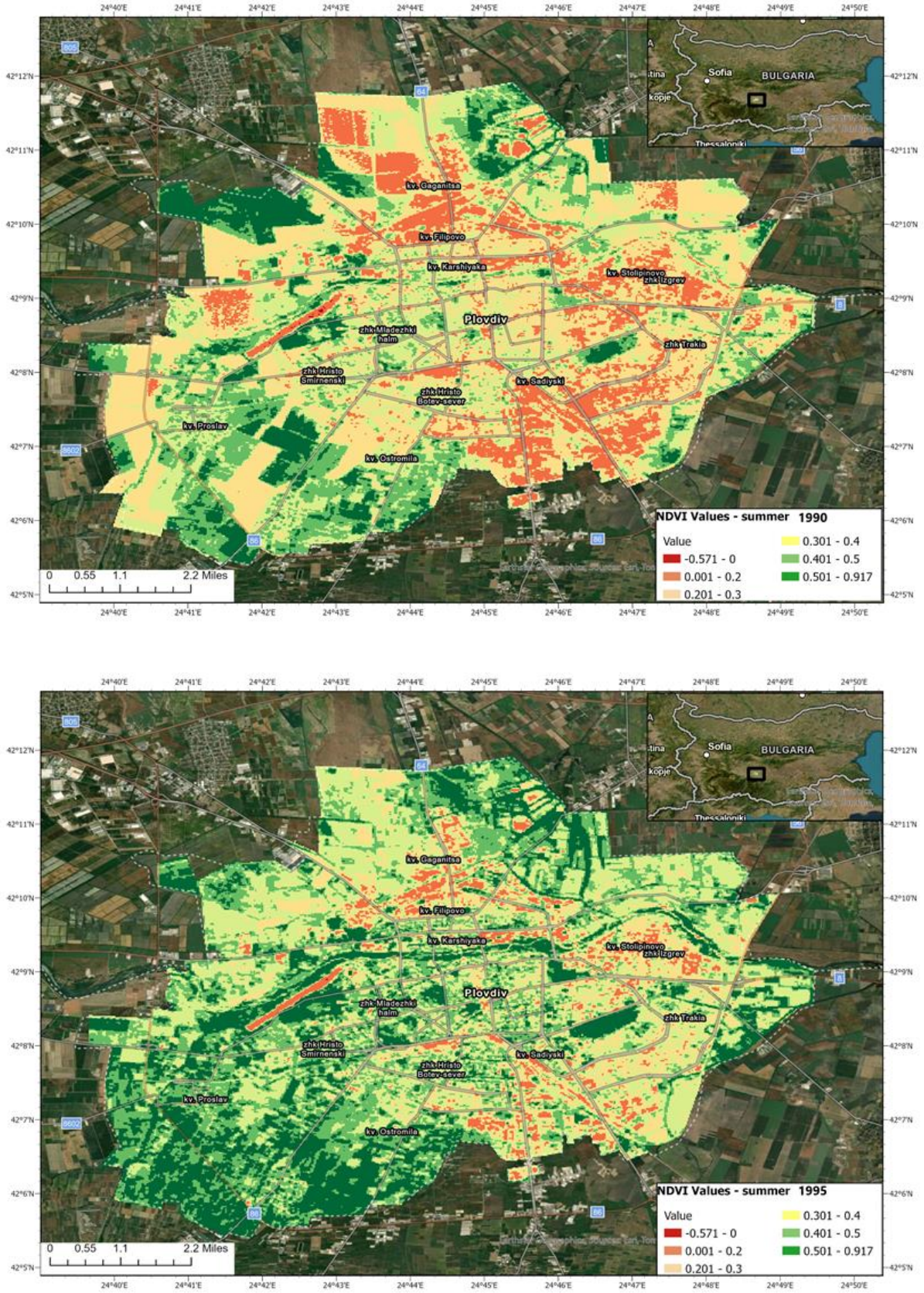


Fig. 4. Dynamics of NDVI values for the period 1990–1995; values above 0.50 represent dense and healthy vegetation.

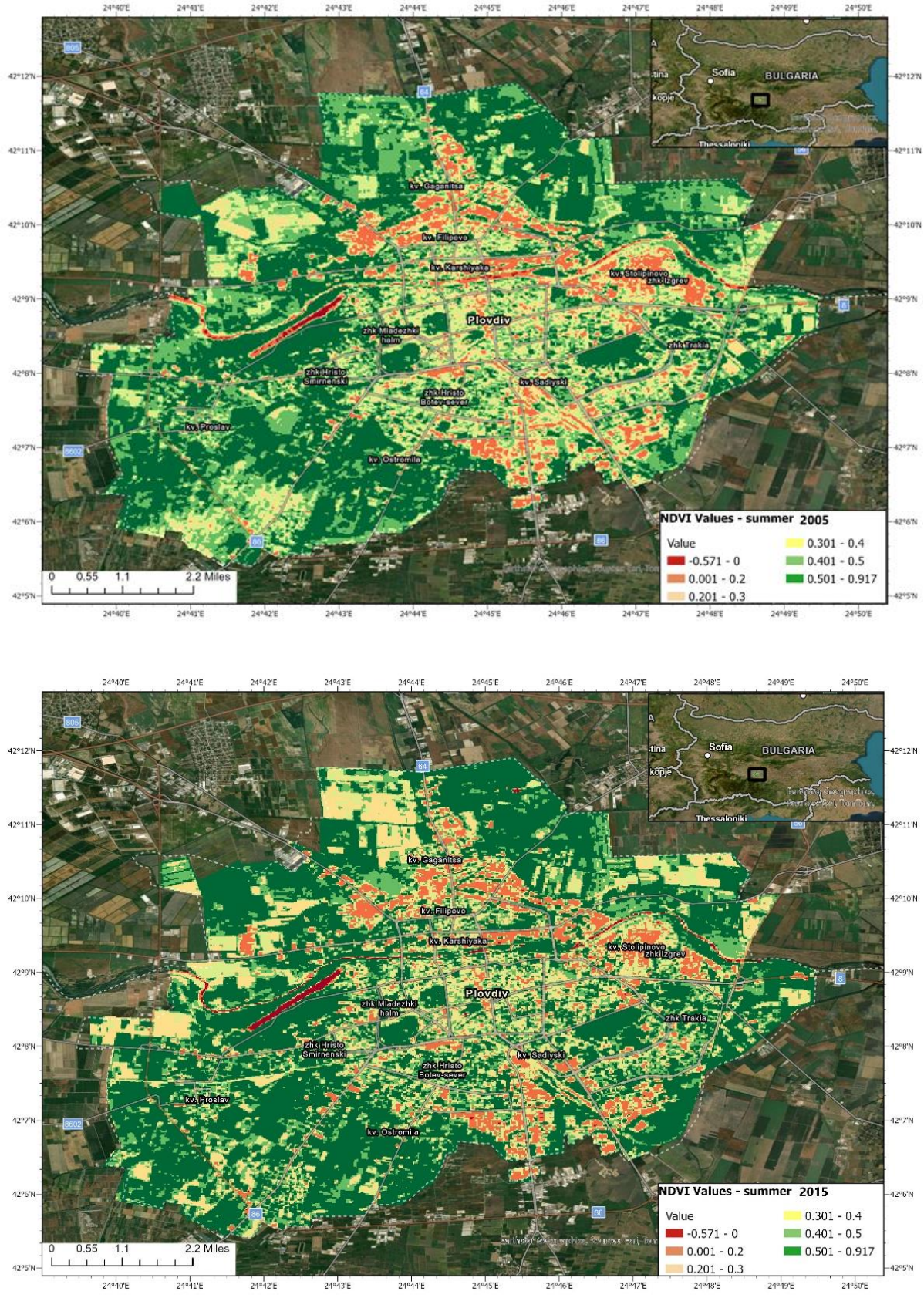


Fig. 5. Dynamics of NDVI values for the period 2005–2015; values above 0.50 represent dense and healthy vegetation.

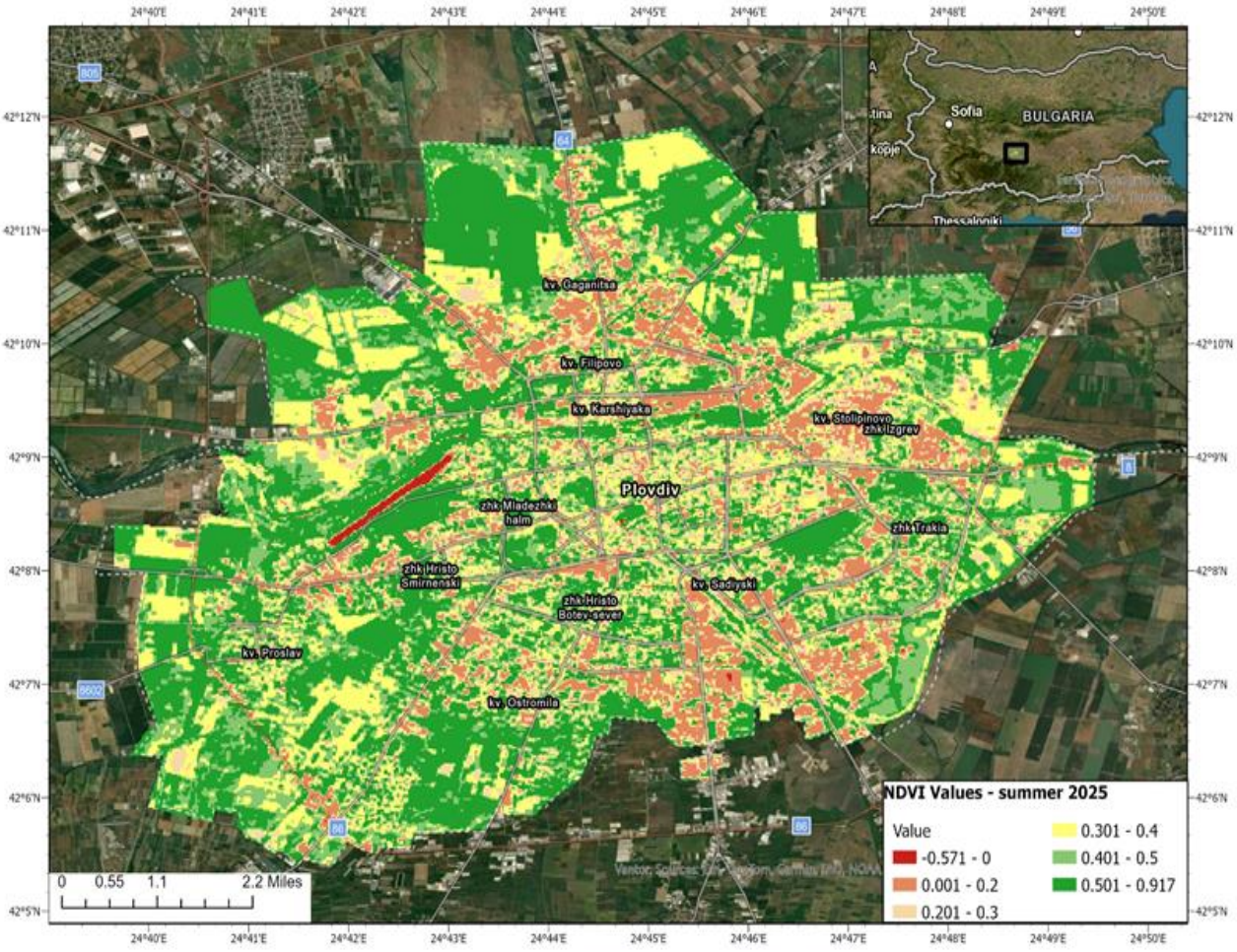


Fig. 6. Dynamics of NDVI values for the year 2025; values above 0.50 represent dense and healthy vegetation.

The well-developed green infrastructure within the central urban area, as well as the vegetated corridor along the Maritsa River, exerts a mitigating effect on heat vulnerability in certain parts of the city. However, a lack of green infrastructure is evident within the so-called heat island belt, which includes the industrial zones surrounding the city core, newly developed peripheral neighbourhoods, and socially vulnerable residential areas with lower population income levels, such as Stolipinovo (Fig. 10).

