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Article

Artificial Intelligence in Integrated Disaster Risk Management: Sustainability and Human Security in the Republic of Serbia

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Abstract

The Republic of Serbia has formally committed to integrating sustainability principles into its development framework, implementing them in accordance with the sustainable development principles of the European Union and the United Nations. The objective is to establish a balance between economic growth, environmental protection, social inclusion, and institutional resilience. The National Sustainable Development Strategy of the Republic of Serbia (NSDS) is a strategic public policy document adopted by the Government in 2008. This strategy represents the first comprehensive framework for integrating economic development, environmental protection, and social cohesion into a unified, long-term development vision. Although the NSDS formally expired in 2017, its principles continue to influence the formulation of public policy. This paper analyzes the implementation of sustainability principles in Serbia from the perspective of human security, with an emphasis on protecting citizens and communities from economic, environmental, health, food, and institutional risks. The analysis iden-

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tifies significant implementation gaps in which formal sustainability policies fail to sufficiently reduce vulnerability, exposure, and inequality. Weak coordination among environmental, health, social, and infrastructure policies limits the effectiveness of sustainability principles in human security, particularly for vulnerable social groups and at-risk regions. Artificial intelligence (AI) offers substantial potential to overcome these shortcomings by enabling anticipatory, data-driven, and cross-sectoral governance. The application of AI can enhance environmental monitoring, health risk forecasting, resilience of energy and infrastructure systems, social vulnerability mapping, and the assessment of public policy impacts. However, AI achieves its full potential only when used as a decision-support instrument integrated into institutional processes, supported by interoperable data systems, ethical safeguards, and continuous human oversight. Based on these insights, the paper proposes an AI-based governance architecture for improving sustainability in Serbia. This conceptual governance model is designed as an integrative and adaptive framework, grounded in human security principles, that aims to reduce the risks posed by natural and other hazards through real-time data-driven decision-making and strengthened institutional coordination.

Keywords

Sustainability, human security, artificial intelligence, governance architecture, institutional coordination.

1. Introduction

From the earliest human interventions in the natural environment, we can recognize the need to assess the sustainability of human activities. Certainly, today's content of the term covers a much wider area of human activity than in the time of the original human community. Today, when we talk about sustainability, we do not mean only the ecological aspects of human activities, but also the effects of the work of all systems established by man. To conclude the sustainability of a process or system's operation, it is important to analyze the input and output parameters of that unit. It is necessary to analyze the effects of used resources not only in terms of the ecological footprint but also on employees' earned income, the possibility of renewing used resources, and the workforce's motivation to continue working. Sustainability can also be connected to demographic factors and to factors that decisively influence the choice of a place to live, i.e., the decision to leave a certain area. The quality of life observed through the prism of infrastructure, terrain, air quality, health system functionality, personal safety, and community safety is refracted by the functioning of institutions and the nature of the political system. Respecting the will of the majority and the extent to which their interests are incorporated into the legislative framework decisively affects all aspects of life, ultimately affecting the sustainability of the community living in a given territory.

Given the number of variables to be accounted for in the analysis of the sustainability of socio-economic systems, it is necessary to develop analytical models that yield the most accurate results. In this context, the concept of human security is a useful analytical framework that encompasses the greatest number of relevant factors for assessing the degree of sustainability and identifying the causes of problems that call into question the system's functionality and survival. Artificial intelligence is a valuable tool that can improve analysis quality by processing large amounts of data in a short period.

2. Methods

The research adopts an interdisciplinary approach that combines analysis of prior research and available statistical data to determine the relationships among sustainability, human security, and the functioning of modern socio-economic systems. The United Nations Development Program's concept of human security, promoted in the 1994 Human Development Report, was adopted as an analytical framework (UNDP, 1994). The holistic nature of the concept of human security enables the identification of gaps and the correlation among environmental, health, social, and infrastructure policies in the context of applying the principles of community sustainability and enhancing resilience to disasters (Đorđević, 2024).

The aforementioned methodological approach was chosen because the relationship between sustainability and human security is complex and requires analyzing political, economic, environmental, and institutional processes, as well as their impacts on individuals' and communities' quality of life and security. We use statistical analysis to test, based on available sources, a simulation model based on the system dynamics approach, which is applied to the analysis of complex systems with time-varying variables, using the Vensim software tool. The model structure is represented by a system of first-order nonlinear differential equations containing both system and auxiliary variables, with appropriate parameters that characterize the model's behavior over time.

