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Digital servitization of the Russian agro-industrial complex: functional roles of regions based on multidimensional scaling

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ABSTRACT
Relevance. While all Russian regions are potentially capable of occupying functional niches in the national agro-industrial ecosystem, prior studies have focused mostly on agricultural regions and have assessed digitalization potential using a limited set of indicators.
Research Objective. The study aims to identify and analyze the functional roles of Russian regions within the ecosystem of agricultural servitization.
Data and Methods. Using 2023 data from Rosstat, the study applies hierarchical cluster analysis to group regions with similar digital profiles and multidimensional scaling to visualize their roles in the digital agricultural servitization ecosystem.
Results. The analysis identified three distinct types of Russian regions in the emerging digital servitization system: regions that generate digital solutions, regions that serve as pilot sites for testing these solutions, and regions that primarily receive them.
Conclusions. By moving beyond purely regional comparisons, multidimensional scaling highlights the functional roles of regions in the digital servitization of the agro-industrial complex. This approach shifts the focus from regions "digital readiness" to their roles in the national ecosystem, thereby advancing research on digital servitization and offering a basis for more differentiated state policies on agro-industrial digitalization.

KEYWORDS
digital servitization, agro-industrial complex, ecosystem approach, regional economy, multi-dimensional scaling

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Цифровая сервитизация АПК России: функциональные роли регионов на основе многомерного шкалирования

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АННОТАЦИЯ
Актуальность. Инновационное развитие АПК напрямую зависит от интеграции в сельскохозяйственную практику технологий цифровой агрономии, качества и эффективности сервисного сопровождения аграрной техники. Несмотря на то, что все российские регионы потенциально способны занять функциональные ниши в национальной агропромышленной экосистеме, вопросы цифровизации АПК рассматриваются исследователями преимущественно на уровне аграрных регионов. При этом оценка потенциала цифровизации их АПК сводится к расчету некоторого набора индексов.

КЛЮЧЕВЫЕ СЛОВА
цифровая сервитизация, агропромышленный комплекс, экосистемный подход, региональная экономика, многомерное шкалирование

Цель и объект исследования. Целью данного исследования является выявление и анализ потенциальных функциональных ролей российских регионов в экосистеме цифровой сервитизации АПК. Объектом исследования выступают российские регионы.
Данные и методы. Для группировки регионов по схожим цифровым профилям используется иерархический кластерный анализ. Для визуализации позиций регионов по возможной роли в экосистеме цифровой сервитизации АПК применяется метод многомерного шкалирования. Источником информации послужили данные Росстата за 2023 год.
Результаты. Идентифицированы три статистически значимых и качественно различных типа российских регионов, соответствующих различным функциональным ролям в формирующейся экосистеме цифровой сервитизации АПК: регионы-генераторы цифровых решений для АПК; регионы-пилотные площадки для апробации цифровых сервисных решений в АПК; регионы-реципиенты цифровых сервисов для АПК.
Выводы. Использование метода многомерного шкалирования в исследовании цифровой сервитизации АПК позволяет перейти от констатации региональных различий к функциональному позиционированию регионов, что формирует основу для адресной государственной политики. Новизна исследования заключается в методологическом расширении проблематики цифровой сервитизации, переходя от анализа факторов «цифровой готовности» отдельных регионов к определению их функциональных ролей в национальной агропромышленной экосистеме. Результаты исследования могут быть использованы для выработки дифференцированной государственной политики в отношении реализации стратегии цифровизации АПК.

БЛАГОДАРНОСТИ
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俄罗斯农业工业综合体的数字化服务化：基于多维尺度的区域功能角色划分

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摘要
现实性：农业工业综合体的创新发展直接取决于数字农业技术在农业实践中的融合程度，以及农业技术设备服务保障的质量与效率。尽管俄罗斯所有地区在理论上都有能力在国家农工生态系统中占据一定的功能生态位，但研究者对农业工业综合体数字化问题的探讨主要聚焦于农业产区层面。在此类研究中，对农业产区数字化潜力的评估通常归结为对若干指标指数的计算。
研究目的与对象：本研究的目的是识别并分析俄罗斯各地区在农业工业综合体数字化服务化生态系统中的潜在功能角色。研究对象为俄罗斯各地区。
数据与方法：为按相似数字特征对地区进行分组，采用了层次聚类分析。为直观展示各地区在农业工业综合体数字化服务化生态系统中可能扮演的角色，运用了多维尺度分析法。信息来源为俄罗斯联邦国家统计局2023年度的数据。
研究结果：研究识别出三种具有统计显著性和本质差异的俄罗斯地区类型，它们与正在形成的农业工业综合体数字化服务化生态系统中的不同功能角色相对应：农业工业综合体数字化解决方案的“生成地区”；农业工业综合体数字化服务解决方案的“试验平台地区”；农业工业综合体数字化服务的“接受地区”。
结论：在多维尺度分析方法应用于农业工业综合体数字化服务化研究，使得研究视角能够从描述地区差异转向界定地区的功能定位，从而为制定有针对性的国家政策奠定基础。本研究的创新之处在于从方法论层面拓展了数字化服务化的研究范畴，将关注点从分析个别地区的“数字化准备”因素，转向确定它们在国家农工生态系统中的功能角色。研究结果可用于制定差异化的国家政策，以实施农业工业综合体数字化战略。