If current trends of building densification and rapid peripheral urbanization continue, combined with the expected rise in summer temperatures, the planning and implementation of new green infrastructure, along with additional measures to reduce the thermal footprint of existing buildings, will become increasingly necessary.

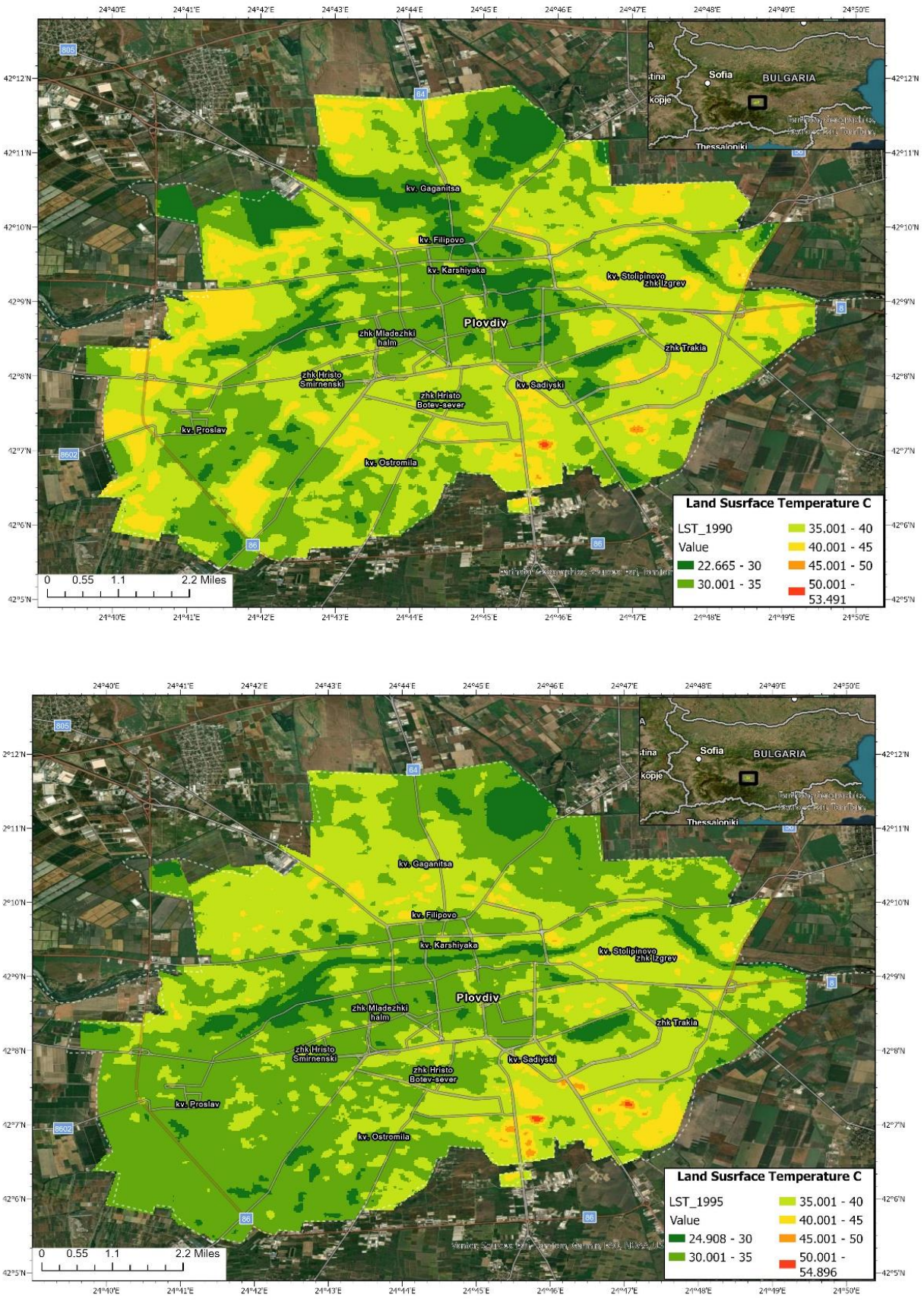


Fig. 7. Distribution of average summer land surface temperatures (LST) for the period 1990–1995.

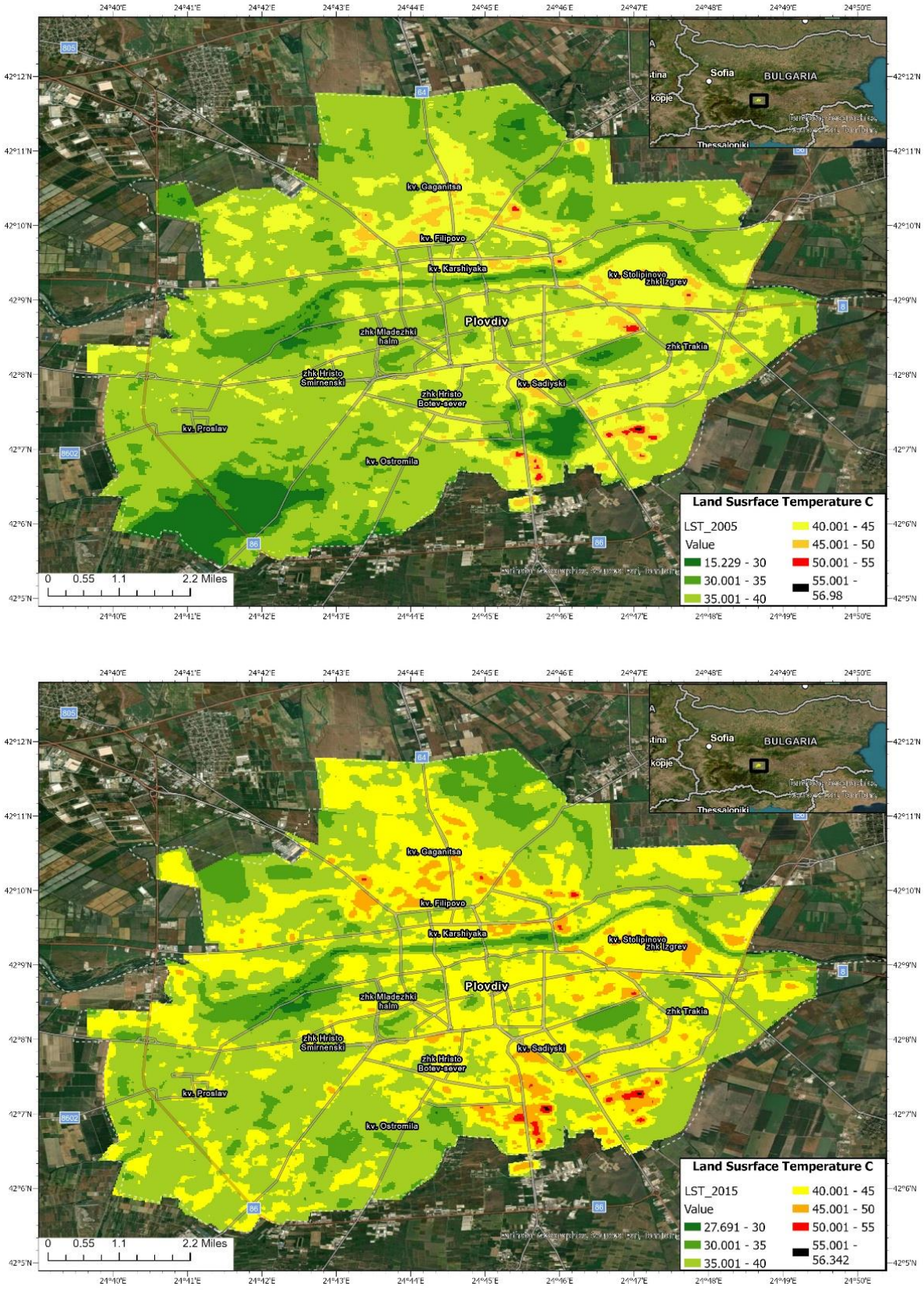


Fig. 8. Distribution of average summer land surface temperatures (LST) for the period 2005–2015.

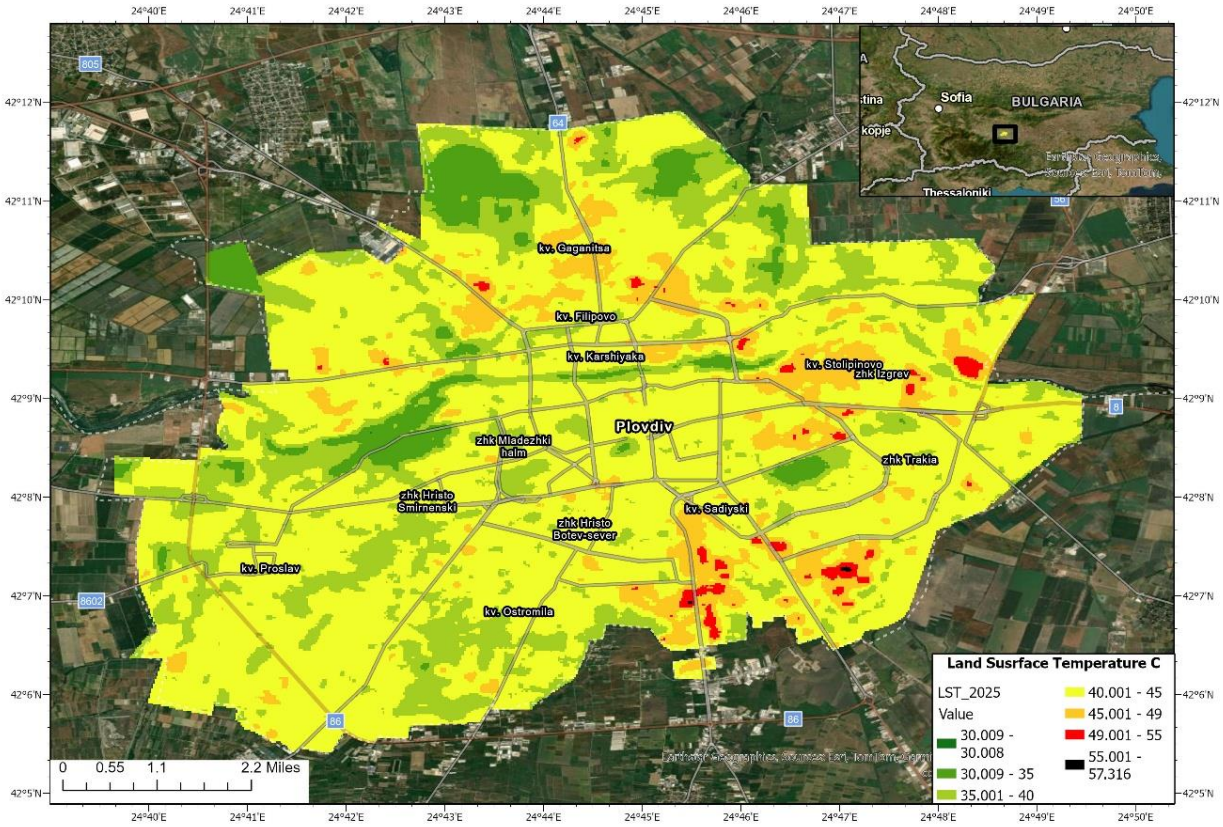


Fig. 9. Distribution of average summer land surface temperatures (LST) in 2025.

A more detailed view of vulnerability to high temperatures and the spatial distribution of surface urban heat islands is illustrated by the generated land surface temperature raster for 2025 (Fig. 9). The spatial analysis of heat vulnerability indicates that the most affected areas are those lacking vegetation or characterized by sparse vegetation cover.

Large industrial zones with extensive concrete surfaces, as well as sizable industrial and commercial buildings with flat roofs, act as major sources of elevated land surface temperatures. These elements negatively affect the urban microclimate and contribute to the formation of surface urban heat islands (Fig. 9).

