A CLUSTER ANALYSIS OF ARMENIA'S STRATEGIC ROLE IN THE GLOBAL BLOCKCHAIN LANDSCAPE

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Abstract

The aim of the study is to quantitatively assess Armenia's strategic role in the global blockchain ecosystem, revealing the country's position relative to global competitors. The study was conducted on a selection of 50 countries, using a number of other elements: cryptocurrency adoption, innovation potential, and digital infrastructure. For practical analysis, the K-means clustering method was used, which allows classifying countries into homogeneous groups, as well as Principal Component Analysis (PCA).

As a result of the cluster analysis, three main clusters were identified: "Global Leaders", "Emerging Integrators" and "New Entrants". Armenia falls into the "Emerging Integrators" cluster, which is characterized by an above-average innovation potential (≈ 0.53) and a strong digital infrastructure (≈ 0.8), but a relatively low crypto adoption rate (≈ 0.019).

In addition to cluster analysis, an optimization model was also used, which showed that Armenia's transition to the "Global Leaders" cluster will require capital investments, a sharp improvement in the legislative framework, and human resource development.

This research fills a scientific gap by providing a quantitative assessment of Armenia's position on the global blockchain map and forming a practical basis for developing targeted state policies, optimal resource allocation, and technological integration strategies.

Keywords: Blockchain, cluster analysis, innovation index, digital economy, armenia, strategic positioning.

Introduction: Blockchain technology, based on the immutability principle of Distributed Ledger Technology (DLT), has expanded beyond cryptocurrencies in the last decade to become a key driver of the global digital economy[10]. Global market analysis shows that by 2030, the volume of investments in blockchain technologies will increase dramatically, forming the infrastructure of a new digital economy. In this context, the Republic of Armenia, which has a strong engineering tradition and a developing technological ecosystem, aspires to become a regional digital center. According to official reports, Armenia's IT sector is showing a steady growth of more than 20% annually, and the Innovation Index (0.534) and Digital Infrastructure Index (0.8) correspond to an above-average level compared to a sample of 50 countries. These indicators indicate that Armenia has the technological readiness for the adoption and spread of blockchain.

However, there is a significant disparity between Armenia's high-tech potential and the market adoption of blockchain: the Crypto Adoption Score is only 0.019, which proves that technological capabilities are not yet fully reflected in the level of market integration.

A study of global blockchain strategies shows that the key success factors for large and small economies are strategic government support, an open regulatory environment, and policies aimed at human capital development. However, for small and developing economies like Armenia, what is needed is not a direct transfer of the experience of world leaders, but a comprehensive quantitative modeling that will allow understanding the interaction between the country's innovation potential and investment constraints[4]. In this regard, this study fills a scientific gap by providing a quantitative assessment of Armenia's position on the global blockchain map based on multivariate statistical analysis and optimization modeling.

The main objectives of the research are:

• to quantitatively assess Armenia's integration into the global blockchain ecosystem,

• to identify the factors that shape the country's position in different clusters,

• to develop the structure of strategic investments that will have the greatest impact on Armenia's level of blockchain integration.

Therefore, three main research questions are formulated:

1. What is Armenia's level of integration into the global blockchain ecosystem compared to 50 countries?

2. By what factors do different clusters (e.g. "Strategic Transformation Nodes" and "Adjustable Potential

Levers") differ according to the main components identified by PCA?

3. What are the optimal investment directions that will have the greatest impact on Armenia's blockchain integration and strategic positioning?

Literature review: The literature has extensively explored the theoretical foundations of blockchain and its transformative potential[5][9]. Recent research has focused on quantifying the economic impact of blockchain. Tapscott and Tapscott[10] highlight the importance of creating an "Internet of Value" that enables decentralized and intermediary-free transactions. Scholarly sources document that blockchain adoption is positively correlated with a country's GDP growth and digitalization indices[3]. However, this impact varies greatly depending on a country's digital infrastructure, level of human capital, and regulatory environment[1]. A significant number of studies analyze the role of blockchain in increasing financial inclusion[1] and ensuring transparency in supply chains[7]. The general consensus is that active government support and "open" regulation are vital for the blockchain ecosystem to flourish. Attempts to map the global blockchain landscape have been made in both academic and corporate circles. Corporate reports often use multi-attribute indices to rank countries by blockchain readiness criteria (e.g., regulatory framework, talent, funding). Academic studies that use cluster analysis typically classify countries into four to five main clusters: "Leaders", "Followers", "Potential", and "Needs Development"[8]. These studies often use Principal Component Analysis (PCA) or Factor Analysis to reduce multiple indicators to one or two main dimensions (e.g., "Innovative Capacity" and "Regulatory Support"). This methodology allows for a quantitative determination of a country's position, free from subjective assessments.