关键词
数字化服务化、农业工业综合体、生态系统方法、区域经济、多维尺度分析

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Introduction

A key challenge in the development of the Russian agro-industrial complex (AIC) is digital servitization, as its efficiency directly depends on the quality, reliability, and timeliness of preventive maintenance services (Chernova, Dolgova, 2025). As noted by Abiri et al. (2023), digital agriculture, particularly when based on advanced agricultural machinery, enhances the efficiency of agribusiness by providing accurate, real-time data on crops, soil, and other critical production factors.

Russian regions demonstrate considerable disparities in terms of development of digital and service infrastructure, workforce skills, IT sector maturity, and the readiness of agricultural enterprises and farms to adopt digital technologies. Contemporary literature on digital servitization in the AIC mainly focuses on the internal characteristics of agro-industrial firms, especially their digital maturity, while regional factors shaping the environment for digital innovation often receive limited attention. It is, however, regional conditions that play a decisive role in digital servitization. In regions with small farms and limited service infrastructure, demand for advanced agricultural machinery remains low, as farmers rely on traditional solutions (García-Quevedo et al., 2017; Mantovani et al., 2019).

The pronounced heterogeneity of Russian regions determines the need for appropriate analytical tools, as rating- and index-based approaches fail to reveal hidden structural relationships among multiple digitalization factors. This methodological limitation constrains understanding of the functional roles of regions within the national agro-industrial ecosystem and creates the need for more advanced methods suitable for analyzing multidimensional data. To address this gap, this article aims to analyze and identify the potential functional roles of Russian regions in the ecosystem of the digital servitization of the AIC. To this end, the article pursues the following goals, which also determine its structure:

— to review research literature on the factors of digital transformation in the agro-industrial complex, focusing on regional differences;

— to cluster regions using multidimensional scaling and identify similar profiles in their potential for digital servitization;

— to identify typical functional roles of regions and provide recommendations for differentiated policy-making on digital servitization.

Theoretical Basis

Scholars studying innovative economic development have paid increasing attention to digital servitization, recognizing it as an important component of this process. Digital servitization is understood as a shift from traditional business models toward product–service systems, in which manufacturers move beyond selling products to providing integrated solutions (Lerch et al., 2026). In this study, digital servitization of the AIC is defined as the provision of integrated digital solutions for agribusiness encompassing the entire life cycle of agricultural machinery (Chernova, 2025). This way the focus in value creation shifts from the machinery itself to the data generated during its operation and related analytical services (Coreynen, Pier van Gosliga, 2023).

As our review has shown, the academic literature on digital servitization of the AIC can be grouped into three main research streams.

The first group of publications examines the effects of digital servitization of the AIC at the micro, meso, and macro levels. Studies range from analyses of the benefits of digitalization for individual value-chain actors (Reitano, 2025) and rural innovation (Leushkina, 2022) to assessments of contributions to the Sustainable Development Goals through the optimization of logistics (Sridhar et al., 2023) and reductions in the carbon footprint of agri-food markets (Camel et al., 2025). Digital technologies are widely recognized as drivers of intensive agricultural growth, contributing to improved quality of life in rural regions (Kivarina, Yurina, 2025) and acting as catalysts for greater overall efficiency and sustainable development of the AIC (Denisova, Proskura, 2023).

Studies in the second group assess the effectiveness of specific digital technologies for the innovative development of the AIC. For example, Fakhraddine et al. (2025) review the current evidence on the effectiveness of digital technologies in Morocco's agro-industrial complex, comparing their implementation with best practices from leading countries. Thann et al. (2025) analyze the impact of digital innovations in the AIC on the development of ASEAN countries. A special focus is made on artificial intelligence, whose potential expands alongside the exponential growth of data on agricultural operations (Benfenati et al., 2025). AI enhances the efficiency of agricultural machinery by supporting predictive analytics for failure prevention (Yalunina et al., 2024).

The third stream of research, which is most important for understanding the spatial aspects of digital development in the AIC, deals with the factors and conditions of digital transformation. Among the constraining factors, Smania et al. (2024) highlight coordination problems in value chains that generate paradoxical tensions in emerging digital servitization ecosystems. In rural areas traditionally oriented toward low-technology production, insufficient educational attainment limits the effective adoption of modern digital technologies, slowing the development of digital servitization processes (Balashova et al., 2025; Lombardi et al., 2022). Trofimets and Azieva (2025) emphasize the critical role of infrastructure constraints in rural areas, noting that limited access to broadband internet service prevents the adoption of modern digital services, while network expansion is costly and often inefficient due to low population density and the remoteness of farms. Zhang et al. (2024) also point out high entry barriers to digital agribusiness, explaining that many small farmers lack the skills needed to adopt new technologies.