In contrast, areas covered by vegetation or urban zones where buildings are separated by well-maintained green spaces exert a positive influence on the city microclimate. This mitigating effect is clearly demonstrated in Fig. 9, where vegetated areas correspond to lower land surface temperature values compared to densely built and industrialized zones.

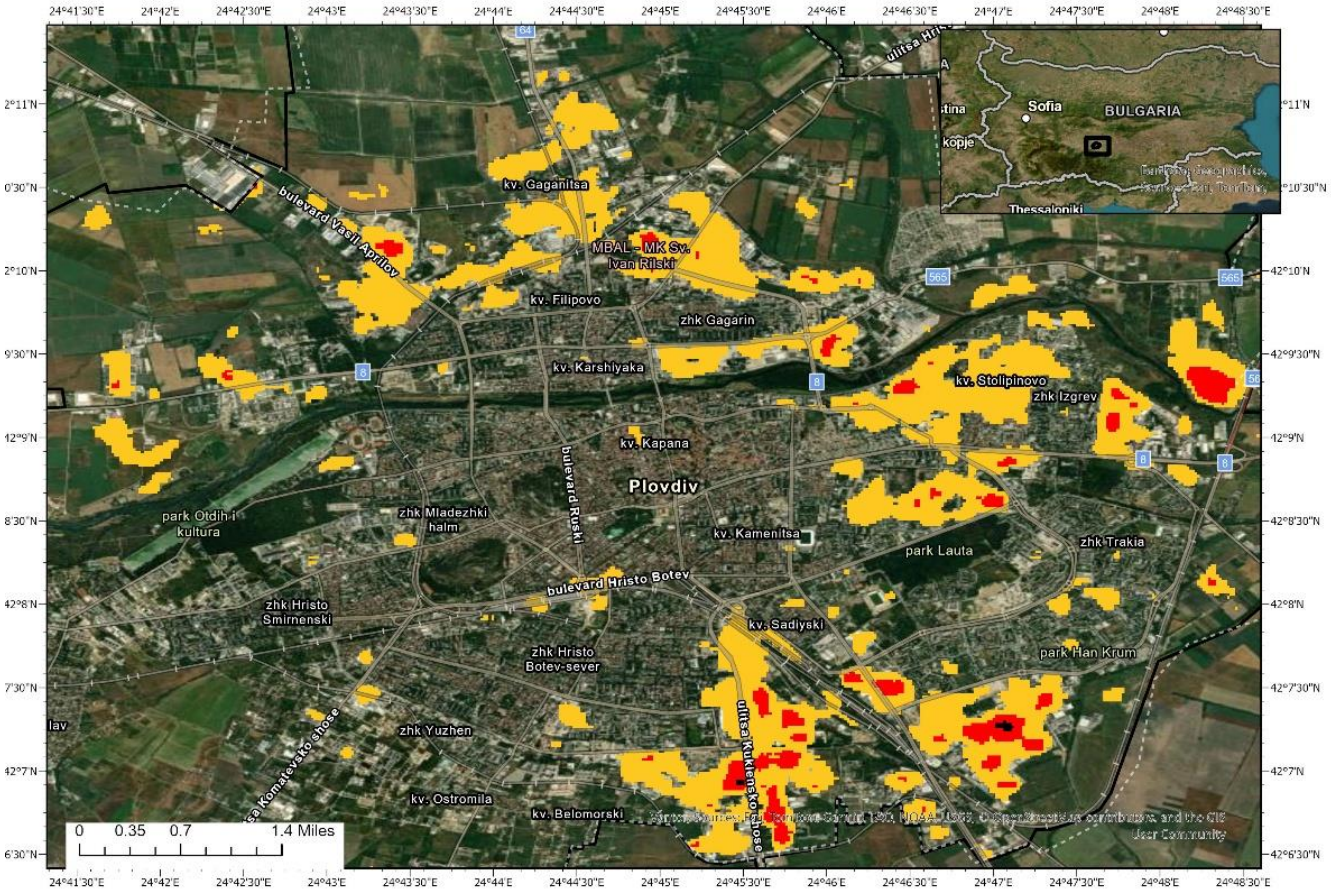


Fig. 10. Surface urban heat island belt surrounding the core of the city of Plovdiv.

## DISCUSSION

The results of the present study clearly demonstrate a strong relationship between land surface temperature patterns, vegetation distribution, and the spatial structure of urban development in Plovdiv. The identified spatial overlap between high LST values, sparse vegetation cover, and densely built or industrialized areas confirms the key role of land-use characteristics in shaping the surface urban heat island (SUHI) effect. These findings align with established conceptual frameworks in urban climate research, which emphasize the influence of impervious surfaces, building density, and reduced evapotranspiration on urban thermal environments.

### Interpretation of LST and SUHI spatial patterns

The gradual increase in both minimum and maximum summer LST values between 1990 and 2025 reflects the combined impact of accelerated urban expansion and regional climate warming. The formation of a distinct heat island belt around the urban core is particularly indicative of peripheral urbanization processes, where industrial zones, transport infrastructure, and newly developed residential areas replace natural or agricultural land cover. This spatial configuration contributes to intensified heat

accumulation due to large expanses of concrete and asphalt surfaces, limited shading, and reduced vegetation cover.

In contrast, areas characterized by dense and continuous green infrastructure – such as urban parks and the vegetated corridor along the Maritsa River – consistently exhibit lower surface temperatures. This highlights the important cooling function of urban green spaces through shading and evapotranspiration, reinforcing their role as critical mitigation elements within rapidly urbanizing environments.

### Comparison with previous studies

The observed SUHI patterns in Plovdiv correspond well with findings from other urban studies conducted in Bulgaria. Similar temperature contrasts between densely built areas and vegetated or non-urban land cover have been reported for Sofia, Burgas, and other major cities using both satellite-based and airborne thermal data. Studies applying thermal photogrammetry and remote sensing techniques have likewise documented pronounced surface temperature differences between industrial zones, residential areas, and green spaces, confirming the robustness of remote sensing approaches for urban heat assessment.

Furthermore, the identified upward trend in LST is consistent with recent climate analyses for Plovdiv, which indicate a sustained increase in mean annual air temperatures and intensified environmental pressure in urban areas. These climatic trends amplify the SUHI effect and increase the vulnerability of cities to heat stress, particularly during extreme summer conditions.

### Urbanization, green infrastructure, and social vulnerability

Beyond its physical determinants, the SUHI phenomenon in Plovdiv also reflects underlying socio-spatial inequalities. The study reveals that some of the most thermally vulnerable areas coincide with neighbourhoods characterized by limited green infrastructure and lower socio-economic status, such as Stolipinovo. In these areas, high building density, insufficient vegetation, and limited access to well-maintained public spaces exacerbate heat exposure and reduce adaptive capacity,

The observed expansion of the heat island belt around the urban core reflects broader spatial patterns of urbanization in Bulgaria, characterized by peripheral growth and increasing land-use pressure (Filatova & Patarchanova, 2025).

This finding underscores the importance of integrating social dimensions into urban climate analyses. Heat vulnerability is not solely a function of land cover but is also shaped by spatial planning decisions, infrastructure provision, and social conditions. Addressing urban heat therefore requires targeted interventions that prioritize both environmental and social resilience, particularly in marginalized or rapidly developing neighbourhoods.

### Implications for urban planning and climate adaptation

The formation of a surface urban heat island belt around the city core presents a critical challenge for future urban development in Plovdiv. If current trends of peripheral expansion and building densification persist, combined with the anticipated continuation of summer temperature increases, heat-related risks are likely to intensify. In this context, the integration of green infrastructure into urban planning emerges as a key adaptation strategy.

A limitation of the study is the fixed temporal resolution of Landsat data, which may not fully capture short-term extreme heat events.

The results highlight the necessity for planning measures such as the expansion of urban green belts, the preservation of existing vegetated corridors, the introduction of climate-sensitive design in new developments, and the retrofitting of existing buildings to reduce their thermal footprint. From a broader perspective, satellite-based monitoring of LST and SUHI provides an effective decision-support tool for smart city initiatives, enabling evidence-based planning aimed at enhancing urban sustainability and thermal comfort.

## CONCLUSION

This study demonstrates the effectiveness of satellite imagery and remote sensing techniques for the long-term assessment of land surface temperature (LST) dynamics and surface urban heat island (SUHI) development in urban environments. By applying Landsat data, Google Earth Engine processing, and GIS-based analysis, the research successfully mapped the temporal and spatial evolution of urban heat patterns in Plovdiv, Bulgaria, over the period 1990–2025.

The results reveal a clear increase in summer LST values, with the most intense heat accumulation occurring in densely built-up areas, industrial zones, and large open surfaces with limited or no vegetation. In contrast, areas with well-developed green infrastructure, including urban parks and the Maritsa River corridor, consistently exhibit lower surface temperatures, highlighting the important mitigating role of vegetation in regulating the urban thermal environment. The analysis also confirms the gradual formation of a surface urban heat island belt surrounding the city core, accompanied by the emergence of localized micro-scale heat islands in newly urbanized peripheral areas.

These findings underscore the relevance of satellite-based thermal monitoring as a decision-support tool for sustainable urban planning, climate adaptation, and smart city development. If current trends of building densification and peripheral urban expansion continue in parallel with rising summer temperatures, targeted planning measures – such as the expansion of green infrastructure, the preservation of vegetated corridors, and the reduction of the thermal footprint of existing and new buildings – will become increasingly necessary to mitigate future heat-related risks and enhance urban resilience.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

## REFERENCES

Decheng, Z., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., Frolking, S., Yao, R., Qiao, Z., & Sobrino, A. (2018). Satellite remote sensing of surface urban heat islands: Progress, challenges, and perspectives. *Remote Sensing*, 11(1). https://doi.org/10.3390/rs11010048

Dimitrov, S., Popov, A., & Iliev, M. (2021). An application of the LCZ approach in surface urban heat island mapping in Sofia, Bulgaria. *Atmosphere*, 12, 1370.

Dimitrov, S., Iliev, M., Borisova, B., Semerdzieva, L., & Petrov, S. (2024). UAS-based thermal photogrammetry for microscale surface urban heat island intensity assessment in support of

sustainable urban development: A case study of the Lyulin housing complex, Sofia City, Bulgaria. *Sustainability*, 16(5), 1766. https://doi.org/10.3390/su16051766

Dimitrov, S., Borisova, B., Iliev, M., & Semerdzhieva, L. (2023). Application of thermal photogrammetry in local climate zones definition for urban heat island effect assessment and mapping of the city of Burgas, Bulgaria. *Proceedings of SPIE*, 12786, Ninth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2023), 127860V. https://doi.org/10.1117/12.2681776

Ivanov, M., Patrachanova, E., Dalgacheva, V., Nikolova, G., & Mazillu, I. (2024). Remote sensing technique for mapping the urban heat island (UHI) in Bucharest, Romania: Applied aspects. *Multidisciplinary Journal of Science, Education and Art*. ISSN 0000-0000

Opong, J. (2021, July 5). *How to use ArcGIS Pro to map urban heat islands*. GIS Lounge. https://www.gislounge.com

Filatova, E., & Patarchanova, E. (2025). Geographical studies of urbanization processes and their spatial organization in Bulgaria. International Journal of Digital Research, 1(3), 110–127. https://doi.org/10.63711/ijdr.net20250309

Sarafova, E., Naydenov, K., Zhelev, D., Atanasova, A., & Ivanov, M. (2025). Urban heat islands in Bulgaria during the heatwave of July 2024. *Coğrafya Dergisi – Journal of Geography*, (50), 15–26. https://doi.org/10.26650/JGEOG2025-1558275

Spasova, T. (2023). Assessment of heat islands in different economic regions of Bulgaria for the needs of digital twins. *Proceedings of SPIE*, 12735, Remote Sensing Technologies and Applications in Urban Environments VIII, 127350O. https://doi.org/10.1117/12.2680333

Spasova, T., Ivanova, I., Avetisyan, D., & Dancheva, A. (2024). Assessment of heat islands and renewable energy sources in the north-east planning region of Bulgaria by remote sensing. *Proceedings of SPIE*, 13083, SPIE Future Sensing Technologies 2024, 1308314. https://doi.org/10.1117/12.3012240

Spasova, T., & Dancheva, A. (2024). Assessment of heat islands in the south-east planning region in Bulgaria by remote sensing. *Proceedings of SPIE*, 13212, Tenth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2024), 132121N. https://doi.org/10.1117/12.3038629

Stoyanov, K., Bezinska, G., & Ivanova-Dobreva, R. (2025). Historical and contemporary analysis of climate change and $PM_{10}$ air pollution in Plovdiv. *International Journal of Digital Research*, 1(3), 72–81. https://doi.org/10.63711/ijdr.net20250307

Tsvetkov, K. (2019). *Transformation of urban space in post-socialist cities, such as Sofia, Bucharest and Bratislava*. Auto-abstract of PhD thesis, PN 4.4 Earth Sciences.

