The Journal of Accounting and Management

Information Systems for Real-Time Decisions: A Strategic Approach to Strengthening National Security and Economic Resilience

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Abstract: The integration of circular economy indicators into decision-making processes with an impact on national security requires a rigorous conceptual foundation of three essential dimensions: real-time decision-making, circular supply chains, and economic and national security. These concepts are interdependent, articulated in a complex framework of sustainable and digital governance. In the current geopolitical context marked by instability, energy crises, and pressures on natural resources, the capacity of states to adopt rapid and efficient decisions becomes a critical element of economic resilience. This paper examines, through a quantitative analysis of data provided by EUROSTAT for the period 2010-2022, how two main indicators of the circular economy – the circular material use rate (CR) and the waste recycling rate (RW) – can underpin real-time decision-making processes, with implications for strengthening economic security. In this endeavor, information systems play a central role, facilitating the collection, processing, and analysis of data by applying clustering techniques (K-means) and identifying distinct patterns of circular performance among the Member States of the European Union. The results highlight the fact that the integration of circular indicators into decision-making flows, through advanced information systems, contributes significantly to increasing economic resilience and reducing systemic vulnerabilities. The development of autonomous circular chains, supported by digital decision-making technologies, underlines the importance of information systems as a strategic infrastructure for national security in a volatile global economic environment.

Keywords: information systems; real-time decisions; circular economy; economic security; national resilience

JEL Classification: O33, D81, Q57, F52, H56

1. Introduction

In an international context marked by increasing concerns about sustainable development, the circular economy has consolidated as a strategic direction within the policies of the European Union. By promoting the reuse, recycling, and reduction of the consumption of natural resources, it contributes not only to reducing the pressure on the environment but also to strengthening the economic security of the Member States. Initiatives such as the Circular Economy Directive and the Circular Economy

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Action Package, launched by the European Commission, support technological innovation, increasing resource efficiency and generating sustainable jobs, all of which have as their objective the expansion of the strategic autonomy of the region (Tache, 2010; Tache & Postolache, 2010).

In this framework of economic transformation, decision-making information systems take on an essential role by facilitating the rapid collection and interpretation of relevant data. The use of advanced digital technologies – such as big data analytics, artificial intelligence, and optimization algorithms – allows for real-time adaptation of circular supply chains and prompt response to exogenous shocks. In this sense, the ability to monitor indicators such as employment in circular sectors, resource productivity, or the level of private investment becomes a sine qua non condition of efficient and resilient economic governance (Dragomir, 2016; Dragomir, 2017). At the same time, recent research highlights how digital infrastructure, through intelligent information systems, contributes to shaping strategic decisions in uncertain environments, strengthening the link between sustainability, economic stability, and national security (Dragomir & Dumitriu, 2021). An economy capable of maintaining robust local production and consumption cycles proves to be less dependent on foreign imports and more resilient in the face of global dysfunctions. In addition, investments directed towards circular infrastructure and green sectors can play a decisive role in supporting social and economic balance, essential pillars of contemporary national security.

2. The Role of Information Systems in Supporting Real-Time Decisions for Smart Circular Governance

In the context of accelerated digital transformation, real-time decisions designate the ability of a system, be it human, automated, or hybrid, to collect, process, and interpret continuous flows of information, so as to adopt rapid and appropriate decisions in relation to the dynamics of the operational environment. Unlike traditional decision-making models, characterized by extended analysis and reaction times, real-time decision-making processes involve a direct integration between data and action, significantly reducing human intervention and increasing the efficiency of the adaptive response (Dragomir, 2017).

The development of these capabilities was possible due to technological advances in the field of information systems, in particular through the proliferation of IoT (Internet of Things) sensor networks, cloud infrastructures, ERP (Enterprise Resource Planning) systems, as well as machine learning algorithms and applied artificial intelligence. These information components allow not only the collection of impressive volumes of data from supply chains, production processes or consumption behaviors, but also their processing in real time in order to generate adaptive operational responses – whether in the form of dynamic resource redistribution, order adjustment, optimization of transport routes or automatic activation of emergency protocols (Dragomir & Alexandrescu, 2018b).

The specialized literature highlights the importance of implementing decision-making models based on hierarchical and adaptive information systems to strengthen the security of economic infrastructures, emphasizing the relevance of predictive modeling technologies in supporting complex decision-making processes (Dragomir & Alexandrescu, 2018a). In addition, the integration of decision-making support technologies within circular economies leads to the optimization of material flows and the reduction of energy losses by dynamically recalibrating production processes based on information obtained in real time (Tache & Postolache, 2010).