Overall, despite differences in perspectives on the AIC's digital servitization, all authors explicitly or implicitly identify three core conditions that determine the scope and depth of this process. These include economic and production capacities, encompassing natural resources, the size of the regional agro-industrial sector, economic contribution, and financial sustainability; technological readiness, that is, a region's ability to adopt and use modern technologies, including digital services; and infrastructure availability, which determines the capacity for data transmission.

However, assessments of the AIC's digital development potential are often limited to evaluating the digital maturity of individual agro-industrial companies through various sets of parameters. These parameters allow companies to compare themselves with competitors but do not reflect the regional context (Cristobal-Fransi et al., 2020; Kivarina, Yurina, 2025; Sandu et al., 2025). Only a few researchers specifically focus on territorial factors, providing empirical evidence of how the regional context shapes the trajectories of digital transformation in the AIC. For example, Li et al. (2025) use a group regression model that divides regions spatially and categorizes them as pilot or non-pilot to show how regional conditions affect the integration of digital technologies in agro-industrial systems. Sun and Chen (2025) argue that disparities in the development of digital infrastructure across regions directly determine variations in the pace and depth of digital transformation in the Chinese AIC. Similarly, Hu et al. (2024) measure total factor productivity to show that digital development in China's AIC varies significantly across regions depending on the type of agricultural production and the overall level of productive forces.

Russian researchers also highlight the contextual specificity of AIC digitalization, which is reflected in its fragmented nature. This fragmentation results from substantial differences in the digital maturity of participants within a unified value chain, which means that isolated business processes are digitalized while no systemic impact is achieved (Fedorov, Peshkova, 2022; Mitrofanova et al., 2023). Some studies also emphasize the importance of interregional cooperation in mitigating the risks of uneven spatial development (Chistyakova et al., 2024; Golovanov et al., 2025).

Although the above-mentioned studies convincingly demonstrate the existence and significance of spatial differences in the development of digital servitization in the AIC, the methodological tools typically used, such as factor models, regression analysis, classification trees, indices, and so on, help identify and rank individual factors but fail to reveal the relationships between them, treating them in isolation. Digital servitization also demands that regional AIC companies should possess specific capabilities, which determine their ability to function within an agro-industrial ecosystem — an integrated network of AIC participants collaborating through digital technologies to reach common development objectives (Ushachev et al., 2025). A region can participate in an agro-industrial ecosystem only if it has certain competencies and resources that allow it to perform a specific functional role — specialization within the overall process of creating a product–service offering. To address this gap, this study applies multidimensional scaling, which, unlike factor analysis, allows variables to be grouped and regions to be visualized in a multidimensional feature space based on their similarities or differences across multiple criteria. This approach enables us to gain a better understanding of regions' functional roles in the ecosystem of digital servitization.

Methods and Data

This study covers all Russian regions and uses 2023 data from the Federal State Statistics Service (Rosstat). It adopts an ecosystem based understanding of digital servitization, according to which each region, regardless of its industrial specialization, has a distinct profile shaped by a combination of competencies, resources, and institutional conditions. These characteristics allow regions to occupy specific functional niches within the agro-industrial ecosystem, such as producers of agricultural machinery, developers of digital solutions for the AIC, or consumers of agricultural equipment. Since regions perform such diverse roles, limiting the analysis to predominantly agricultural areas would overlook important aspects of digital servitization in the AIC.

Regions with missing values for key indicators were excluded from the analysis. These were the following: the Nenets, Yamalo-Nenets, and Chukotka autonomous districts, Leningrad, Moscow, and Ulyanovsk regions, the Karachay Cherkess Republic, Ingushetia, the city of St Petersburg, the Donetsk and Luhansk People's Republics, Zaporizhzhia and Kherson regions. As a result, the final analytical sample comprised 76 regions.

The proposed methodology comprises the following stages:

— develop a system of indicators that characterizes each region's potential for participation in the digitalization of the AIC;

— collect and prepare data to ensure that the analytical tools applied in subsequent stages can be used accurately;

— perform cluster analysis to group regions in the sample according to similar profiles;

— apply multidimensional scaling to visualize the positions of regions depending on their potential role in the digital servitization ecosystem of the AIC.

For a comprehensive assessment, we selected eight indicators and grouped them into three sets to capture the key conditions for digital servitization of the AIC (Table 1).

The relationships between these factors can be summarized as follows. Agricultural potential determines whether a region is suitable for digital servitization of the AIC. The condition of the AIC's material and technical base indicates whether there is sufficient technical infrastructure to support digital servitization. Finally, the level of digital servitization in the AIC reflects the regional environment for implementing digital servitization business models.

Table 1

Set of indicators for assessing regional profiles

Set of indicators	Indicators
Agricultural potential	Agricultural production index Share of gross value added from agriculture, forestry, hunting, fishing, and aquaculture in the regional economy Share of unprofitable organizations in agriculture, forestry, hunting, fishing, and aquaculture Share of agricultural land in the total land area of the region
AIC's material and technical base	Degree of depreciation of fixed assets in agriculture, forestry, hunting, fishing, and aquaculture Energy supply of agricultural organizations per 100 hectares of sown area
Digital infrastructure development	Share of organizations reporting a maximum data transmission speed of 256 Kbit/s or higher (broadband Internet access) Number of connected mobile devices per 1,000 population

Source: compiled by the authors.