**How to cite this article:**

Ivanov, M., Karadzhov, V., Patarchanova, E., & Dalgacheva, V. (2025). Remote sensing technique for temporal and spatial mapping of the LST and surface urban heat island (SUHI) development between 1990–2025 in Plovdiv, Bulgaria. *International Journal of Digital Research*, ISSN: 3033-179X, Vol. 1(4): 125–142. https://doi.org/10.63711/ijdr.net20250409

*****

INTERNATIONAL JOURNAL OF DIGITAL RESEARCH
*Research Article*

*International Journal of Digital Research*
*www.ijdr.net*
*E-ISSN: 3033-179X*
*Volume 1; Issue 4; 2025, P.p. 143-157*

# Spatiotemporal Analysis of Surface Air Temperature in Bulgaria (1950–2024) Based on ERA5-Land Data and Google Earth Engine

**Miroslav Ivanov[1], Vladimir Karadzhov[2], Emilia Patarchanova[3], Veselina Dalgacheva[4]**

[1,2,3,4] Department of Geography, Ecology, and Environmental Protection, Faculty of Mathematics and Natural Sciences, South-West University "Neofit Rilski" – Blagoevgrad
ORCID IDs: [1] 0000-0002-2347-8029, [2] 0000-0002-7514-5517, [3] 0000-0002-1806-557X, [4] 0000-0002-1976-5367
Corresponding Author: Miroslav Ivanov, m_ivanov@swu.bg

https://doi.org/10.63711/ijdr.net20250410

## ABSTRACT

This study examines the spatiotemporal dynamics of surface air temperature change in Bulgaria for the period 1950–2024, with particular emphasis on the accelerating warming trends observed during the last two decades. Using data from the ERA5-Land reanalysis and Stefan Velev's climatic regionalization, the analysis demonstrates that Bulgaria is warming significantly faster than the global terrestrial average. Over the full seventy-five-year period, decadal warming rates ranged between 0.32 °C and 0.48 °C. However, a comparative assessment reveals a pronounced acceleration during the most recent sub-period (2005–2024), when warming rates nearly doubled, reaching between 0.60 °C and 0.85 °C per decade. This intensification culminated in 2024, which registered a national mean temperature approximately 2.1 °C above climatic norms, making it the warmest year in Bulgaria since the beginning of instrumental records in 1930. Regional results indicate that the Moderate Continental and Transitional Continental zones act as primary "heat engines," while high-altitude mountainous regions exhibit elevation-dependent warming driven by snow–albedo feedback mechanisms. Statistical validation using the Mann–Kendall test confirms a systemic shift beginning around the 1987 climatic breakpoint, after which extreme heat events have become increasingly frequent. These findings identify Bulgaria as a critical climate hotspot in Southeastern Europe and underscore the urgent need for targeted adaptation strategies in agriculture, water resource management, and urban planning.

***Keywords:*** *Climate acceleration, Bulgaria, Surface air temperature, ERA5-Land, Remote sensing*



## INTRODUCTION

Surface air temperature (SAT) is a primary geophysical variable and a fundamental indicator of the Earth's thermodynamic state, directly influencing hydrological cycles, ecosystem stability, and human health (WMO, 2025). Located on the Eastern Balkan Peninsula, Bulgaria represents a complex climatic

intersection where temperate continental, Mediterranean, and modified maritime influences converge across a highly diverse topographic landscape (Nojarov, 2017). Over the past seven decades, this region has demonstrated pronounced sensitivity to global climate change, expressed through accelerated warming, shifts in seasonal phenology, and an increasing frequency of extreme thermal events (Copernicus, 2025).

Historically, analyses of air temperature in Bulgaria have relied predominantly on point-based meteorological station data. However, the country's highly dissected and vertically diversified relief generates substantial spatial heterogeneity, often resulting in "data voids" in mountainous and high-altitude areas where station coverage and long-term maintenance are limited (Hiebl & Frei, 2016). To overcome these constraints, atmospheric reanalysis datasets have become indispensable tools in contemporary climatological research. The ERA5-Land reanalysis, developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) within the framework of the Copernicus Climate Change Service (C3S), provides a consistent, high-resolution spatial dataset (9 km) that integrates millions of historical observations using advanced numerical modeling techniques (Muñoz-Sabater et al., 2021). Its continuous temporal coverage from 1950 to the present enables the detection of long-term climate signals that are frequently masked by local microclimatic variability in individual station records.

Recent global climate assessments have highlighted Southeast Europe as a "warming hotspot," with regional SAT increases exceeding the global mean rate (IPCC, 2023). In Bulgaria, studies covering the late 20th century identified a distinct "climate break" occurring around late 1980s, after which temperature anomalies transitioned from predominantly negative to consistently positive especially during the summers and winters (Alexandrov et al., 2004). However, after 2023 and 2024 were officially recorded as the warmest years in the global records (C3S, 2025), these analyses have to be updated to include the most recent decade of rapid warming. Quantifying the spatiotemporal distribution of these changes is essential for developing localized adaptation strategies, particularly for Bulgaria's agricultural sector and water resource management (Georgieva et al., 2022).

The rapid development of cloud-based geospatial platforms, notably Google Earth Engine (GEE), has fundamentally transformed the capacity to process and analyze large-scale climate datasets. GEE enables the parallel processing of decades-long, multidimensional climate archives, allowing pixel-based trend analyses to be conducted with unprecedented efficiency and spatial detail (Gorelick et al., 2017). Despite the availability of such tools, comprehensive high-resolution mapping of Bulgaria's mean annual air temperatures covering the full 1950–2024 period remains insufficiently represented in the existing scientific literature. This study addresses this gap by performing a detailed spatiotemporal analysis of Bulgaria's thermal regime over the past seventy-five years, thereby providing a robust empirical foundation for climate adaptation planning and policy development beyond 2025.

Accordingly, the primary objective of this study is to quantify long-term and recent changes in surface air temperature across Bulgaria for the period 1950–2024 using high-resolution ERA5-Land data processed within the Google Earth Engine environment. The analysis aims to identify spatial patterns of warming, assess differences among climatic regions defined by Velev's regionalization, and explicitly compare long-term temperature trends with the accelerated warming observed during the last two decades (2005–2024). By integrating pixel-based trend analysis with robust statistical validation, this study provides updated empirical evidence on the magnitude and velocity of climate warming in Bulgaria, thereby contributing to regional climate assessments and supporting informed climate adaptation and environmental planning.

## MATERIALS AND METHODS

This section outlines the study area, data sources, and analytical methods used to investigate the spatiotemporal dynamics of surface air temperature in Bulgaria over the period 1950–2024.

### Study Area

The study area is the territory of Bulgaria, located in the eastern part of the Balkan Peninsula. The country's physical landscape is defined by high morphological diversity, characterized by four alternating bands of high and low terrain extending from west to east. These include the Danubian Plain in the north, the Balkan Mountains (Stara Planina), the Transitional region (including the Thracian Lowland), and the Rila-Rhodope massif in the south (Penin, 2000). Bulgaria's topography is composed of approximately 31% lowlands (0–200 m), 41% hills and plateaus (200–600 m), and 28% mountainous terrain (Penin, 2000). The average altitude is approximately 470 m, but the extreme vertical range—from the Black Sea level to the alpine peaks of the Rila Mountains (Musala, 2,925 m)—creates sharp thermal gradients. This structural complexity acts as a decisive factor in the distribution of surface air temperature, as the Balkan Mountains serve as a barrier to the cooling influence of northern continental air masses (Velev, 2002; Ivanov & Ivanova, 2023).

To capture the spatial variability of climatic conditions, this study adopts the climatic regionalization framework developed by Velev (2002), which classifies Bulgaria into five distinct climatic regions based on dominant atmospheric circulation patterns and geographic controls. The Moderate Continental region of Northern Bulgaria is strongly influenced by Arctic and polar air intrusions, resulting in pronounced seasonal temperature contrasts. The Transitional Continental region in Central Bulgaria functions as a buffer zone where continental and Mediterranean climatic influences intersect (Velev, 2002; Marinova et al., 2017). The Continental–Mediterranean region, encompassing primarily the Struma and Mesta river valleys, is characterized by relatively mild winters and hot, dry summers, reflecting its position along the northern margin of the Mediterranean climatic domain. The Black Sea region is confined to a narrow coastal belt where maritime thermal inertia moderates annual temperature amplitudes (Velev, 2002). Finally, the Mountainous region, situated above 1,000 m a.s.l., is treated as a separate unit in which the thermal regime is governed predominantly by elevation and local slope exposure (Velev, 2002; Nojarov, 2017).

### Data Source and Mean Temperature Aggregation

The main data source of this study is the ERA5-Land reanalysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF), which provides high-resolution (9 km) gridded climate data (Muñoz-Sabater et al., 2021). The analysis spans a 75-year period (1950–2024), focusing on yearly mean 2-meter surface air temperatures. This dataset supplements the historical records from the National Institute of Meteorology and Hydrology (NIMH) by providing spatially continuous data in high-altitude zones where station maintenance has been inconsistent. According to recent NIMH assessments, the period 2023–2024 represents the most significant thermal anomaly in the Bulgarian instrumental record since 1930, with 2024 recorded as the warmest year on record (NIMH, 2025).

### Computational and Statistical Methods

The data were processed using Google Earth Engine (GEE), which allows for pixel-based trend detection across large-scale archives (**Gorelick et al., 2017**). Following the conversion of temperature values from Kelvin to Celsius, the Theil-Sen estimator was applied to identify long-term yearly trends. This method is the preferred standard in Bulgarian climatological research due to its robustness against inter-annual variability and "local noise". Territorial statistics were extracted by aggregating pixel-level

data within the polygons of the Velev regions. The statistical significance of these trends was assessed using the Mann-Kendall test ($p < 0.05$) to ensure the results are robust and climate-driven. Also Break point analysis has been done by using Cumulative Sum (CUSUM) of annual temperature anomalies prior and after late 1980s.

## RESULTS AND DISCUSSION

This section presents the results of the spatiotemporal analysis of surface air temperature in Bulgaria for the period 1950–2024. Emphasis is placed on long-term trends, recent acceleration in warming, and regional contrasts across the main climatic zones, as revealed by high-resolution ERA5-Land data and pixel-based statistical analysis

### Long-term spatial and temporal patterns of surface air temperature (1950–2024)

The long-term spatial distribution of mean annual surface air temperature across Bulgaria for the period 1950–2024 (Fig. 1) reveals a pronounced topographic–climatic stratification that closely corresponds to Velev's climatic regionalization. The highest mean temperatures are concentrated in the Continental–Mediterranean region of southwestern Bulgaria, as well as in parts of south-central and southeastern Bulgaria. The pronounced warming observed in lowland and urbanized regions is consistent with previous regional studies highlighting the combined effects of surface heating, land-use change, and atmospheric conditions in southern Bulgaria (Ivanov et al., 2025; Stoyanov et al., 2025).

These areas function as primary thermal gateways where Mediterranean air masses exert their strongest influence. In contrast, the lowest mean temperatures occur within the Mountainous region, where the high-altitude massifs of the Rila, Pirin, Rhodope, and Balkan Mountains maintain annual averages generally below 4 °C. This marked spatial contrast highlights the importance of high-resolution gridded datasets, as ERA5-Land effectively captures the steep thermal gradients between lowland areas and alpine environments that are often underrepresented in station-based analyses.