Therefore, information systems represent the backbone of smart circular governance, transforming operational data into rapid, sustainable, and strategically oriented decisions, in a global context marked by volatility and pressure on resources.

2.1. Information Systems in Reconfiguring Circular Supply Chains: A Foundation for Economic Resilience and Strategic Sustainability

Circular supply chains mark a structural transformation of the traditional economic paradigm, replacing the conventional linear model – “extraction-production-consumption-waste” – with a closed-loop architecture, in which resources are kept in the economic circuit for extended periods of time. This reconceptualization involves extending the life of products and materials through reuse, reconditioning, remanufacturing, and recycling processes, with the fundamental objective of reducing dependence on primary resources and reducing environmental impact.

In these circular chains, waste is no longer viewed as simple residues, but is reinterpreted as valuable resources for new production cycles. Circular logic thus redefines the essential functions of reverse logistics, inventory management, and resource planning, leading to a profound reconfiguration of production and consumption relationships. The efficient functioning of these chains requires an optimized coordination of material and information flows, which can only be achieved through the extensive integration of digital technologies and through real-time decision-making, facilitated by advanced information systems.

The use of artificial intelligence solutions and predictive tools in the management of urban recycling logistics opens up prospects for significant increases in efficiency, not only in terms of material collection and sorting, but also in anticipating congestion and risks of blockages in circular chains. Through these adaptive mechanisms, industrial and commercial processes can maintain their continuity even in conditions of high volatility, emphasizing the role of information systems in ensuring operational resilience.

Also, supply chains based on the reuse of local and regional resources demonstrate reduced vulnerability to global shocks, such as geopolitical conflicts or international trade blockades. Therefore, the circular economy acquires strategic values, becoming not only an ecological option but a genuine geopolitical strategy, with direct implications for economic autonomy and national security. In this context, local chains acquire a crucial role in ensuring the continuity of supply in strategic areas such as agriculture, energy, and the technology industry, even in conditions of international instability.

In support of the development of circular infrastructures, public policies become decisive by developing appropriate regulations, supporting the digitalization of production processes, and stimulating technological innovation. The integration of circularity indicators into economic governance and strategic planning instruments favors the emergence of smart and sustainable chains, capable of mitigating the structural vulnerabilities of national economies and increasing long-term competitiveness.

Therefore, circular supply chains, supported by high-performance information systems, can no longer be conceived only as ecological alternatives but must be assumed as essential strategic infrastructures for strengthening adaptability, autonomy, and resource security in a global environment characterized by systemic uncertainty and economic volatility.

2.2. Integrating Information Systems into the Circular Economy: An Emerging Pillar of Economic and National Security

The concept of national security has undergone a broad expansion, going beyond the traditional military framework and incorporating economic, social, ecological, and digital dimensions, in response to new forms of systemic vulnerability. In this expanded approach, economic security is defined by the state's ability to support the stable, resilient, and autonomous functioning of its economy, even under the pressure of internal or external crises. This implies uninterrupted access to essential resources, the protection of critical infrastructures, the maintenance of domestic production capacity, and the provision of employment at sustainable levels. In this context, the circular economy is emerging as a strategic tool to reduce dependence on imports, strengthen local supply chains, and mitigate the risks associated with the volatility of international raw material markets. Dimitrov and Petrov (2022) highlight, in a study published in Sustainable Production and Consumption, the fact that systematic investments in circular infrastructure, coupled with the digitalization of resource flows, contribute decisively to increasing economic security by reducing external vulnerabilities and increasing autonomy over the internal resource cycle. They propose the integration of circular economy indicators into economic and urban defense strategies, facilitating the anticipation and prevention of systemic crises through the use of predictive information systems.

This approach is reinforced by research conducted by Li et al. (2023) in Technological Forecasting and Social Change, which highlights the fact that economies that have implemented digital decision-making networks for circular resource management have demonstrated superior economic continuity in the face of systemic shocks generated by the COVID-19 pandemic and the 2022 energy crisis. The correlation between private investments in circular infrastructure and the development of state rapid response capacities is highlighted as a critical factor in strengthening economic resilience.