The indicators were chosen because they capture the key conditions for digital servitization and are regularly published by Rosstat, ensuring comparability across regions and ongoing monitoring.

In the "Agricultural potential" group, the agricultural production index was chosen because it measures the level of development of the agricultural sector. The share of the AIC in gross value added was included because it indicates whether the sector is a priority for the regional economy, and therefore whether innovations in it would have strategic significance. The share of unprofitable enterprises was selected because it reflects the financial capacity of regional agribusiness to implement such innovations. The proportion of agricultural land was chosen because it determines the potential scale of machinery use and the need to improve operational efficiency.

In the "AIC's material and technical base" group, the degree of depreciation of AIC fixed assets was included because it shows how suitable existing machinery is for digital services and highlights the need to transition to modern equipment. Energy supply in agricultural organizations was selected because it complements the data on machinery wear, reflecting the capacity of the existing technical fleet.

In the "Digital infrastructure development" group, the proportion of organizations with broadband Internet access was included because it measures the availability of basic digital infrastructure for businesses. The number of connected mobile devices per 1,000 people was chosen because it reflects the development of cellular networks and the use of IoT devices, which are essential for most digital servitization services.

To eliminate the effects of heterogeneous measurement units and indicator scales, all raw data were normalized to a range from –1 to 1 using formula:

$$x' = 2 \cdot \frac{x - \min(x)}{\max(x) - \min(x)} - 1.$$

The chosen method makes the data relatively easy to interpret: a value of zero represents the indicator's average, while positive or negative values show above- or below-average performance. MDS enables us to preserve the distances between variables and the direction of differences, making patterns easier to understand. Symmetric normalization ensures that all features are represented more evenly in the lower-dimensional space.

To group regions with similar profiles, we applied hierarchical cluster analysis. Euclidean distance was used as the measure of proximity, and Ward's method was employed to merge clusters, minimizing within-group variance. To determine the optimal number of clusters, we calculated silhouette coefficients for solutions ranging from 2 to 10 clusters. A three-cluster solution yielded the highest silhouette coefficient (0.216), which means that these clusters offer the best structural separation and internal homogeneity. Since some indicators (such as energy supply and gross value added) are not normally distributed, Spearman correlations were used to assess multicollinearity among factors before clustering.

We used multidimensional scaling (MDS) to visualize regional differences in two dimensions. The quality of the resulting 2D plot was assessed using Kruskal's Stress coefficient, which was 0.197. According to commonly accepted interpretation scales, a stress value below 0.2 indicates that the MDS visualization adequately reflects the original differences among the given indicators, accounting for natural errors due to the large number of variables analyzed.

Results

The multicollinearity analysis of the factors revealed two pairs of indicators with notable dependencies: 1) A positive correlation (0.603) between the share of AIC gross value added and the share of agricultural land, which makes sense, as a region's agricultural potential largely depends on the size of its land resources; 2) A negative correlation between the share of agricultural land and energy supply (–0.616), reflecting the lack of infrastructure in agricultural regions. We also observed a moderate correlation (0.466) between the share of AIC gross value added and the agricultural production index, which can be explained by the fact that higher productivity in the agricultural sector is often associated with a larger contribution to the regional economy. For the other indicators, the detected correlation levels were not high. Overall, the analysis showed that the observed moderate and average correlations reflect meaningful but not identical relationships between different aspects of AIC digital servitization and do not make the selected factors redundant. Therefore, it was decided to retain all selected variables for further analysis.

All calculations were performed using Orange Data Mining software. We used hierarchical cluster analysis to group the Russian regions under study into three main clusters.

The results of the clustering are presented in Figure 1 and Table 2.

The first cluster includes industrial regions characterized by a high level of digitalization but very low agricultural potential.

The second cluster is the largest and includes regions where agriculture is significant for the regional economy but not dominant. These regions show average values for most indicators, the lowest wear of fixed assets in the AIC, and the highest share of enterprises with broadband internet access.

The third cluster mainly consists of regions with agricultural or agro-industrial specialization. These regions have the highest agricultural potential, but at the same time, they show low digital infrastructure development and the poorest state of the AIC material and technical base.

A two-dimensional map of Russian regions, based on conditions for implementing digital servitization using MDS, is presented in Figure 2 below. Colors correspond to cluster numbers, and the size of the points represents the share of agricultural land. Lines connect the regions that are most similar to each other.