3. The concept of human security and sustainable development

The concept of human security as an analytical framework emerged during a period of dramatic changes in the functioning of civilization following the fall of the Berlin Wall. The basic idea of the authors of the UNDP human development report for 1994 was to provide an analytical model to determine the sources of problems in countries (and/or communities) experiencing disturbances in the functioning of the system. The primary goal was to, through the analysis of transition processes and their effects in the area of the former Eastern bloc and the peripheral countries of the capitalist world, identify the causes that led to results contrary to expectations. However, as time progressed, the need for similar analyses emerged in the very center of the capitalist system.

The globalization of human activities has expanded the field of effects of many processes that were once limited to the national space. But even so, national institutions are still the only ones with real power to influence the nature of concrete processes and their effects at both the global and local levels. A holistic approach to modern processes entails a comprehensive analysis of key factors that determine the final result of their development. That's why we opted for a sustainability analysis based on the human security analytical model, which includes seven dimensions essential to people's quality of life. We think about sustainability, in the given context, as a necessary factor for the survival of the living world on planet Earth. Starting from the assumption that the basic goal of all activities undertaken by people is their well-being, and raising the level of living standards.

At the center of the analytical model based on the concept of human security is man as a factor that creates the environment, but also as one who suffers the consequences of the functioning of his activities. The neoconservative capitalist model that became dominant after the fall of the Berlin Wall propagates economic efficiency as its core value. However, in all likelihood, this efficiency has its price, as evidenced by the deterioration of the ecological situation and by climate changes that call into question the survival of the living world. If we want to determine the causes of the problems that call into question the sustainability of the modern civilizational model, then we must remember the basic postulate of democracy, which holds that the will of the majority is decisive in choosing the form of work and the way the system functions. That's why we have to introduce into the analysis the nature of political systems and the way in which an environment is created in which laws are adopted and implemented. Certain problems challenge the logic of the forward-looking democratic principle of the will of the majority. This is supported by evidence showing that the system is increasingly instrumentalized to serve the interests of financial oligarchies. The results of the current socio-economic model indicate that the majority fall into the category of losers. At the same time, a small percentage of the world's population enjoys enormous luxury and wealth (Đorđević, 2007). The perceived problems require careful analysis to develop arguments grounded in concrete research and data that would compel the centers of power to change their relationship with the rest of humanity and with the planet as a living habitat.

The effects of such research depend on the objective presentation of the situation and the results obtained under realistic parameters. That's why we believe that research that includes the economic aspects of the process and their effect on people's health, quality of nutrition, living environment, community safety, personal safety, and the ability of the individual to express his position through the institutions of the system is the only one that can bring a qualitative change in relation to the long-term interests of civilization.

3.1. Sustainability and Human Security - Formal/integral approach

Sustainable development represents the unity and interdependence of the environment, the economy, and social relations. However, this action often results from planned and unplanned activity in these domains, leading to instability and uncertainty regarding sustainable development. A typical example is the relationship between the economic and environmental domains, where contradictory decisions are possible: a positive activity in one domain can lead to a negative process in another, and vice versa.

To that end, the paper proposes an AI-based governance architecture to improve sustainability in Serbia. This conceptual governance model is designed as an integrative and adaptive framework, grounded in human security principles, that aims to reduce the risks of natural and other hazards through real-time data-based decision-making and strengthened institutional coordination.

The conceptual model is based on three pillars that form the basis for research in the field of sustainability (Rabbi, 2025):

- Environment
- Economy
- Society

For our research, this model has been extended to the domain of human security (Jahan, 2023):

- Environment
- Economy
- Society
- *Human*

This expanded model of sustainability is shown in Figure 1.

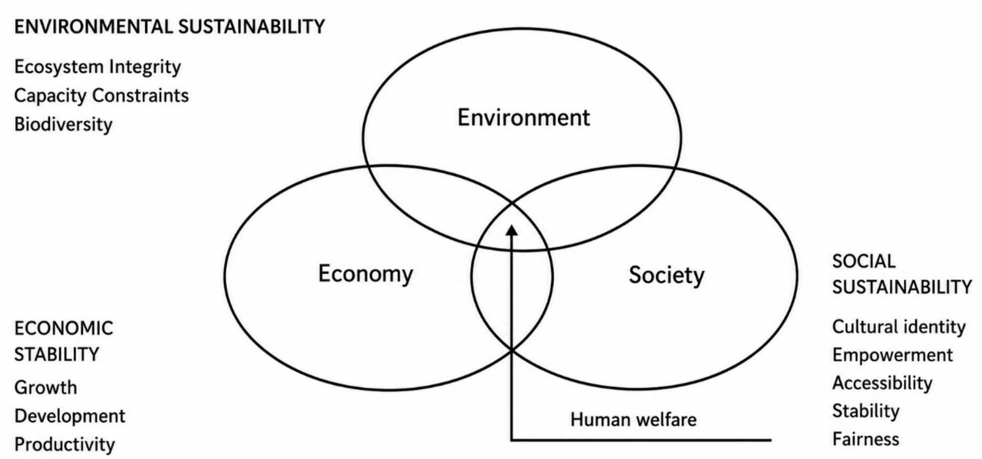

Figure 1. Elements of sustainable development. Source: Jevremović, 2007.