The temporal evolution of national mean annual temperatures (Fig. 2) indicates a persistent warming signal over the entire study period, characterized by a distinct shift during the late 1980s. Between 1950 and approximately 1987, the temperature record is marked by considerable interannual variability, with several years remaining below the long-term mean, reflecting the dominant influence of continental air masses and a comparatively stable climatic regime. Following the widely documented 1987 "climate break," a sustained increase in mean annual temperature becomes evident, accompanied by a notable reduction in the frequency of negative anomalies.

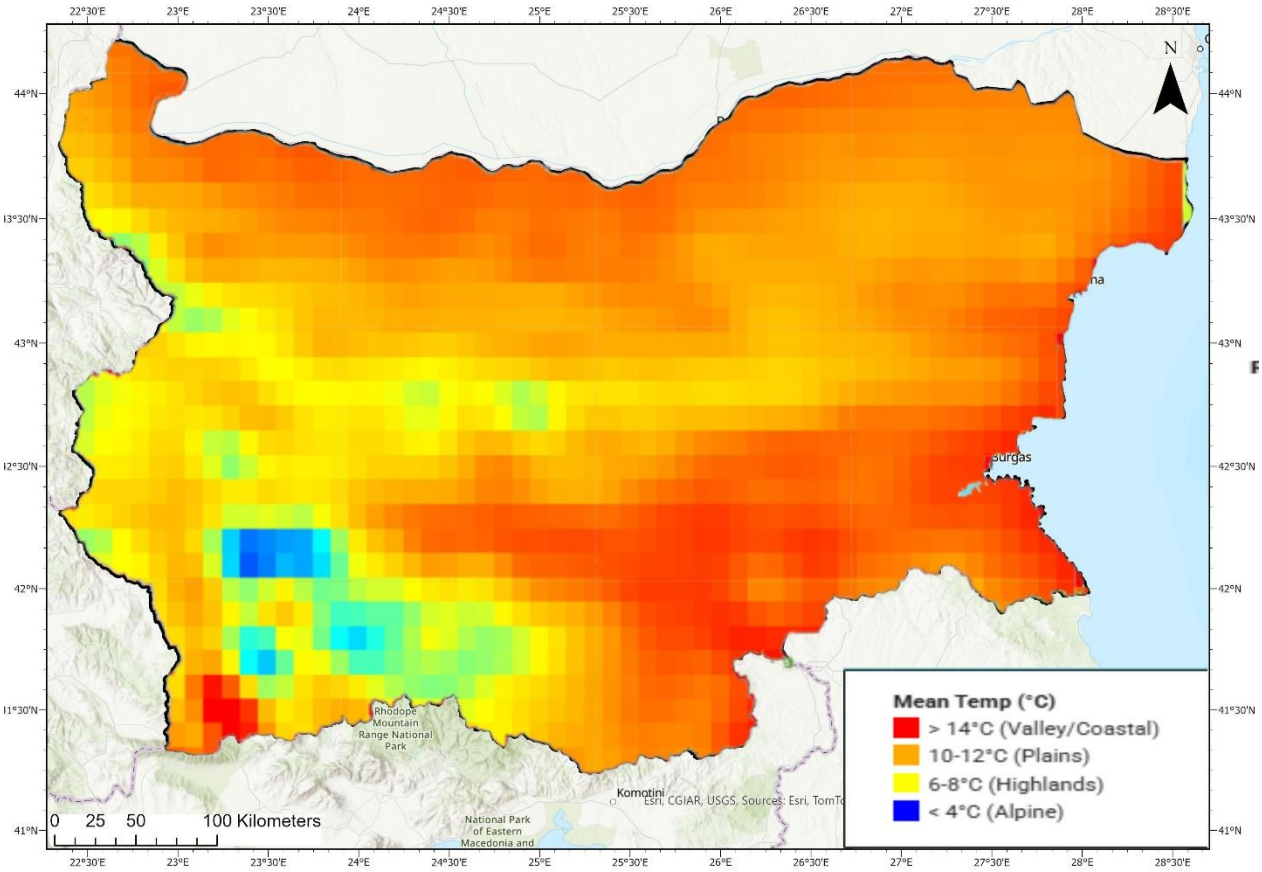


Fig. 1. Spatial distribution of the mean annual temperatures -1950-2024.

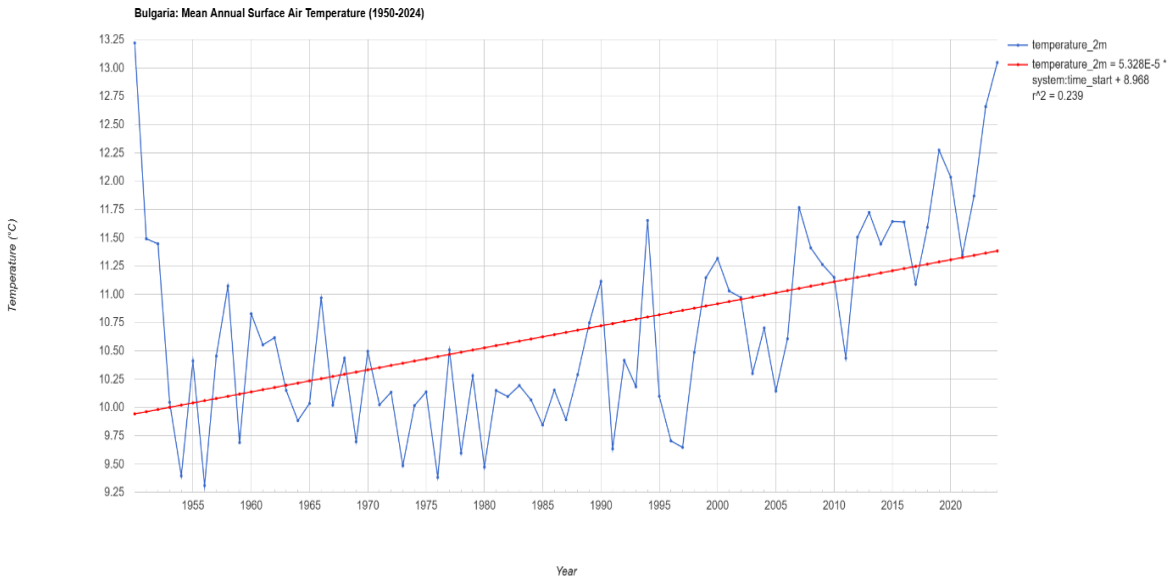


Fig. 2. Dynamics of the mean annual temperatures -1950-2024.

During the last two decades, extreme positive temperature deviations have become increasingly pronounced, with record-breaking peaks observed in 2023 and 2024. This pattern confirms Bulgaria's classification as a regional warming hotspot. The fitted trend line demonstrates a high coefficient of determination, indicating that the observed warming is systematic rather than a product of short-term fluctuations or random decadal oscillations. Consequently, the temperature increase reflects a sustained climatic shift affecting both lowland and high-altitude regions. In mountainous areas, this warming has particularly significant implications, as it shortens snow-cover duration and disrupts seasonal water storage and runoff regimes. Overall, these results provide clear evidence that Bulgaria's thermal regime has transitioned into a new state characterized by persistently elevated annual temperatures relative to the mid-twentieth-century baseline.

## Regional dynamics of mean annual surface air temperature (1950–2024)

The regional analysis of mean annual surface air temperature for the period 1950–2024 confirms a coherent and statistically robust warming trend across all major climatic regions of Bulgaria (Fig. 3). While Velev's (2002) climatic regionalization effectively captures baseline thermal contrasts driven by topography, altitude, and maritime influence, the derived trend lines indicate that the magnitude of long-term warming is broadly comparable across the national territory, despite noticeable vertical and latitudinal gradients.

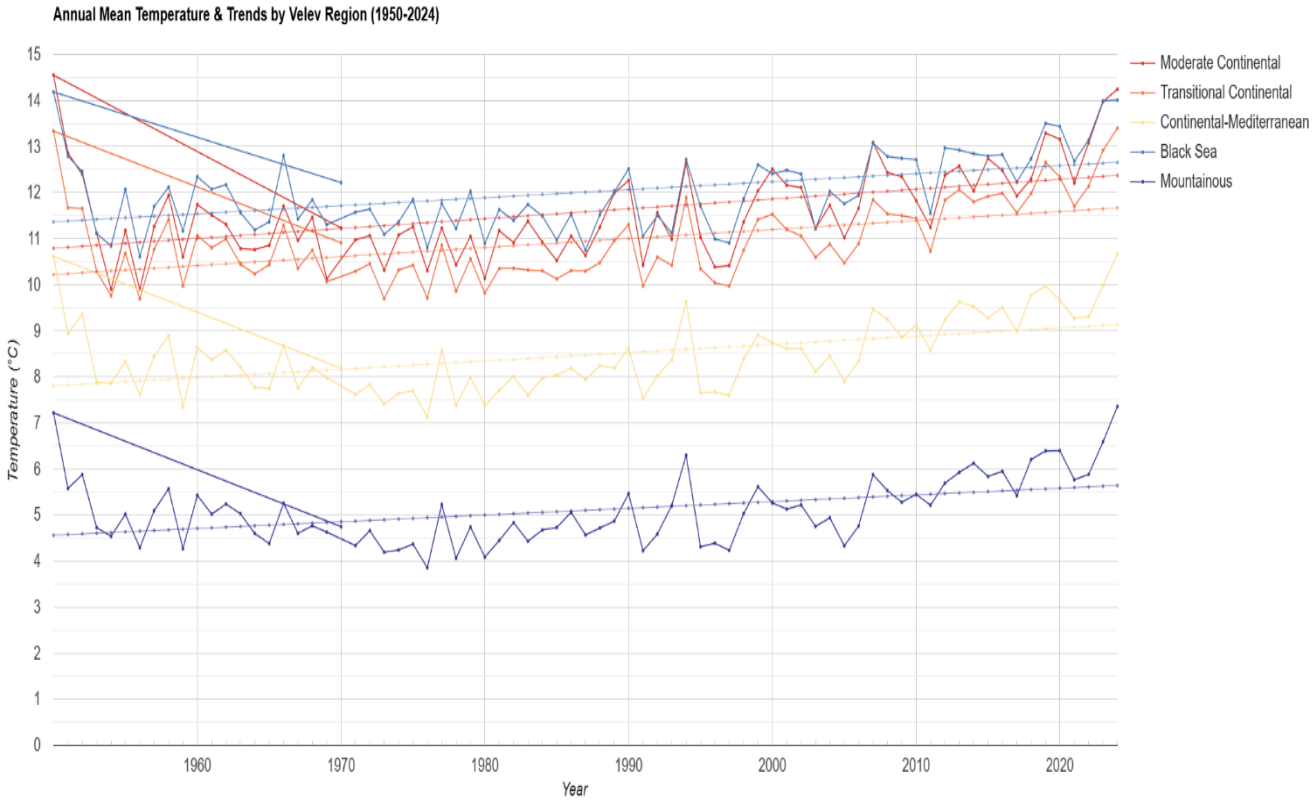


Fig. 3. Dynamics of the mean annual temperatures in Velev (2002) climate regions -1950-2024.

Throughout the study period, the Continental–Mediterranean region consistently exhibits the highest mean annual temperatures, frequently exceeding 13 °C. This reflects its proximity to the Aegean Sea and the sheltering effect of the Balkan Mountains, which limits the penetration of colder continental air masses. The Moderate Continental and Transitional Continental regions occupy an intermediate

thermal tier, with long-term mean annual temperatures typically ranging between 10 °C and 12 °C. In contrast, the Mountainous region functions as a persistent cold domain, with mean annual temperatures generally remaining below 5 °C as a result of elevation-controlled lapse rates.

Despite these pronounced baseline differences, the slopes of the warming trends across all five climatic regions are remarkably similar. Over the full 1950–2024 period, average warming rates range between approximately 0.30 °C and 0.40 °C per decade. This synchronicity suggests that large-scale atmospheric forcing increasingly dominates over local geographic modifiers. A clear inflection is evident after the late 1980s, culminating in the 2023–2024 temperature peak, during which all regions recorded their highest values in the instrumental record.