The data shown in Figure 2 can be interpreted as follows. The X-axis (MDS-X) clearly reflects the division of regions according to the sectoral specialization of their economies: highly urban-

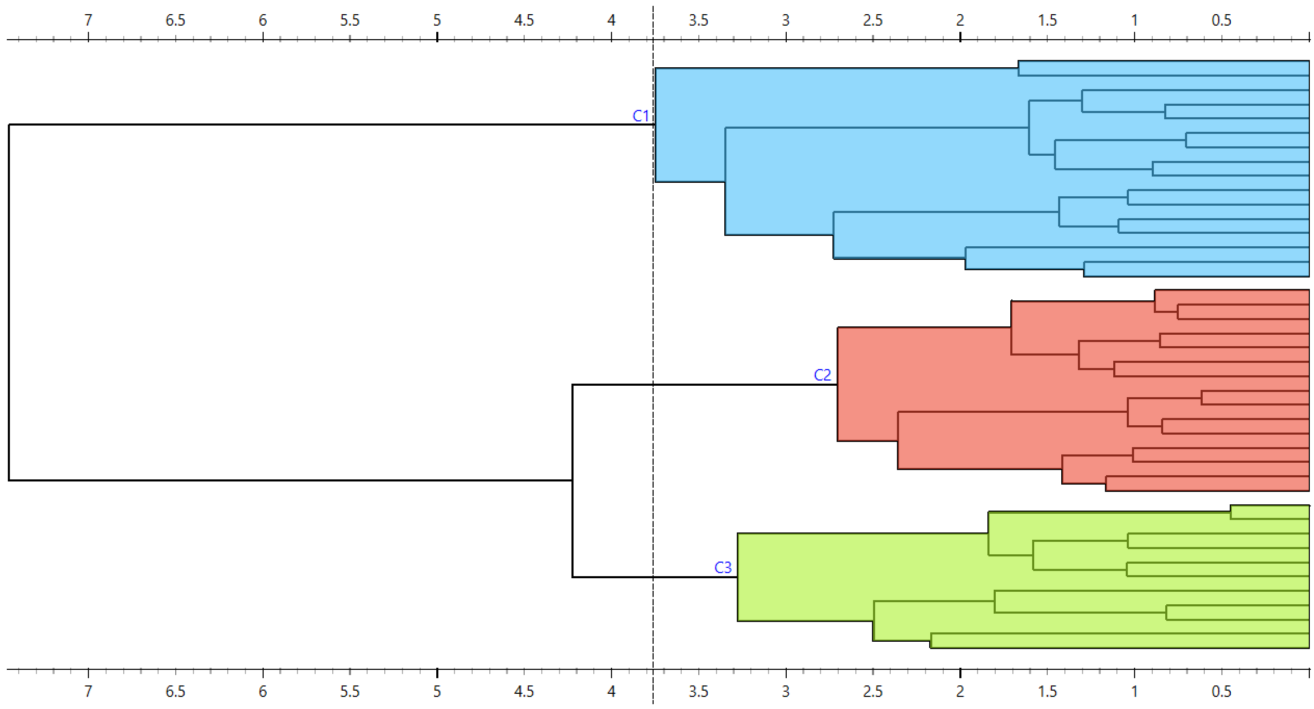

Figure 1. *Cluster analysis of conditions for digital servitization in Russian regions*
Source: calculated by the authors.

Table 2

Clustering of regions by their readiness for AIC digital servitization

Cluster	Regions	Cluster description
1	Amur Region, Arkhangelsk Region, Vologda Region, City of Moscow, City of Sevastopol, Zabaykalsky Krai, Irkutsk Region, Kemerovo Region, Kostroma Region, Krasnoyarsk Krai, Magadan Region, Murmansk Region, Novgorod Region, Perm Krai, Primorsky Krai, Pskov Region, Altai Republic, Republic of Buryatia, Republic of Karelia, Komi Republic, Republic of Sakha (Yakutia), Republic of Tyva, Sakhalin Region, Sverdlovsk Region, Smolensk Region, Tomsk Region, Tyumen Region, Khabarovsk Krai, Khanty-Mansi Autonomous District — Yugra	Regions with a high level of digital infrastructure but low agricultural potential
2	Vladimir Region, Ivanovo Region, Kaluga Region, Ryazan Region, Tver Region, Tula Region, Yaroslavl Region, Kaliningrad Region, Republic of Adygea, Republic of Crimea, Krasnodar Krai, Astrakhan Region, Chechen Republic, Republic of Bashkortostan, Republic of Mari El, Republic of Tatarstan, Udmurt Republic, Chuvash Republic, Kirov Region, Nizhny Novgorod Region, Samara Region, Kurgan Region, Chelyabinsk Region, Republic of Khakassia, Altai Krai, Novosibirsk Region, Omsk Region	Regions with average values for most indicators, minimal wear of fixed assets, and the highest share of enterprises with broadband internet access
3	Belgorod Region, Bryansk Region, Voronezh Region, Kursk Region, Lipetsk Region, Orel Region, Tambov Region, Republic of Kalmykia, Volgograd Region, Rostov Region, Republic of Dagestan, Kabardino-Balkarian Republic, Republic of North Ossetia — Alania, Stavropol Krai, Republic of Mordovia, Orenburg Region, Penza Region, Saratov Region, Kamchatka Krai, Jewish Autonomous Region	Regions with the highest agricultural potential, but low digital infrastructure development and weak material and technical base of the AIC

Source: compiled by the authors.