For the analysis of internal dynamic processes in a complex system of sustainability, a simulation model was realized using the appropriate Vensim software tool (Vensim). The model is based on the System Dynamics approach, which is applied to the analysis of complex systems that contain time-varying processes and sub-processes (Sterman, 2000).

From a theoretical point of view, the model is presented as a system of first-order nonlinear differential equations that include both system and auxiliary variables, with parameters that characterize its behavior over time.

3.1.1. Mathematical model

System variables

dSustainability/dt= α*(w1*EconSEC+w2*SocSec+w3*EcologSec+w4*PolSec)+β*DM - -γ*Sustainability

dInstQual/dt= δ*DM+ε*PolSec-InstQual

Auxiliary variables

$$HumSec=w1*EconSEC+w2*SocSec+w3*EcologSec+w4*PolSec$$

$$DM=\omega*HumSec-\eta*Sustainability+\theta*Public+\lambda*Training+\mu*Legal+\varrho*AI+\sigma*Assets$$

$$AI=\kappa-\tau*Sustainability-\varphi*HumSec-\upsilon*InstQual$$

HS domains

$$dEconSEC/dt = a1*EconGain-a2*EconLoss-a3*EconSEC+a4*DM-Disturbance$$

$$dSocSec/dt = b1*SocGain-b2*SocLoss-b3*SocSec+b4*DM$$

$$dEcologSec/dt = c1*EcoLGain-c2*EcolLoss-c3*EcologSec+c4*DM$$

$$dPolSec/dt= d1*PolGain-d2*PolLoss-d3*PolSec+d4*DM$$

External variables

Public - public opinion

Legal - legal regulations

Training - training and education

Assets - material, financial, and other resources

Where is:

w1…w4 - weighting factors that determine the relative importance of HS domains, (determined using expert assessment and AHP methodology, (Saaty, T.L., 1980).

$\alpha \ldots \omega$ - model parameters that determine the behavior of the model in time (stability, transition regimes, etc.),

a1…d4 - parameters that determine the dynamic characteristics of the HS domain.

For consistent analysis, all variables in the model are normalized to the range 0-1.

This model represents a dynamic system of sustainability and human security, structured as an interconnected stock-and-flow framework with feedback loops driven by policy, institutional capacity, and AI-enabled decision-making.

At its core, four sectoral human security stocks - economic (EconSEC), social (SocSEC), ecological (EcologSEC), and political (PolSec)- evolve through a balance of gains, losses, natural decay, and policy intervention (DM). These sectors are aggregated into a composite input (HSIn) that determines the level of human security (HumSec), capturing the system's overall resilience and well-being.

In the Human Security (HS) framework, each domain is typically decomposed into core components (sub-dimensions) that capture both structural conditions and risk exposures. Operationalization for modeling and determination of parameters and indices in the model is based on the following contents of HS sub-dimensions:

Economic Security (*EconSec*): stability of income, livelihoods, and economic resilience.

Ecological (Environmental) Security (*EcoSec*): sustainability of natural systems and exposure to environmental risks.

Social Security (*SocSec*): well-being, social cohesion, and access to essential services.

Political Security (*PolSec*): governance, rights, and institutional stability.

Furthermore, Sustainability is modeled as a higher-order stock influenced by sectoral performance (SusIn) and policy effectiveness (DM). At the same time, institutional quality (InstQual) reflects governance capacity shaped by political security and decision making, with a delay representing bureaucratic inertia.

A central endogenous driver is decision-making capacity (DM), which depends on human security, sustainability conditions, public response, legal frameworks, available assets, and AI capability. AI acts as a strategic modifier of decision-making, while also being indirectly influenced by system performance, creating a feedback loop between technology and governance.

The model includes an exogenous disturbance (shock) that perturbs the economic sector, allowing simulation of system resilience and recovery dynamics.

This model effectively represents an AI-enabled governance resilience system where:

- AI improves training capacity,
- training improves decision-making,
- better decision-making enhances sustainability,
- sustainability improves public trust,
- public trust feeds governance quality,
- Governance quality influences security domains.