Particular attention has been paid to the role of small countries, which often have flexible regulatory bodies and small communities of highly qualified IT professionals. For example, Malta, Switzerland (Crypto Valley), and Singapore are seen as small economies that have become global blockchain hubs thanks to their regulatory approaches[2][6]. The successes of these countries demonstrate that economic size is not necessarily a barrier if there is strategic government support and an innovation culture. However, regional (Caucasus) comparative analyses using quantitative cluster models remain limited.

Despite the general mapping of the global blockchain landscape, a specific scientific gap is observed in the quantitative assessment of Armenia's strategic position. The existing literature mainly focuses on developed countries or on individual technical aspects of blockchain. There is a lack of a model that would apply cluster analysis to rank Armenia among global competitors based on multiple socio-economic and technological indicators. Moreover, there are no publications that would apply optimization modeling to provide clear indications on how Armenia can maximize (max) its integration index given the available resources and constraints (e.g. budget, infrastructure). This study aims to fill this gap by providing a quantitative, methodologically rigorous analysis that will serve as a basis for informed policy development.

Methodology: The methodology of the present study is based on quantitative and comparative analytical approaches, the purpose of which is to reveal the position and strategic role of Armenia in the global blockchain ecosystem. The study was conducted in three stages: data collection, cluster analysis, and optimization assessment.

In the first stage, open data was collected from various international sources, including the annual reports of the World Bank, OECD, Statista, and Chainalysis. The data included the level of blockchain technology adoption, digital asset turnover, investment climate indicators, as well as assessments of the legal and institutional environment for different countries.

In the second stage, cluster analysis was performed using the K-Means and Hierarchical Clustering methods, aiming to classify countries by the level of blockchain development and adoption. The data was normalized using the Z-score method to reduce the impact of different doses. The optimal number of clusters was determined using the Elbow Method and Silhouette Score criteria.

At the final stage, an optimization analysis was conducted to assess the factors whose improvement could contribute to Armenia's transition to a more advanced cluster, the so-called "Global Leaders" group. For this purpose, a baseline regression and multi-criteria optimization model was built that assesses the impact of investments, legislative reforms, and technological innovations on the competitiveness of Armenia's blockchain sector.

The research methodology is aimed at ensuring the comparability and objectivity of the results obtained, allowing for the formation of a scientific justification for Armenia's strategic position and development potential in the global blockchain environment.

Analysis: The aim of the study is to quantitatively assess Armenia's position in the global blockchain ecosystem based on key indicators of digital readiness, innovation potential, and cryptocurrency adoption. For this purpose, a comparative analysis framework was selected, covering 50 countries representing different levels of economic and technological development.

The study is based on four key metrics, which are considered key factors in blockchain integration and technological readiness[7][4].

1. Crypto Adoption Score - reflects the degree of mass adoption of cryptocurrencies by the population of a given country. It serves as the best proxy for the financial activity of blockchain.

2. Innovation Index - shows the development of the country's overall innovation ecosystem, which is directly related to the ability to create and implement blockchain and other innovative technologies.

3. Digital Infrastructure Index - reflects the physical and technical foundations (e.g. network quality, data centers) necessary for the operation of any digital technology, including blockchain.

4. Internet Penetration (%) - shows the percentage of the population that has internet access, which is a

fundamental prerequisite for mass adoption of blockchain.

The indicators calculated for Armenia are:

• Crypto Adoption Score -0.019 (Low score, indicating limited mass adoption).

• Innovation Index - 0.534 (Above average, consistent with the country's IT role).

• Digital Infrastructure Index - 0.80 (High, indicating a strong technical foundation).

These data indicate a gap between a high-tech foundation and market adoption, which was further confirmed by the results of the caste analysis.

To ensure the accuracy of the multivariate analysis, all variables were standardized before conducting the K-means clustering and PCA analyses. The Z-Score method was used, which brings each indicator to the same scale, having a zero mean and one standard deviation. This process prevents the situation where variables with a large value range dominate the analysis.

To divide the countries in the data set into homogeneous groups (clusters), the K-means clustering algorithm was used, which aims to minimize the sum of squared errors (SSE) within the groups. The optimal number of clusters was determined using the Elbow method.