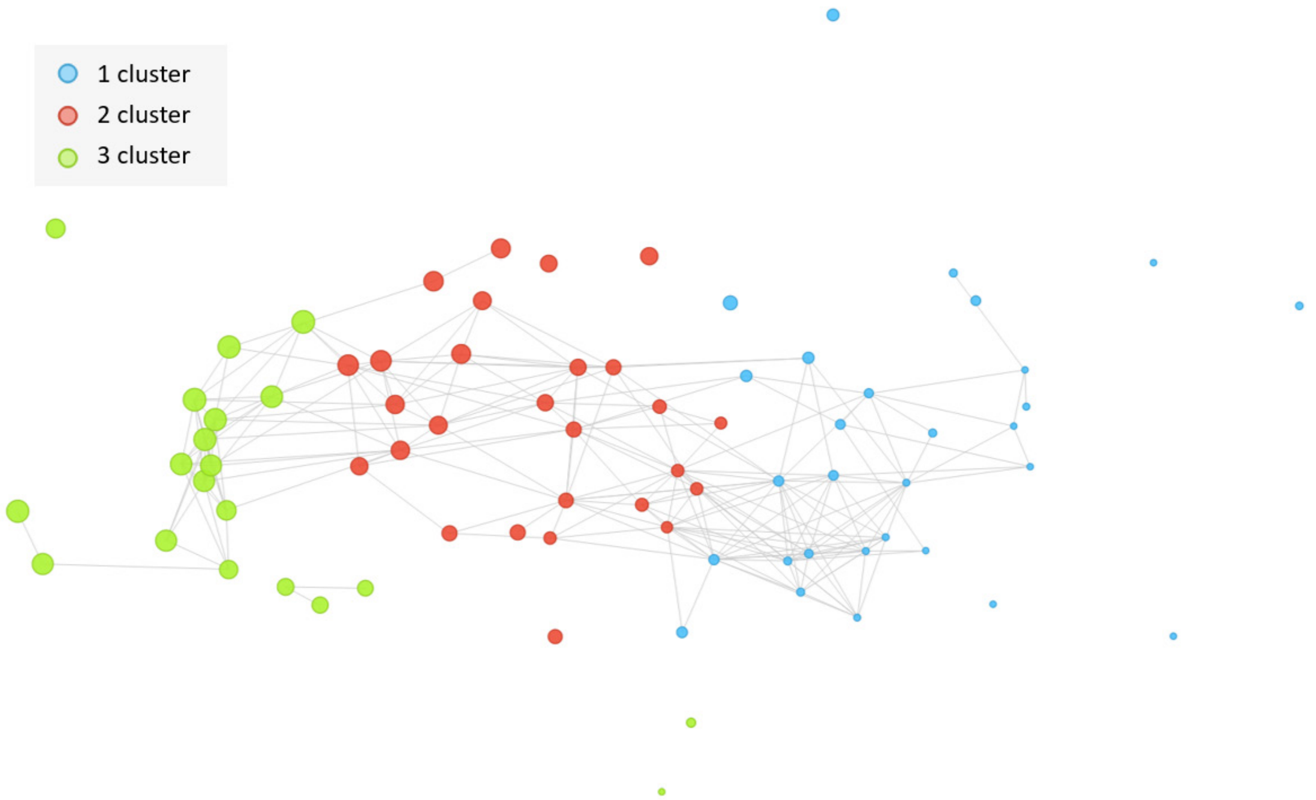

Figure 2. *Two-dimensional MDS-based visualization of Russian regions' potential for digital servitization*
Source: created by the authors.

ized industrial regions with little or no agro-industrial sector appear on the right side of the figure, on the left are regions with agro-industrial specialization. The Y-axis (MDS-Y) reflects different relationships between the development indicators of the AIC and the level of digital infrastructure. Regions in the lower part of the figure have developed digital infrastructure but weak potential for the development of the agricultural sector as well as poor AIC material and technical base. Regions in the upper part have relatively high agricultural development indicators but struggle with the development of their digital infrastructure.

Overall, the figure clearly shows that the size of a region's agricultural sector mainly corresponds to its position on the map. Larger points (regions with more agricultural land) tend to cluster on the left side of the graph. They may appear in the upper part, reflecting challenges in digitalization, or closer to the center, indicating a more balanced development across indicators. At the same time, regions with the highest natural, climatic, and land-resource potential for agriculture tend to have the least developed digital environment and the highest wear of agricultural machinery. This points to a structural mismatch between the sector's economic requirements and its technological capacity for digitalization in the AIC.

To better interpret the data shown in Figure 2, Figures 3–5 show a more detailed graphical representation of regions in each cluster.