In addition, the study by Fernández-Viñé et al. (2023) explores the convergence of circularity, digitalization, and national security in the European context, highlighting that the digitalization of circular infrastructures through advanced monitoring and prediction systems not only optimizes the use of resources but also protects them against cyber threats and operational dysfunctions. Thus, the circular economy, supported by real-time decisions and robust information systems, becomes an essential pillar of national security in the digital age. In the same vein, Rodriguez and Paunescu (2023) propose an integrated vision of national security, which includes both the components of ecological sustainability and adaptive economic capacity. In a world marked by increasing climate, energy, and geopolitical risks, the authors argue that national security strategies must include circularity indicators such as waste recycling rates, resource productivity, and employment in green sectors.

Therefore, the circular economy and the related digital decision-making mechanisms cannot be analyzed exclusively from an ecological perspective, but must be understood as constitutive elements of economic and national security strategies. The state's capacity to implement real-time decisions regarding the management of internal resources, supported by high-performance information infrastructures, becomes an advanced expression of functional sovereignty in a global environment dominated by uncertainty, interdependence, and systemic risk.

3. Methodology

3.1. Defining Analytical Objectives and Selecting Circularity Indicators Through Information Systems

The methodology applied in this study is based its approach on a rigorous comparative analysis of a set of data collected from the official EUROSTAT database, targeting five key indicators of circular economy performance in the Member States of the European Union. The selection of these indicators was carried out according to their relevance in assessing the functional efficiency of circular supply chains and real-time decision-making capacity, in close correlation with the dimension of economic security and strategic resilience.

The indicators used are defined as follows:

• PE – People employed in circular economy sectors;

• RS – Resource productivity (euro/kg);

• CR – Circular material use rate (%);

• RW – Waste recycling rate (%);

• PVA – Private investments in the circular economy (million euros).

These metrics provide an integrated perspective on the economic, ecological, and social dimensions of circularity, allowing not only a descriptive analysis of national performance but also the modeling of causal relationships between private investments and other critical factors of circular sustainability. By integrating decision-making information systems, the analysis becomes capable of supporting the prediction and optimization of public policies and economic strategies, in order to achieve the objectives of resilience and sustainability.

3.2. Data Processing and Analytical Methodology Assisted by Information Systems

The analyzed data come from the official EUROSTAT platform and cover the period 2010-2022 for most of the European Union Member States. To ensure accuracy and cross-country comparability, the dataset was aggregated, cleaned of missing values or formatting anomalies, and standardized through specific statistical normalization procedures. In some cases, the initial variables were transformed to reflect percentage ratios or temporal trends relevant to the dynamics of circularity.

The transition to a circular economy is one of the major priorities of the European Union within the framework of sustainability and resource efficiency strategies. In this sense, the circular material use rate (CR) and the waste recycling rate (RW) are considered fundamental indicators for monitoring progress towards an economy based on the conservation of resource value.

In order to identify patterns of behavior and performance between European countries, the analysis used an unsupervised learning approach by applying the K-means clustering algorithm. This method was chosen for its ability to group observations (countries) according to the relative similarities of circular performance. The dataset, composed of the annual values of the CR and RW indicators for the 27 European countries over the period 2010-2022, was pre-processed, standardized, and introduced into the clustering algorithm.

The number of clusters selected was 2, in accordance with the working hypothesis regarding the existence of two distinct groups: an advanced group, characterized by higher levels of circularity, and a standard group, with average or low performance. By applying this methodology assisted by information systems, the analysis proposes an objective classification of states according to the degree of integration of the circular economy and the decision-making potential related to supporting economic resilience.

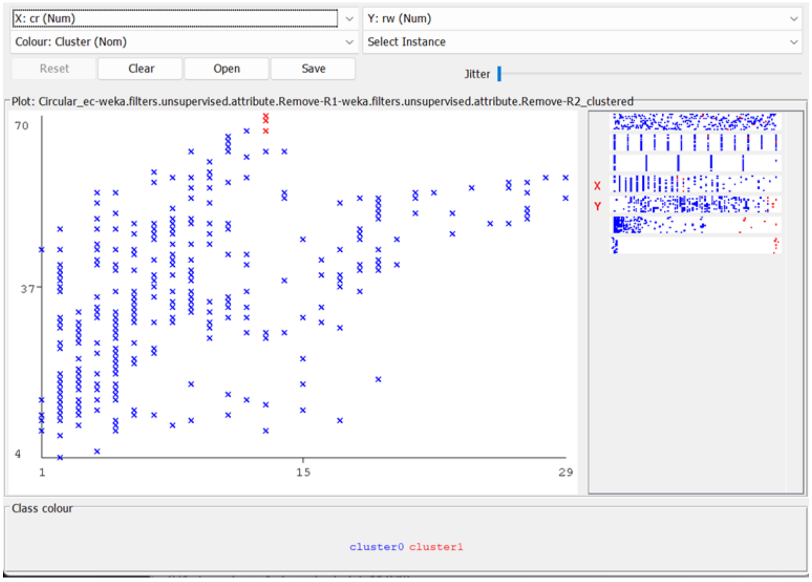

Figure 1. Clustering process. Realized by the author in Weka software.