Overall, the model structure captures:

- Interdependence of sustainability and human security,
- Feedback between governance, AI, and system performance,
- Resilience dynamics under external shocks.

The simulation model, created with the Vensim software, is shown in Figure 2.

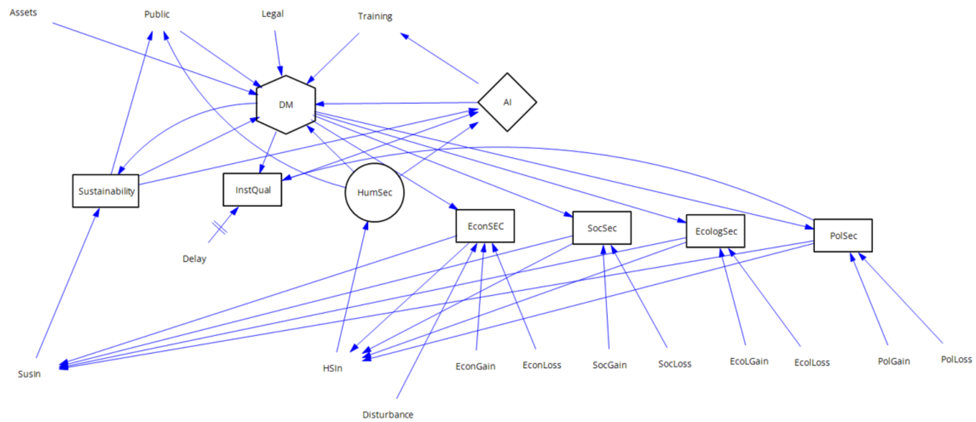

Figure 2. Simulation model of the relationship between the dimensions of human security and sustainability. Source: Authors.

The parameters in the model are determined based on **Serbian empirical indicators and** on datasets and policy benchmarks aligned with frameworks of the United Nations, the European Union, and Serbia's National Sustainable Development Strategy of the Republic of Serbia. In addition, the parameters are determined based on expert assessments, official reports, and AI assessments that are relevant to the Republic of Serbia. For this purpose, data from the following sources were used: The United Nations in Serbia, the United Nations Development Program, the Sustainable Development Goals in the Republic of Serbia, The Organisation for Economic Co-operation and Development, the Serbian Artificial Intelligence National Platform, the Environmental Performance Index, the European Environment Agency, and the World Economics Platform.

To explain the parameters using real Serbian data, should reinterpret each variable as an empirical proxy derived from official statistical indicators. This model then becomes an operationalized AI-human security-sustainability framework for Serbia.

A strong approach is to normalize all variables to a 0-1 scale. This allows heterogeneous Serbian indicators (GDP growth, corruption index, pollution, unemployment, etc.) to coexist within a single SD model.

An example of determining parameters for the economic domain within human security.

The EconSec variable that represents this domain in the model can generally represent:

- macroeconomic stability,
- employment security,
- household resilience,
- fiscal sustainability.

Table 1. Examples of data sources for indicators of economic security. Source: Authors.

Indicator	Serbian source
GDP growth	World Bank
Unemployment	Statistical Office of Serbia
Inflation	National Bank of Serbia
Public debt/GDP	Ministry of Finance
Real wages	Statistical Office of Serbia

Furthermore, the EconSec variable in the model has two components: EconGain and EconLoss. EconGain increases economic security, while EconLoss decreases it in this domain. EconGain depends on GDP growth, Employment growth, and foreign direct investment (FDI). EconLoss shows inflation, public debt pressure, external shocks, and the burden of the informal economy.

After determining the appropriate indicators for EconSec from the mentioned databases, normalization is performed to obtain parameters that are then implemented in the simulation model.

A similar procedure can be applied to the variables in other domains of human security: EcolSec, SocSec, and PolSec. However, due to limited space in the work, it was omitted.

In addition, a similar analysis and parameter determination were carried out for the variables AI, DM, InstQual, and Sustainability.

An additional condition for determining the parameters is the stability requirement (Jacobian stability conditions), which additionally determines the quality of the model's behavior over time.