As Figure 3 shows, the first cluster consists of regions with similar potential for implementing digital servitization projects in the AIC, alongside a few anomalies — regions that deviate from the cluster's general characteristics. For example, Sevastopol has the lowest number of mobile devices per 1,000 people (15 compared to the cluster average of 2,008) but also the highest energy supply level among the regions in this cluster. The Khanty-Mansi Autonomous District–Yugra has the highest number of unprofitable organizations in the AIC, very low AIC gross value added, and a small area of agricultural land. Moscow shows very high energy supply and the highest number of mobile devices per 1,000 population. Magadan Region has a very low share of agricultural land and the lowest wear of fixed assets, while having one of the highest energy supply levels.

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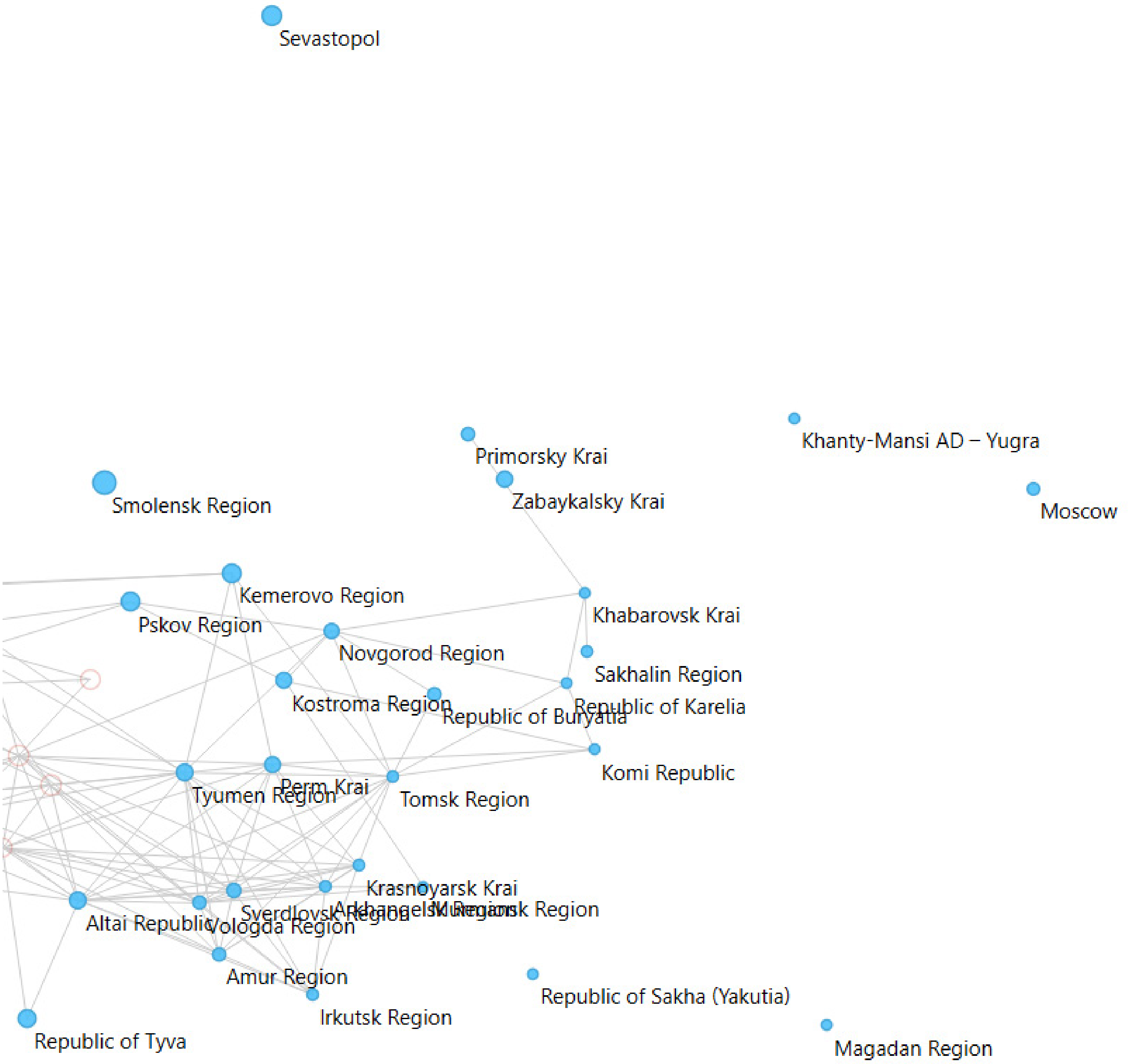

Figure 3. *Two-dimensional visualization of Cluster 1 regions*

Source: created by the authors.

Cluster 2 as shown in Figure 4 is fairly homogeneous and consists of regions with similar characteristics. There are two outliers that stand out within this cluster: Chelyabinsk Region, with a relatively large share of agricultural land but very low energy supply, and Nizhny Novgorod Region, with exceptionally high digital infrastructure development.