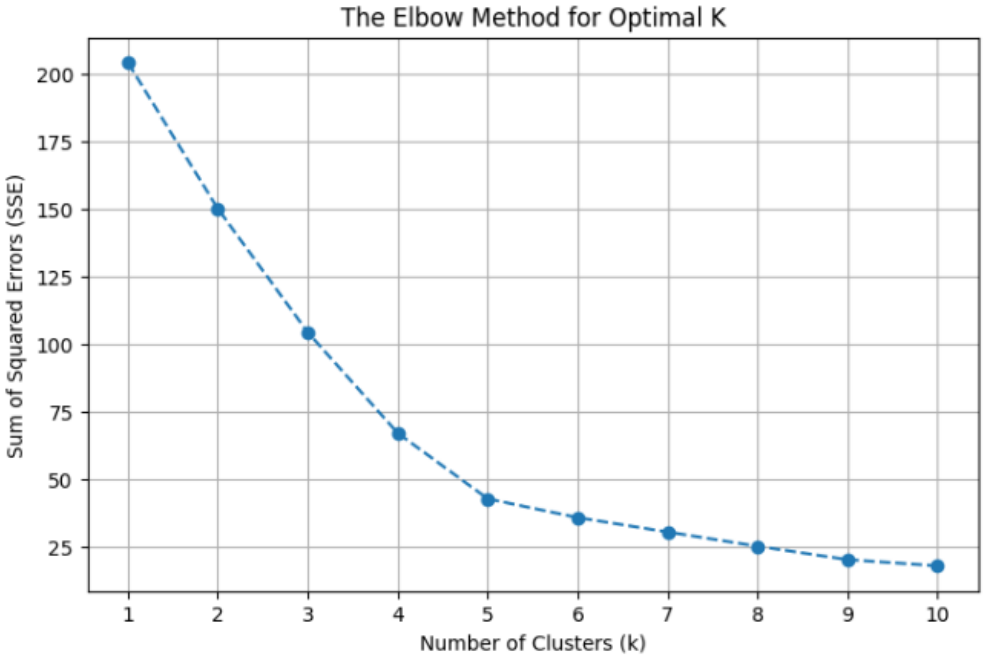

Figure 1 : Elbow metod klasters

Examination of the graph shows that the Elbow forms at K=3, indicating that the separation of three clusters provides an optimal balance between intra-cluster homogeneity and the number of clusters. Therefore, the value of K=3 was chosen for further analysis.

PCA was applied for two main purposes:

a) To reduce the multidimensionality of the four indicators

b) To show how the baseline indicators cluster into new Principal Components (PCs).

The application of the K-means algorithm revealed three distinct groups of 50 countries based on blockchain adoption, innovation, digital infrastructure, and internet access.

	Crypto_Adoption_Score	Innovation_Index	\
Global Leaders (K0)	0.217	0.479	
Emerging Integrators (K1)	0.043	0.711	
New Entrants (K2)	0.128	0.845	

	Digital_Infrastructure_Index	Internet %
Global Leaders (K0)	0.770	0.769
Emerging Integrators (K1)	1.000	100.000
New Entrants (K2)	0.914	1.071

Armenia's Classification: Global Leaders (K0)

Figure 2: Mean indicators for each cluster

The figure allows us to characterize each cluster.

The “Global Leaders” cluster shows the highest average values for all four indicators, especially in terms of Crypto_Adoption_Score and Innovation_Index. They represent the most advanced countries in the implementation of blockchain and digital technologies.

The “Emerging Integrators” cluster occupies an average position, having a fairly high Internet access

indicator, but they are inferior to the leaders in terms of Crypto_Adoption_Score and Innovation_Index.

The "New Entrants" cluster is characterized by the lowest values for all four indicators, which indicates that they are at the very initial stage of development.

Table 1:

Classification of Countries by Cluster

Global Leaders	Emerging Integrators	New Entrants
Armenia	Saudi Arabia	Estonia
Azerbaijan	UAE	Latvia
Georgia		Lithuania
Russia		Turkey
Ukraine		Israel
Kazakhstan		Qatar
Uzbekistan		Germany
Kyrgyzstan		France
Tajikistan		Italy
Moldova		Spain
Belarus		Poland
Iran		Netherlands
India		Sweden
Indonesia		Norway
Philippines		Finland
Vietnam		Switzerland
Brazil		China
Mexico		Japan
Argentina		South Korea
Nigeria		Singapore
South Africa		Malaysia
Egypt		Thailand
Kenya		USA
		Canada
		Chile

1. Global Leaders. This cluster is characterized by the highest average values in all four indicators, especially in the Crypto Adoption Score and Innovation Index. The group includes Emerging Markets (e.g. India, Nigeria, Brazil), where high crypto investment is driven not by institutional factors but by financial instability and the need for money transfers (P2P motives).