By running a simulation for the model thus formed, with the application of an exogenous **disturbance (shock)** that perturbs the economic sector of human security, the time responses for the variables in the model are obtained:

- *Sustainability* **–** level of **sustainability**
- *HumSec* **-** level of **human security**
- *DM* – decision-making **capacity**
- *AI* - AI-enabled decision making
- *InstQual* - governance capacity
- *EconSEC* - economic security
- *PolSec* – political security
- *Disturbance* - exogenous **disturbance on** the economic sector

Time responses for these model variables are shown in Figure 3:

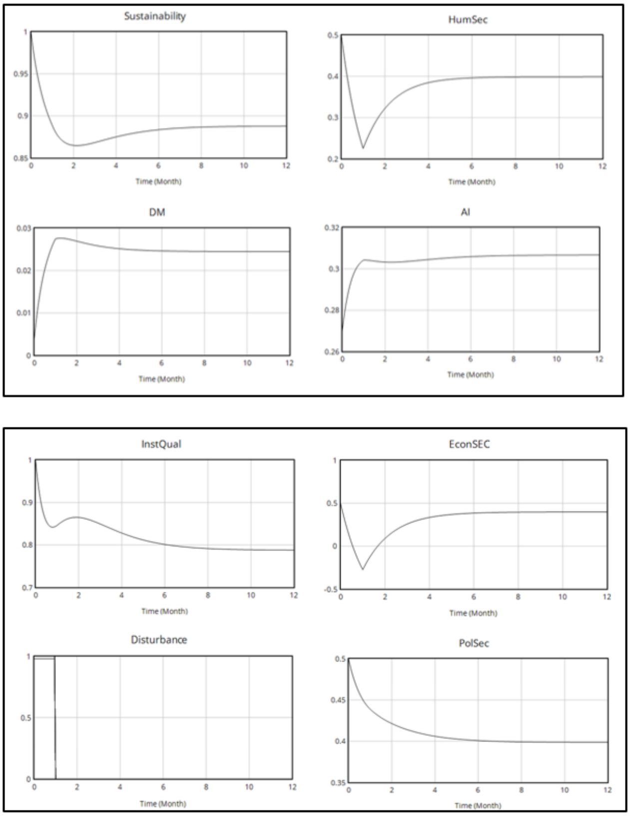

Figure 3. Graphical representation of the time response to changes in observed variables

Source: Authors.

After the conditional application of an exogenous disturbance (shock) lasting one month, all variables in the model exhibit a transitional regime lasting 6 months, after which they enter a stable regime. At the same time, the dependent variables in the model, Sustainability, Human Security (HumSec), Institutional Quality (InstQual), Economic Security (EconSec), and Political Security (PolSec), have a reduction of approximately 20% compared to initial values. This is expected considering the intensity of the disturbance. Control variables Decision Making (DM) and AI-enabled decision making (AI) are at a correspondingly high level, which enables the model to maintain stable behavior over time. In this way, the justification for the selected model parameters based on Serbian empirical indicators is demonstrated.

Performing various simulations in the presented model enables:

- Analysis of internal dynamic processes in a complex system of sustainability,
- Analysis of stability conditions in the model,
- Parameter estimation for various geographical locations (RS, cities, municipalities),
- Analysis of various scenarios in emergencies.

It is also suitable for analyzing policy interventions, AI-enabled governance, and stability of critical socio-economic systems.

4. Conclusions

The presented research was intended to indicate the potential of artificial intelligence for data analysis in situations where processing of large amounts of data is required in a short period of time. The system dynamics-based model contributed to the objectification and efficiency of the decision-making process. Decision-making based on the quantification of real circumstances and factors that influence the process represents a significant contribution to improving the sustainability of civilization, local communities, and the quality of life of people.

Based on the results of comprehensive research and the quantification of factors influencing the processes, the observed shortcomings can be corrected and a rapid response implemented. Thanks to the strength of the arguments, ideological and interest-based moments that are often used to instrumentalize the system in order to realize goals whose basic criterion of success is profit can be avoided.

Each area has certain specificities, and the research approach should be adapted to the conditions on the ground. Experiences and practices formalized through certain ISO standards should receive their national versions in accordance with local specificities. We believe that the basic principles outlined in international strategies and declarations can be universal in nature, but their adaptation to local conditions is necessary. Therefore, the concept of human security as an analytical framework is useful for optimizing local resources in relation to specific circumstances, using appropriate models and algorithms in artificial intelligence. Certainly, the role of experts as users of tools is irreplaceable. Machines are not yet able to replace human creativity, and as far as is known, they still do not have empathy for humans and the rest of the living world on our planet.

The research indicates the complexity of the sustainability problem and the need to harmonize all elements of the system across different levels of government and geographical regions, as well as to make necessary changes to the paradigm on which modern civilization is based. To begin with, it is necessary to raise awareness of the need to incorporate sustainability into all socio-economic processes. The system dynamics model presented here allows us to see the connections that exist between the socio-economic environment and disaster resilience. Determining the correlation between the state of the areas recognized as significant for the quality of people's lives in the concept of human security and the ability of communities to adequately prepare for and respond to natural and other disasters is the first step in building its sustainability.

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