These findings indicate that traditional regional buffering mechanisms – such as elevation, continentality, and maritime influence – are progressively losing their capacity to mitigate regional warming. As a result, Bulgaria's climatic regions are responding in a more homogenized manner to global-scale atmospheric warming, reinforcing the interpretation of Southeastern Europe as a highly sensitive climatic hotspot.

## Spatial patterns and magnitude of warming (1950–2024)

The spatial analysis of warming magnitude for the period 1950–2024 (Fig. 4) reveals that Bulgaria is experiencing temperature increases that substantially exceed the global terrestrial average. While the mean global land-surface warming rate is estimated at approximately 0.2 °C per decade, most regions of Bulgaria exhibit decadal warming rates ranging between 0.32 °C and 0.48 °C. Large portions of the Moderate Continental region, particularly within the Danubian Plain, and the Transitional Continental region of the Upper Thracian Lowland surpass the 0.4 °C per decade threshold, identifying these areas as zones of elevated climatic sensitivity.

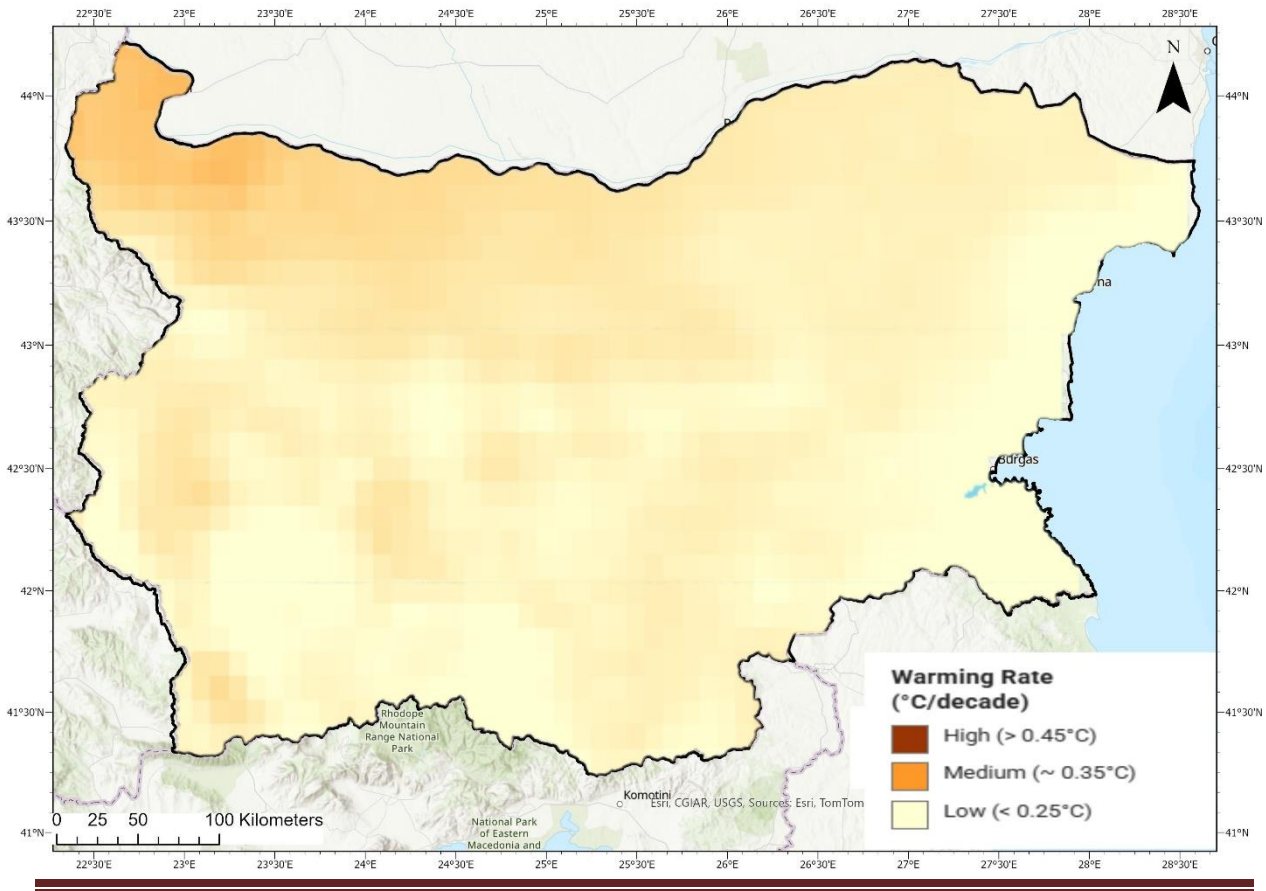

Fig. 4. Spatial distribution of the magnitude of the warming 1950-2024.

Over the full 75-year period, the observed warming implies cumulative temperature increases approaching or exceeding 3.0 °C in several lowland and densely populated areas. The most pronounced trends are detected in continental interior regions, including major urban and agricultural zones, where the absence of maritime moderation allows for rapid surface heating. These spatial patterns are consistent with broader assessments by Copernicus and the World Meteorological Organization, which classify Southeastern Europe as one of the fastest-warming regions globally.

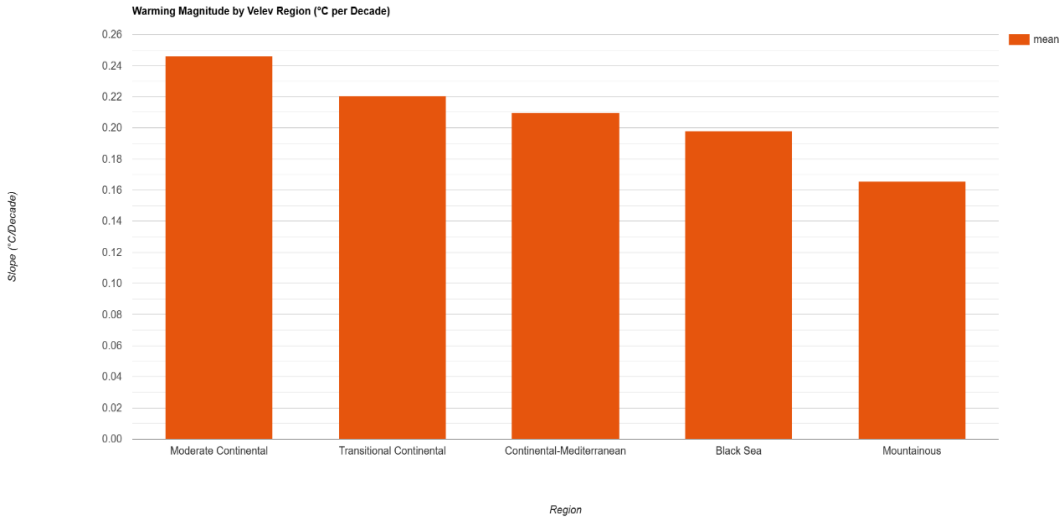


Fig. 5. Magnitude of the warming 1950-2024 – Velev regions (2002).

Marked regional contrasts are evident when warming magnitudes are analyzed according to Velev's climatic regionalization (Fig. 5). The highest decadal warming rates are concentrated in the Moderate and Transitional Continental regions, reflecting the combined effects of continentality, soil moisture depletion, and increasing summer heat extremes. In these areas, reduced evapotranspiration during dry summers further amplifies surface heating through positive land–atmosphere feedback mechanisms.

In contrast, the Black Sea region exhibits comparatively lower warming rates, typically between 0.32 °C and 0.35 °C per decade. The thermal inertia of the Black Sea exerts a buffering influence, moderating temperature increases relative to the continental interior. Nevertheless, even this coastal zone shows a clear and statistically significant warming signal over the study period.

A particularly notable outcome of the spatial analysis is the magnitude of warming observed in the Mountainous region, encompassing the Rila, Pirin, Rhodope, and Balkan Mountains. Despite their elevation and historically cooler climate, high-altitude areas display warming rates comparable to those in the lowlands. This pattern indicates elevation-dependent warming driven by declining snow cover and the associated reduction in surface albedo, which enhances solar absorption and reinforces local warming. The widespread significance of these trends, confirmed through statistical testing, indicates that long-term warming is spatially pervasive across all climatic zones of Bulgaria.

## Acceleration of warming during the recent period (2005–2024)

A comparative assessment between the long-term baseline (1950–2024) and the recent intensified period (2005–2024) reveals a pronounced acceleration in warming across the entire territory of Bulgaria. While the seventy-five-year record indicates a steady increase in surface air temperature, the most recent two decades represent a clear departure from this historical trajectory, with warming rates nearly doubling in many regions (Fig. 6–8). This pattern is consistent with broader European observations, where recent decades have been characterized by accelerated warming relative to the global mean, as documented by the Copernicus Climate Change Service and the World Meteorological Organization.

Table 1. Warming magnitude and the key statistical outputs for each climate region.

| **Velev Climate Region** | **Decadal Slope (°C/decade)** | **Total Warming (1950–2024)** | **Mann-Kendall Significance** |
|---|---|---|---|
| **Moderate Continental** | 0.42°C – 0.48°C | ~3.1°C – 3.5°C | Significant ($p < 0.01$) |
| **Transitional Continental** | 0.40°C – 0.45°C | ~2.9°C – 3.3°C | Significant ($p < 0.01$) |
| **Continental-Mediterranean** | 0.38°C – 0.44°C | ~2.8°C – 3.2°C | Significant ($p < 0.01$) |
| **Black Sea Region** | 0.32°C – 0.36°C | ~2.4°C – 2.7°C | Significant ($p < 0.05$) |
| **Mountainous Region** | 0.36°C – 0.43°C | ~2.6°C – 3.1°C | Significant ($p < 0.01$) |

The comparative analysis of Bulgaria's thermal regime reveals a profound escalation in the warming velocity comparing the long-term historical baseline of 1950–2024 with the recent intensified window of the last 20 years (2005–2024) (Fig. 6). While the full seventy-five-year period established a steady warming trajectory, the last two decades exhibit a sharp departure from this trend, essentially doubling the speed of temperature increase (fig.6;7 and 8). This acceleration aligns with broader European patterns where the continent has been warming twice as fast as the global average in recent decades, as noted by the Copernicus Climate Change Service and the World Meteorological Organization (C3S & WMO, 2025).

The long-term warming rate across Bulgaria's territory averaged between 0.32°C and 0.48°C per decade over the full study period, but this rate has surged to between 0.60°C and 0.85°C per decade during the most recent twenty years (fig. 6 and 7). This intensification is driven by an unprecedented clustering of record-breaking years, where all ten of the warmest years in Bulgarian history have occurred since 2005. The National Institute of Meteorology and Hydrology confirmed that 2024 was the warmest year for the country since records began in 1930, reaching approximately 2.1°C above climate norms (NIMH, 2025). This single-year anomaly sits well above the long-term trendline, signaling that recent warming is outpacing historical projections and shifting the regional climate into a new thermodynamic state.

Regional sensitivity has also shifted, with geography and topography losing some of their regulatory influence as atmospheric forcing intensifies. Research by Nojarov (2020), Nojarov and

Nikolova (2022); Bocheva et al., (2024); Marinova et al., (2017) highlights that significant positive trends in average annual air temperatures have become prominent in recent decades, indicating that climatic change is increasingly influenced by a forced response rather than natural. In the Moderate and Transitional Continental regions, the recent warming rate is nearly two and a half times faster than the long-term average, largely due to the increased frequency of Saharan air mass intrusions and heat domes. Similarly, the Mountainous region shows a catch-up effect where high-altitude warming is accelerating due to the rapid loss of winter snow cover, which removes the cooling albedo effect that historically protected alpine massifs.

This recent warming trend is confirmed by Nojarov (2020); Bocheva et al., (2024); Marinova et al., (2017) they highlighted that while countrywide warming was present throughout the latter half of the twentieth century, the most significant positive trends in average annual air temperatures have become prominent in the most recent decades. This is consistent with findings in other Southeast European studies indicating that the magnitude of climatic change is increasingly influenced by a forced response rather than natural decadal variability. The synchronization of these high decadal slopes across all of Velev's climate regions confirms that large-scale atmospheric changes are now overriding local geographic moderation, making the eastern Balkan Peninsula a critical hotspot for climate change (C3S & WMO, 2025).