The graph presented illustrates the results of the unsupervised clustering process applied to the indicators circular material use rate (CR) and waste recycling rate (RW), for a sample representing 27 European countries, for the period 2010–2022. The classification was performed using the K-means algorithm, configured to identify two distinct clusters (Cluster0 and Cluster1), highlighted in the image by color codes: blue for Cluster0 and red for Cluster1.

Visual analysis of the distribution of points highlights the following essential aspects:

a. Cluster0 dominance

Most observations (blue points) are associated with Cluster 0, indicating that a significant number of European countries present average or low levels for both circular material use rate (CR) and waste recycling rate (RW). This concentration suggests the existence of a critical mass of economies that, although adopting the principles of the circular economy, are still at an early or intermediate stage of maturity in terms of effective circularity.

b. Existence of the Cluster

The observations marked in red (Cluster1) are significantly fewer and are located in the upper area of the graph in terms of indicator values. This distribution indicates that a small group of European countries demonstrate advanced performance, both in terms of circular use of materials and the efficiency of recycling processes. These countries can be considered leaders in implementing the transition to a fully functional circular economy.

c. Distribution of CR and RW values

The horizontal axis (X) represents the circular rate of material use (CR), and the vertical axis (Y) the waste recycling rate (RW). A relatively wide dispersion of CR values is observed, between approximately 1% and 29%, while RW values vary between approximately 4% and 70%. This dispersion reveals significant differences between countries in terms of circularity levels, which justifies the choice of the clustering method to identify latent patterns.

d. Implications for economic resilience

From a strategic perspective, countries located in Cluster 1 have increased economic resilience due to their ability to maintain efficient and sustainable resource cycles. In contrast, countries associated with Cluster 0 may be more vulnerable to volatility in raw material markets and environmental pressures, requiring additional support policies to accelerate the circular transition.

e. The role of information systems

The rapid identification and automatic classification of these circular performance groups was made possible by the use of advanced information systems, which allowed the processing of large volumes of data and the application of unsupervised learning algorithms. This integration of decision-making technology in the analysis of sustainability policies is an example of good practice in supporting data-driven economic governance.

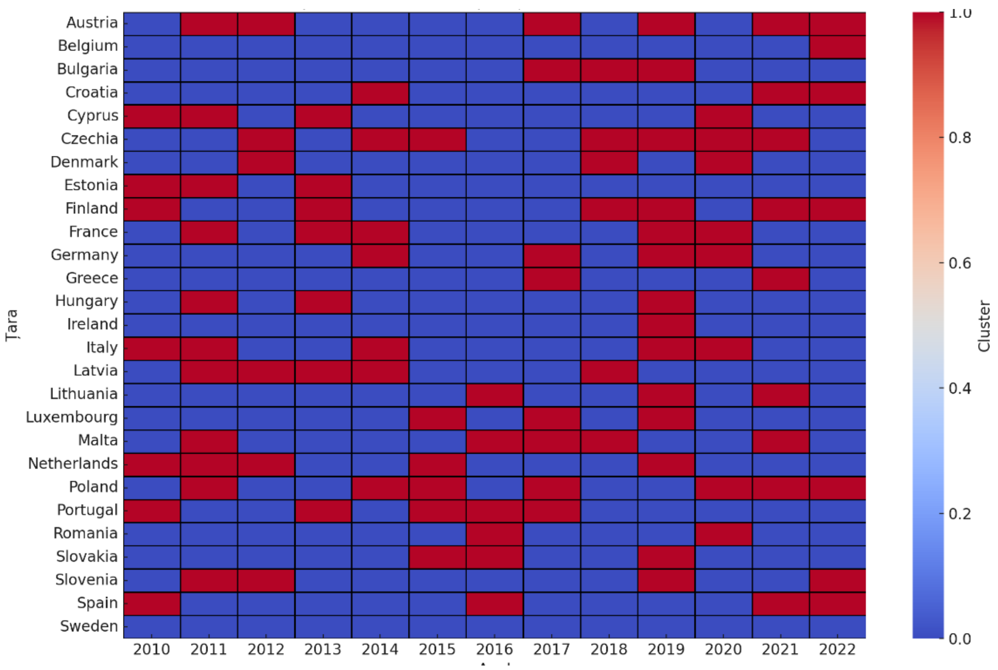

Figure 2. Heat map. Realized by the author in Weka software.