2. Emerging Integrators. This cluster (Saudi Arabia, UAE) has excellent digital infrastructure indicators (Digital Infrastructure Index), but a moderate average level of crypto investment. It represents countries with high resources and government support, which are ready for integration, but currently exhibit a cautious, centralized management model.

3. New Entrants. The cluster consists of highly developed countries in North America and Western Europe. It has the lowest average Crypto Adoption Score and a medium Innovation Index (compared to K0), indicating the dominance of regulatory frameworks and institutional caution before mass adoption. This group is in the initial, foundational stage of technological integration.

Principal Component Analysis (PCA) was used to reduce the dimensionality of the original four indicators and identify the independent factors underlying them.

Explained VarianceThe first Principal Component (PC1) explains 40.81% of the total variance, and the second Principal Component (PC2) explains an additional 28.80%. Thus, the first two components together explain more than 69.61% of the total variance of the data set, which allows further analysis to focus only on PC1 and PC2 without significant loss of information.

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--- 3. Principal Component Analysis (PCA) ---
Explained Variance Ratio:
PC1: 0.4065 (Cumulative: 0.4065)
PC2: 0.2866 (Cumulative: 0.6930)
PC3: 0.2256 (Cumulative: 0.9187)
PC4: 0.0813 (Cumulative: 1.0000)
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Figure 3: Principal component analysis

The study of PC Loadings allows us to make sense of and characterize the essence of the newly obtained components.

"Basic Digital Infrastructure and Innovation Readiness". Axis PC1 exhibits the highest negative loadings on the "Digital Infrastructure Index" (-0.7107) and "Innovation Index" (-0.4825) indicators. Although the loadings are negative, their magnitude indicates a strong relationship. This component reflects the level of Basic Digital Capabilities and Innovation Maturity of a country. That is, countries with a high Digital Infrastructure Index and Innovation Index will have a low (negative) score on PC1, and vice versa.

"Crypto Investment Intensity". Axis PC2 has the highest positive loadings on the "Crypto Adoption Score" (0.6952) and "Innovation Index" (0.6696). PC2 reflects the intensity of actual adoption of blockchain and digital assets, especially in countries where innovation is directly related to the decentralization of financial services. This axis divides countries based on the dynamism of their crypto market. This phase of the analysis confirms that the digital readiness of countries can be effectively measured by two main independent dimensions: one related to the basic infrastructure and innovation capacity (PC1), and the other to the intensity of technological (crypto) investment itself (PC2). Thus, Armenia's current position can be characterized as an innovation-potential but market-cautious economy that has not yet realized its full potential in the field of blockchain integration.

Optimization model construction - based on the results of cluster analysis, an optimization model was developed, the purpose of which is to maximize the strategic influence in the blockchain sector of Armenia, in conditions of limited resources, that is, it is necessary to find out how and where (in which clusters) the maximum strategic influence can be achieved in the global blockchain through joint investments and political steps, taking into account resource constraints (budgetary, energy, human capital, legislative risk, etc.).

In the model, investment directions are divided into five main sub-sectors: Mining, Node Hosting, Startups, R&D and Exchanges.

• The main parameters and constraints of the model are:

• Total investment ≤10 million USD[11][12[13],

• Total energy consumption ≤4 million USD[14][15][16],

• Jobs created ≥ 80[17][18],

• Regulatory risk ≤0.4 (weighted average)[19][20],

• Talent readiness ≥ 0.6[21],

• Minimum R&D funding ≥ 1 million USD.

The formulation of the objective function is to maximize Armenia's strategic impact, taking into account the equivalent efficiency of one million USD investment in each sector.

Optimization calculations have shown that the maximum result is achieved by focusing about 80% of investments on startup development and with minimal mandatory allocations to the R&D sector.

As a result, the value of the calculated objective function was 68.5 points, which represents the maximum level of strategic impact of Armenia's blockchain investment portfolio.

The searchable results in the model are: the amount of annual investments directed by Armenia to the i-th cluster, i=1,2,…,k (k is the number of clusters), the total amount allocated (million USD).

The optimality criterion of the problem is to maximize Armenia's strategic influence and we will calculate it using the following formula:

$$F_{max} = \sum_{i=1}^{k} c_i x_i$$

Where c_j is the strategic impact for every $1 million invested in cluster I. The mathematical model of the problem is:

1. Budget constraint: $\sum_{i=1}^{k} x_i \leq B$` total investments cannot exceed the budget, meaning that the Republic of Armenia has limited financial resources for investments.

2. Human resource costs (hours / talent availability): $\sum_{i=1}^{k} j_i x_i \geq J_{min}$: the minimum number of jobs that must be created to ensure employment.