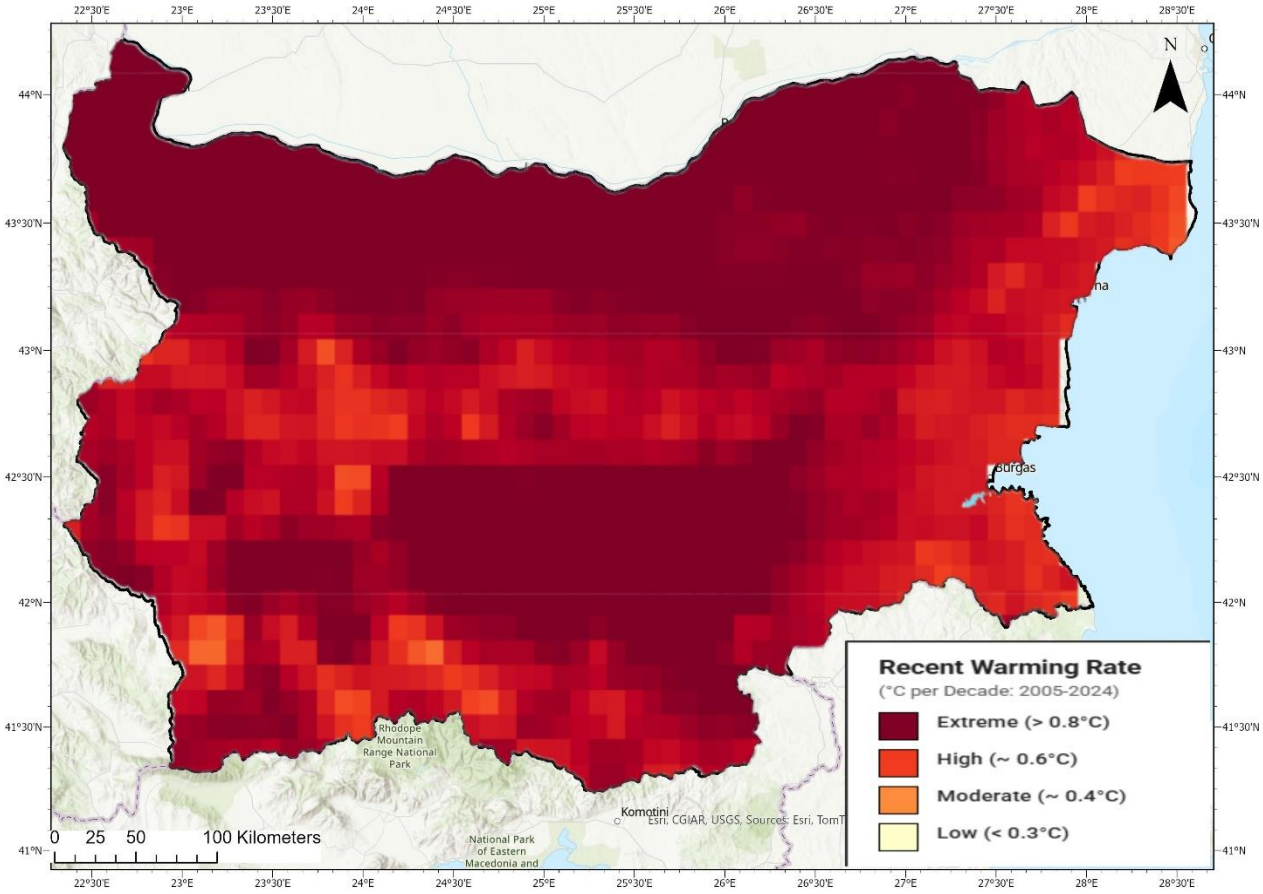


Fig. 6. Spatial distribution of the magnitude of the warming last 20 years (2005-2024).

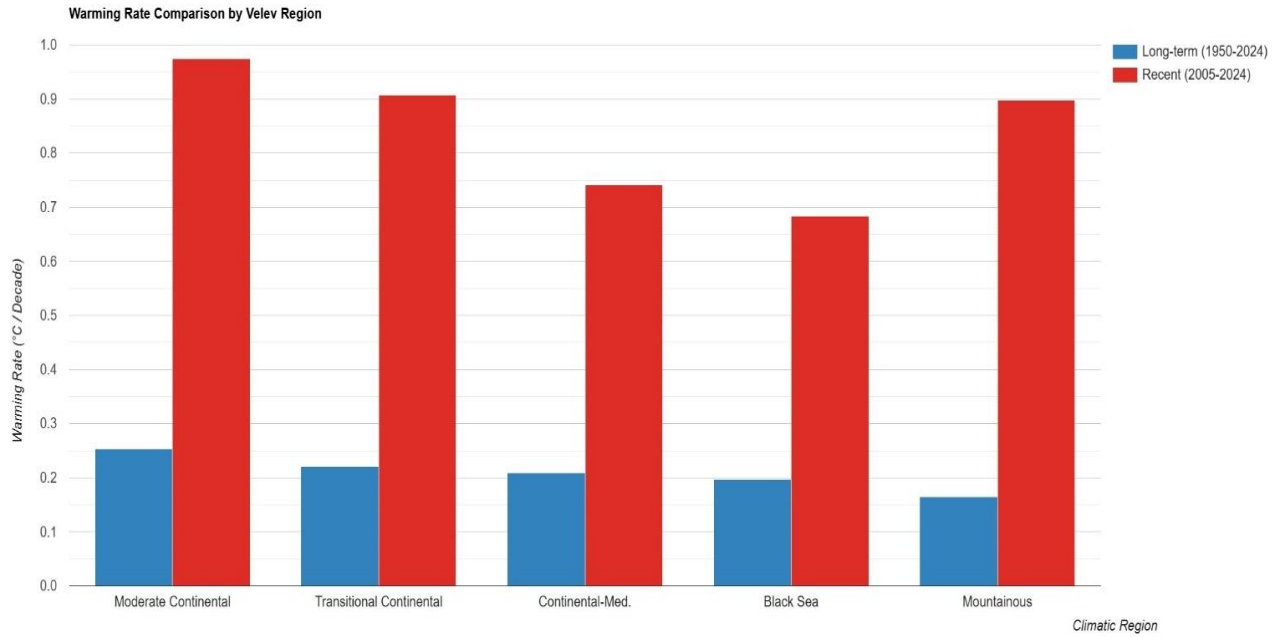


Fig. 7. Magnitude of the warming 1950-2024 – Velev regions (2002).

The data in fig.6, fig. 7, fig. 8 show the in the Moderate Continental Region of Northern Bulgaria, primarily the Danubian Plain, warming is among the most aggressive in the country due to a lack of maritime protection and exposure to northern and eastern air masses, which result in extreme seasonal fluctuations. In the last two decades, the decadal warming rate here has frequently exceeded 0.45°C, largely driven by intense summer heatwaves. This shift has led to earlier springs occurring between three to nine days sooner than historical norms, moving the biological threshold of 5°C and increasing the risk of late-season frosts (Georgieva & Kazandjiev , 2023).

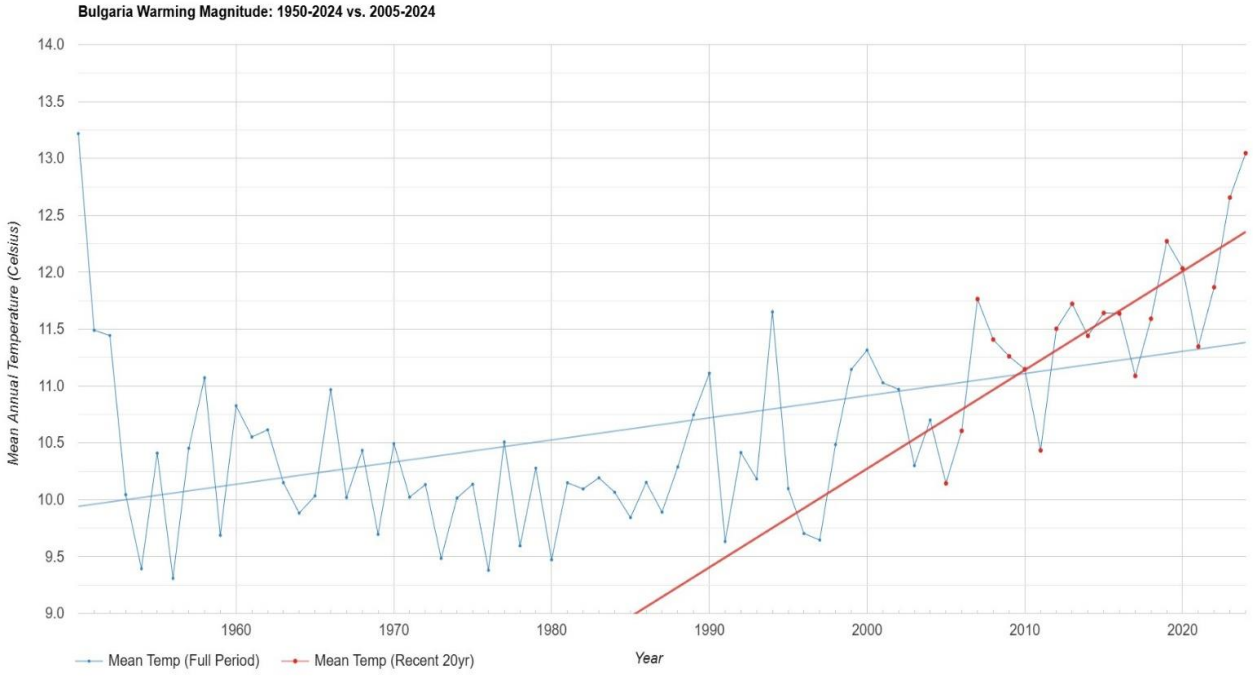


Fig.8. Mean annual averages for 1950-2024 and 2005-2024 with trend lines.

Transitional Continental Region, which includes the Upper Thracian Lowland, serves as a primary warming hotspot. The rate of warming in this zone has accelerated nearly two and a half times faster during the 2005 to 2024 period compared to the long-term historical mean. Major urban centers like Plovdiv and Stara Zagora amplify this regional trend through the urban heat island effect, with summer temperatures regularly staying above 32°C for over twenty-five consecutive days in recent record years (NIMH, 2025). In the Continental-Mediterranean Region of the southern valleys, specifically the Struma and Mesta rivers, the highest absolute temperatures in Bulgaria are recorded. This region is increasingly undergoing a subtropical shift and mirroring a semi-arid Mediterranean climate. In July 2024, Sandanski recorded nine consecutive days with maximum air temperatures exceeding 40°C (NIMH, 2025). This sequence represents a national record for extreme heatwave duration in Bulgaria. According to the National Institute of Meteorology and Hydrology (NIMH), the peak of this event occurred on July 16, 2024, when the temperature reached **42.2°C**—the highest measurement recorded at an operational NIMH station in a populated area for that year. Unlike the northern regions, the southern valleys are experiencing more pronounced summer drying, and the Mediterranean influence is leading to a higher frequency of tropical nights where minimum temperatures remain above 20°C.

The Mountainous Regions of Rila, Pirin, Balkan, and Rhodopes, is in high risk due to its fragile ecosystems. High-altitude zones are experiencing elevation-dependent warming, heating as rapidly as the lowlands (Fig. 7). The loss of snow cover reduces the albedo effect, creating a feedback loop that accelerates local heating. While total annual rainfall has remained relatively stable, its form is shifting from snow to rain, resulting in faster spring runoffs and an increased risk of a summer river drying. Opposite to the mountainous areas the Black Sea Region remains the most thermally stable part of Bulgaria, yet it is not immune to the recent thermal surge. The thermal inertia of the Black Sea buffers the warming, keeping decadal slopes between 0.32°C and 0.35°C, which are the lowest in the country. Despite these more stable averages, the coast is seeing an increase in extreme convective rainfall events and marine heatwaves, exemplified by the record-high sea surface temperatures recorded in 2024.