4. Results

The results obtained by applying the clustering method to circularity indicators highlight the existence of major disparities between the Member States of the European Union in terms of the degree of advancement in the implementation of the circular economy. The distribution of the states into two distinct clusters – Cluster 0 (standard performance) and Cluster 1 (advanced performance) – reflects significant differences in the maturity of circular infrastructures, the coherence of public policies, and the level of integration of emerging technologies.

The states included in the advanced cluster are characterized by well-articulated public policies, digitalized support infrastructures, and a high level of societal awareness regarding the importance of circularity. The integration of decision-making information systems, such as resource flow monitoring platforms, predictive applications, and big data analysis networks, has played a decisive role in strengthening the capacity of these economies to quickly adapt production and consumption processes according to market developments and external pressures.

In contrast, countries in the standard cluster require significant strategic interventions, not only in the area of sustainability policies, but also in the area of supporting digital infrastructures. The lack of integrated information systems for circular resource management limits the capacity of these economies to make rapid and adaptive decisions, increasing their vulnerability to global crises.

Another notable observation is the relative stability of countries' membership in clusters over the period analyzed (2010-2022), which highlights the inertial nature of structural development in the absence of accelerated digitalization and the implementation of intelligent decision-making support systems. However, the cases of countries such as Slovenia and Portugal, which have experienced upward mobility, demonstrate the efficiency of investments in digitalization, circular infrastructure, and applied information technologies.

Also, the positive correlation identified between the volume of private investment in the circular economy (PVA) and membership in the advanced cluster reflects the significant impact of private initiatives in accelerating the digitalization of circular processes. By adopting information platforms such as green ERP, blockchain for resource traceability, and artificial intelligence for optimizing production cycles, the private sector plays a crucial role in transforming the traditional economic paradigm. In conclusion, the clustering model not only maps the circular performance of states but also indirectly highlights the level of integration of the information infrastructures necessary for intelligent and predictive governance. Thus, information systems are not a simple auxiliary tool, but a fundamental element for strengthening economic resilience, anticipating systemic risks, and optimizing the transition to a sustainable and autonomous economic model.

5. Conclusions

Accelerating the transition to a sustainable and fair circular economy requires the formulation of differentiated European public policies, adapted to the level of circular maturity of each Member State. In particular, countries in the low-performing cluster (Cluster 0) require a coherent set of strategic interventions, including the smart allocation of European funds according to structural needs, the development of specialized digital infrastructures for monitoring circular indicators, as well as the formation of qualified human capital, capable of operating in green economic ecosystems and supporting data-driven decisions.

A key aspect for the resilience of economic systems is the systematic integration of circular indicators – in particular, the circular material use rate (CR) and the waste recycling rate (RW) – into the information architectures of economic governance. The use of advanced information systems, capable of processing large volumes of data in real time, facilitates not only the early diagnosis of bottlenecks in supply chains but also the formulation of rapid and accurate strategic decisions. Real-time decision support systems platforms, supported by machine learning algorithms and predictive analytics, are becoming critical tools for anticipating risks and optimizing resources in volatile economic contexts. The complete digitalization of circular supply chains is an indispensable condition for the efficient functioning of the contemporary circular economy. This involves investments in technologies such as the Internet of Things (IoT), artificial intelligence (AI) and blockchain, designed to ensure complete traceability of materials and streamline operational decisions. The automation of decision-making processes in critical nodes – recycling centers, warehouses, sorting units – and the real-time connection of all actors involved in circular flows is achieved exclusively through integrated and interoperable information systems.

In this perspective, circular security must be recognized as a fundamental pillar of the national strategic infrastructure, comparable in importance to areas such as energy, health or transport. Public economic security policies must explicitly include the circular component, by integrating infrastructures, data and information flows into state response strategies. Thus, information systems become the central link between the sustainability, resilience and responsiveness of an economy, shaping an integrated model of data-driven governance and strategic adaptability.

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