3. Energy constraint: $\sum_{i=1}^{k} e_i x_i \leq E_{max}$: The total energy consumption cannot exceed the constraint, i.e. the energy capabilities of the IT infrastructure are limited.

4. Legislative risk: $\sum_{i=1}^{k} r_i x_i \leq R_{max} \cdot \sum_{i=1}^{k} x_i$, a small market investment confidence indicator.

5. Weighted average talent: $\sum_{i=1}^{k} t_i x_i \geq T_{min} \cdot \sum_{i=1}^{k} x_i$, will ensure the educational and technological readiness of the Republic of Armenia.

6. The condition for non-negative filling of variables is: $x_i \geq 0$, since it is a monetary quantity.

The initial data of the problem is presented in the table (Table 3).

Table 2:

Numerical model of the problem

Cluster	Strategic impact per $1M invested (economic/strategic units per 1 million USD) (score per $1M)	Energy intensity — MW required per $1M invested (MW / $1M)	Jobs created per $1M invested (direct + indirect) (jobs / $1M)	Regulatory risk score (0 = no risk, 1 = very high risk)	Talent readiness score (0 = low, 1 = high)
Mining[22]	7.5	0.33	12	0.6	0.5
Node Hosting (Data centers / validator nodes / hosting)[23]	6	0.043	8	0.2	0.7
Startups (DeFi, apps, fintech startups)[24, pp. 5–9][25, Table 2.4][26, p. 12]	7	0.06	10	0.3	0.65
R&D (Universities, training, grants, talent development)[27, pp. 17–23][28]	5	0.02	18	0.1	0.8
Exchanges (exchanges, crypto services, custodial services)[39, pp. 32–34] [30]31, Table 3.2]	6.2	0.05	6	0.4	0.6

As a result of solving the problem, we found the following optimal distribution:

• Startups (DeFi, FinTech, applications) - about 80% of investments,

• R&D (research and education) - minimum mandatory investment - 10%,

• The remaining directions - Mining, Node Hosting and Exchanges - were not included in the optimal plan due to high energy and regulatory risks.

As a result of this distribution, the maximum value of the objective function was 68.5 points, which represents the peak of the strategic impact of the Armenian blockchain investment portfolio.

A more detailed analysis also showed the sensitivity to resource constraints.

• An increase in budgetary resources by one million dollars increases the strategic impact by about 7 points,

• An increase in human capital by one point increases the value of the objective function by an average of 3.3 points,

• Reducing R&D investments, on the contrary, has almost no effect on efficiency, but has an important structural significance in terms of maintaining the educational base.

The data obtained indicate that the most scarce resource in Armenia's blockchain strategy is financial resources, and the second important factor is the limited potential of human capital.

Conclusions: In summary, this study aimed to quantitatively assess Armenia's strategic position in the global blockchain ecosystem based on a combination of digital infrastructure, innovation potential, and cryptocurrency adoption. Using K-means cluster analysis and Principal Component Analysis (PCA), it was possible to map the distribution of countries within the global digital economy and identify three main clusters: "Global Leaders," "Emerging Integrators," and "New Entrants."

Armenia was classified as an "Emerging Integrator" cluster, demonstrating a high digital infrastructure (0.8) and an above-average innovation index (0.534), but a relatively low level of crypto adoption (0.019). This combination indicates that the country's technological potential is not fully translated into market activity.

The application of the optimization model showed that in conditions of limited financial, energy and human resources, the maximum strategic impact is achieved by focusing investments on the development of startups (about 80%), and with minimal mandatory allocations to the R&D sector (about 10%). The lack of human capital and budgetary constraints have been formed as the main limiting factors of Armenia's blockchain strategy. As a result, the value of the calculated objective function was 68.5 points, which represents the maximum strategic impact of Armenia under conditions of optimal resource allocation.

Speaking about the main results, we will say that

• Armenia is at an average level of blockchain integration, having a stable technological base, but weak market penetration,

• Cluster analysis showed that innovation potential and digital infrastructure are the main advantages of Armenia.

• The optimization model revealed that the most effective investment direction is the development of startups, while the issues of the regulatory environment and human resources are priority areas for improvement.

• Budgetary constraints and the lack of human capital are the most influential constraints on Armenia's blockchain strategy.

The research combines cluster analysis and optimization modeling, which allows not only to quantitatively classify Armenia on the global blockchain map, but also to formulate an optimal resource allocation strategy. This is a new giatic approach in the analysis

of Armenia's digital economy, which fills the existing theoretical and applied gaps. The obtained justifications can serve as a political and practical basis for strengthening Armenia's position in the global digital ecosystem and developing a national blockchain strategy.

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