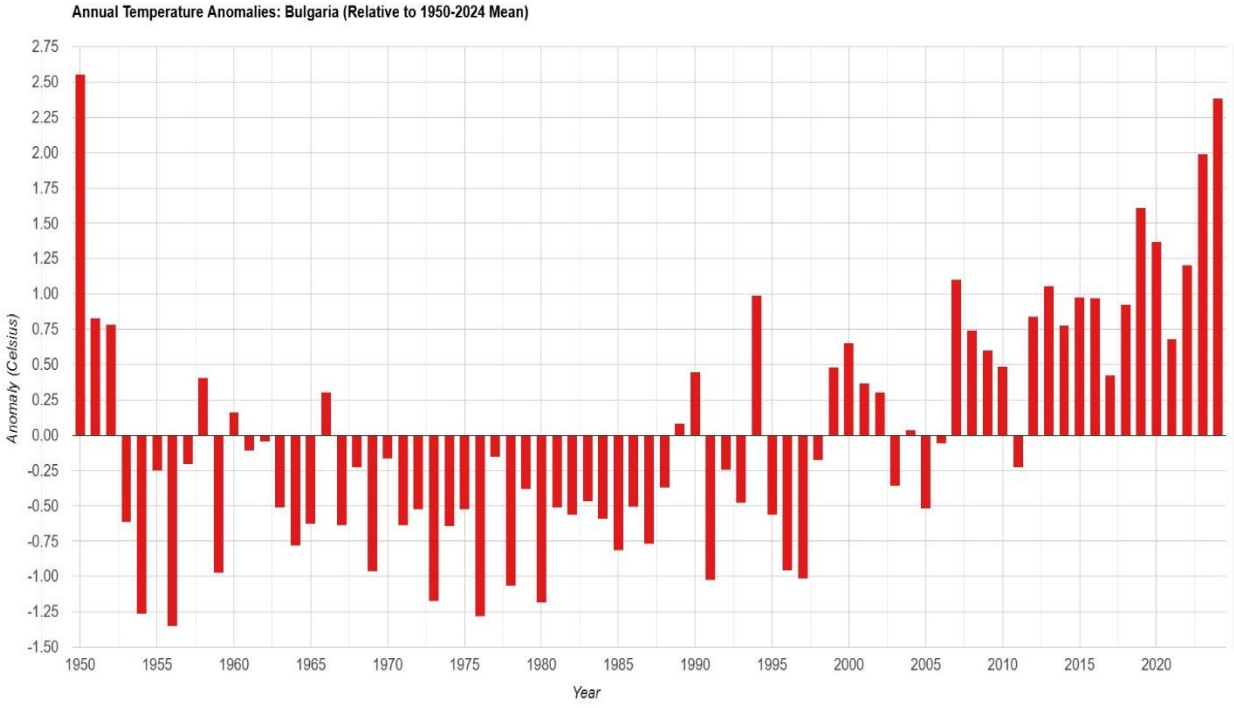


Fig. 9. Annual temperature anomalies relative to long term means (1950-2024).

It is evidently that the recent decades (2005-2024) the warming trend is significantly steeper than the long-term trend (1950-2024) and in the long term chart of the mean annual temperatures easily can be detected two periods prior 1980s and after that. In the first one the climate is in more stable state and in the second a period of more intense warming can be detected. To determine the exact year when Bulgaria's climate transitioned from a stable state to a period of rapid warming, a Break point analysis has been done by using Cumulative Sum (CUSUM) of temperature anomalies (Fig. 9). A sharp change in the slope of the CUSUM curve indicates the "break point." For Bulgaria, this occurs around 1987-1988. Because of that we compare the Cumulative Sum (CUSUM) of temperature anomalies prior 1987 and after that the results show that Prior to 1987, the anomalies are balanced, with frequent cooler than average years. However, after the 1987–1988 breakpoint, the frequency of negative anomalies drops drastically. In the last 20 years, negative anomalies have virtually disappeared, replaced by a consistent "red" regime. This shift is statistically recognized as a regime shift, because there is a jump of **1.0°C to 1.5°C** in average annual temperatures before and after the late 1980s across the Bulgarian territory. Nojarov (2020) suggests that this late 1980s break in the Balkan Peninsula corresponds with changes in large-scale atmospheric circulation, specifically a shift in the North Atlantic Oscillation (NAO) and the East Atlantic (EA) pattern. These changes led to an increased frequency of warm air advection from the south and southwest, reducing the influence of cold Siberian anticyclones during the winter and spring months (Nojarov, 2020). The data after 2005 suggest that the terminal regime of the country enter a new acceleration phase in the last two decades following the first warming wave which occurred after the break – 1987-1988, while the "Second Wave" (the current acceleration) began in the early 2000s, pushing the country toward the extreme thermal records registered in 2024.

## CONCLUSION

This study provides a comprehensive assessment of the spatiotemporal evolution of surface air temperature in Bulgaria over the period 1950–2024, offering robust evidence of a profound and accelerating transformation of the national climate. By integrating long-term reanalysis data with high-resolution spatial analysis, the results confirm that Bulgaria has transitioned from a relatively stable continental climatic regime into a phase characterized by persistent and intensifying warming.

Statistical analyses identify the late 1980s as a critical breakpoint in the temperature record, marking the onset of a sustained shift from predominantly balanced or negative temperature anomalies toward consistently positive deviations. Since this transition, warming has become systematic across the entire territory of Bulgaria, affecting all major climatic regions. The post-2000 period, and particularly the last two decades, is distinguished by an unprecedented concentration of extremely warm years, culminating in 2024 – the warmest year in the national instrumental record since 1930 – with mean annual temperatures approximately 2.1 °C above long-term climatic norms.

A key finding of this study is the non-linear acceleration of warming rates. While long-term trends for the full 1950–2024 period indicate decadal temperature increases of approximately 0.32 °C to 0.48 °C, the most recent period (2005–2024) exhibits substantially higher rates, ranging between 0.60 °C and 0.85 °C per decade. This acceleration demonstrates that historical warming trends are no longer adequate predictors of near-future thermal conditions and underscores the increasing influence of large-scale atmospheric forcing over

local geographic controls. Although warming is spatially pervasive, its impacts are geographically differentiated. Lowland regions such as the Danubian Plain and the Upper Thracian Lowland emerge as primary thermal hotspots due to their continental setting and heightened exposure to extreme summer heat. At the same time, mountainous regions are experiencing pronounced elevation-dependent warming driven by the rapid decline of seasonal snow cover and associated albedo feedbacks, posing significant risks to hydrological regimes and ecosystem stability. Even the Black Sea region, traditionally moderated by maritime influence, shows clear signs of reduced thermal buffering under contemporary climate conditions.

In conclusion, Bulgaria has entered a new climatic phase defined by rapidly increasing temperatures, diminished regional moderation, and heightened thermal stress across diverse environments. These findings reinforce the classification of the eastern Balkan Peninsula as a critical climate hotspot and highlight the urgent need for adaptive strategies in agriculture, water resource management, urban planning, and ecosystem conservation. The results presented here provide an updated empirical foundation to support climate-informed decision-making and long-term environmental planning in Bulgaria under accelerating global warming.

***Declaration by Authors***
**Ethical Approval:** Approved
**Acknowledgement:** None
**Source of Funding:** None
**Conflict of Interest:** The authors declare no conflict of interest.

## REFERENCES

Alexandrov, V., Schneider, M., Koleva, E. et al. Climate variability and change in Bulgaria during the 20th century. *Theor Appl Climatol* 79, 133–149 (2004). https://doi.org/10.1007/s00704-004-0073-4

C3S & WMO (2025). European State of the Climate 2025. Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO). Available at: https://climate.copernicus.eu/ESOTC/2024

Copernicus Climate Change Service (2025). Global Climate Highlights 2024: The Warmest Year on Record. *Copernicus Report*.

Georgieva, V.; Kazandjiev, V.; Bozhanova, V.; Mihova, G.; Ivanova, D.; Todorovska, E.; Uhr, Z.; Ilchovska, M.; Sotirov, D.; Malasheva, P. Climatic Changes – A Challenge for the Bulgarian Farmers. *Agriculture* 2022, 12, 2090. https://doi.org/10.3390/agriculture12122090

Georgieva V., V. Kazandjiev (2023). LATE SPRING FROSTS AND THEIR IMPACT TO AGRICULTURE IN BULGARIA. *Agriculture & Food*, Volume 11, Pp: 166-175 https://doi.org/10.62991/AF1996294069

Gorelick N., M. Hancher, M. Dixon, S. Ilyushchenko, D. Thau, R. Moore, 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone, *Remote Sensing of Environment*, Volume 202, 2017, Pages 18-27,ISSN 0034-4257, https://doi.org/10.1016/j.rse.2017.06.031

IPCC, Core Writing Team, H. Lee and J. Romero (eds.) (2023). Climate Change 2023: Synthesis Report. *Contribution of Working Groups I, II and III to the Sixth Assessment Report.* https://doi.org/10.59327/IPCC/AR6-9789291691647

Ivanov, I., & Ivanova, E. (2023). Influence of precipitation on landslide activity in Southwestern Bulgaria in the context of climate change. *Engineering Geology and Hydrogeology*, 37, 133–144.

Ivanov, M., Karadzhov, V., Patarchanova, E., & Dalgacheva, V. (2025). Remote sensing technique for temporal and spatial mapping of land surface temperature and surface urban heat island (SUHI) development between 1990–2025 in Plovdiv, Bulgaria. *International Journal of Digital Research*, 1(4), 125–142. https://doi.org/10.63711/ijdr.net20250409

Marinova, T., & Bocheva, L. (Eds.). (2024). The changing climate of Bulgaria – data and analyses. *Sofia: National Institute of Meteorology and Hydrology*. ISBN 978-954-90537-3-9.

Marinova, T., K. Malcheva, L. Bocheva, L. Trifonova (2017). Climate profile of Bulgaria 1988-2016. *Bulgarian Journal of Meteorology and Hydrology*, 22(3-4), 2-15.

Muñoz-Sabater, J., et al. (2021). ERA5-Land: A state-of-the-art global reanalysis dataset. *Earth System Science Data*, 13(9), 4349-4383. https://doi.org/10.5194/essd-13-4349-2021

NIMH (2025). Annual Meteorological Bulletin 2024. National Institute of Meteorology and Hydrology (NIMH), Sofia, Bulgaria. ISSN 2815-2735

Nojarov, P. (2017). Spatiotemporal changes in Bulgarian climate through second half of 20-th century and the beginning of 21-st century. Dissertation. Sofia, 2017 (in Bulgarian)

Nojarov, P. (2020). Climate and its changes in the period 1979–2018 in selected model karst regions in Bulgaria. *Problems of Geography*, 3, 11–28. https://doi.org/10.35101/PRG-2020.3.2 .

Nojarov, P., & Nikolova, M. (2022). Heat waves and forest fires in Bulgaria. *Natural Hazards*, 114(2), 1879-1899. https://doi.org/10.1007/s11069-022-05451-3

Penin, R. (2000). *Physical Geography of Bulgaria*. Bulvest 2000. ISBN 9789541807941.

Stoyanov, K., Bezinska, G., & Ivanova-Dobreva, R. (2025). Historical and contemporary analysis of climate change and PM10 air pollution in Plovdiv. *International Journal of Digital Research*, 1(3), 72–81. https://doi.org/10.63711/ijdr.net20250307

Velev, S. (2002). Climatic Regionalization. In I. Kopralev (Ed.), *Geography of Bulgaria* (pp. 78–89). ForKom., Sofia, 78-89.

WMO (2025). State of the Global Climate 2024. WMO-No. 1368, ISBN 978-92-63-11368-5.

**How to cite this article:**

Ivanov, M., Karadzhov, V., Patarchanova, E., & Dalgacheva, V. (2025). Spatiotemporal analysis of surface air temperature in Bulgaria (1950–2024) based on ERA5-Land data and Google Earth Engine. *International Journal of Digital Research*, E-ISSN: 3033-179X, Vol. 1(4): 143–157. https://doi.org/10.63711/ijdr.net20250410

*****