The regions in Cluster 3 are also quite heterogeneous, although some agricultural regions in central and southern Russia show similar levels of development. The cluster, however, also includes regions whose characteristics differ more markedly from most others in the group. These include: the Republic of Dagestan, which has the lowest wear of fixed assets in the cluster; the Jewish Autonomous Region, with the highest agricultural production index and a low share of unprofitable organizations, despite the highest wear of fixed assets; Kamchatka Krai, which has the smallest share of agricultural land but the highest share of AIC gross value added; Oryol

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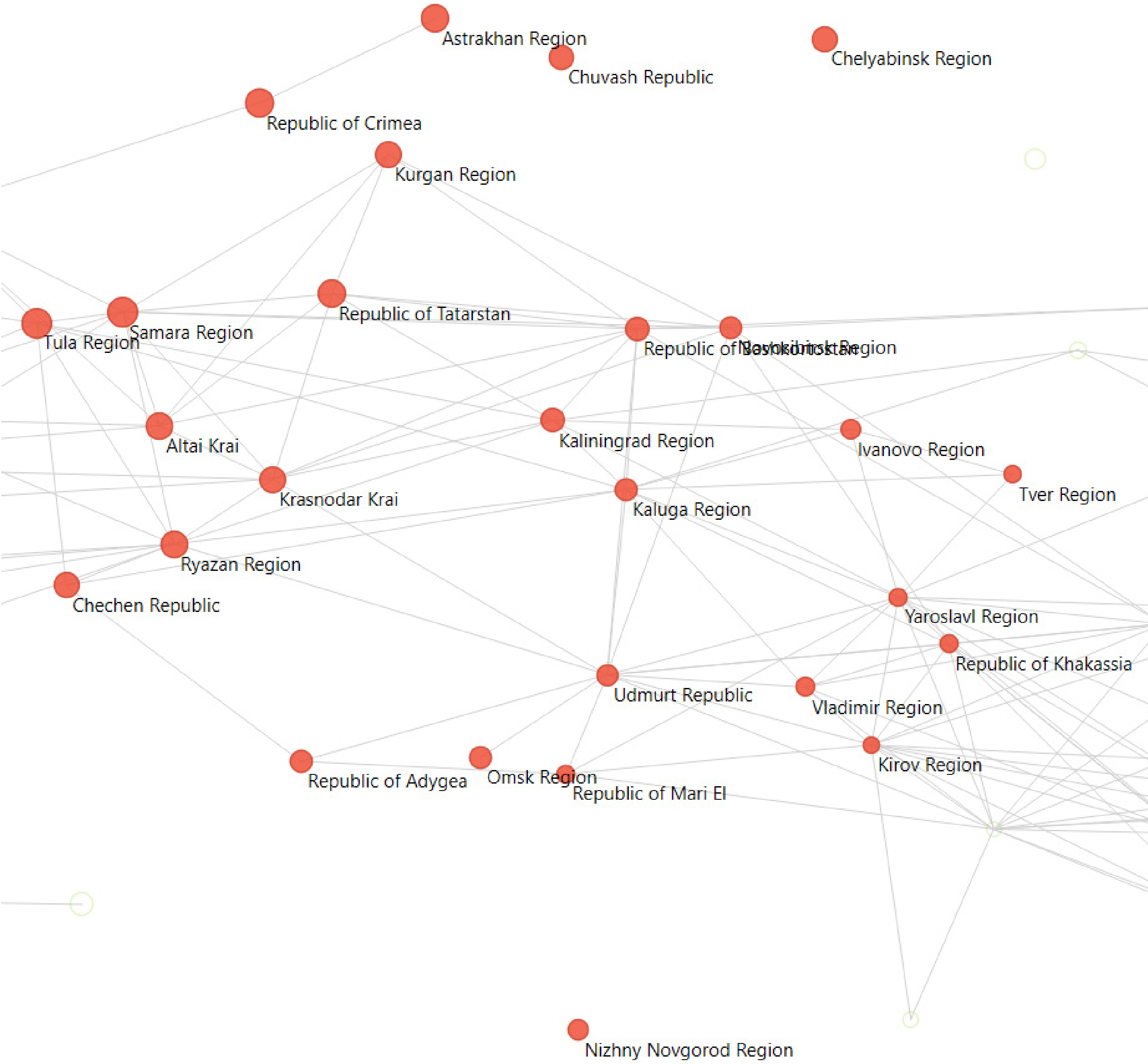

Figure 4. *Two-dimensional visualization of Cluster 2 regions*

Source: created by the authors.

and Tambov regions, with very high values for several indicators, including the share of organizations with broadband internet, gross value added of the AIC, and the agricultural production index.

Importantly, multidimensional scaling reveals variations and anomalies in the first and third clusters that standard clustering fails to detect. This heterogeneity may be related to the socio-economic situation in the regions or to the sectoral structure of their economies.

Discussion

We used multidimensional scaling and cluster analysis to identify three statistically significant and qualitatively distinct types of Russian regions, each playing a different functional role in the emerging digital servitization ecosystem of the AIC.

The first cluster comprises regions with well-developed digital infrastructure but low intrinsic agricultural potential. These regions can act as generators of complex digital solutions for the AIC sector

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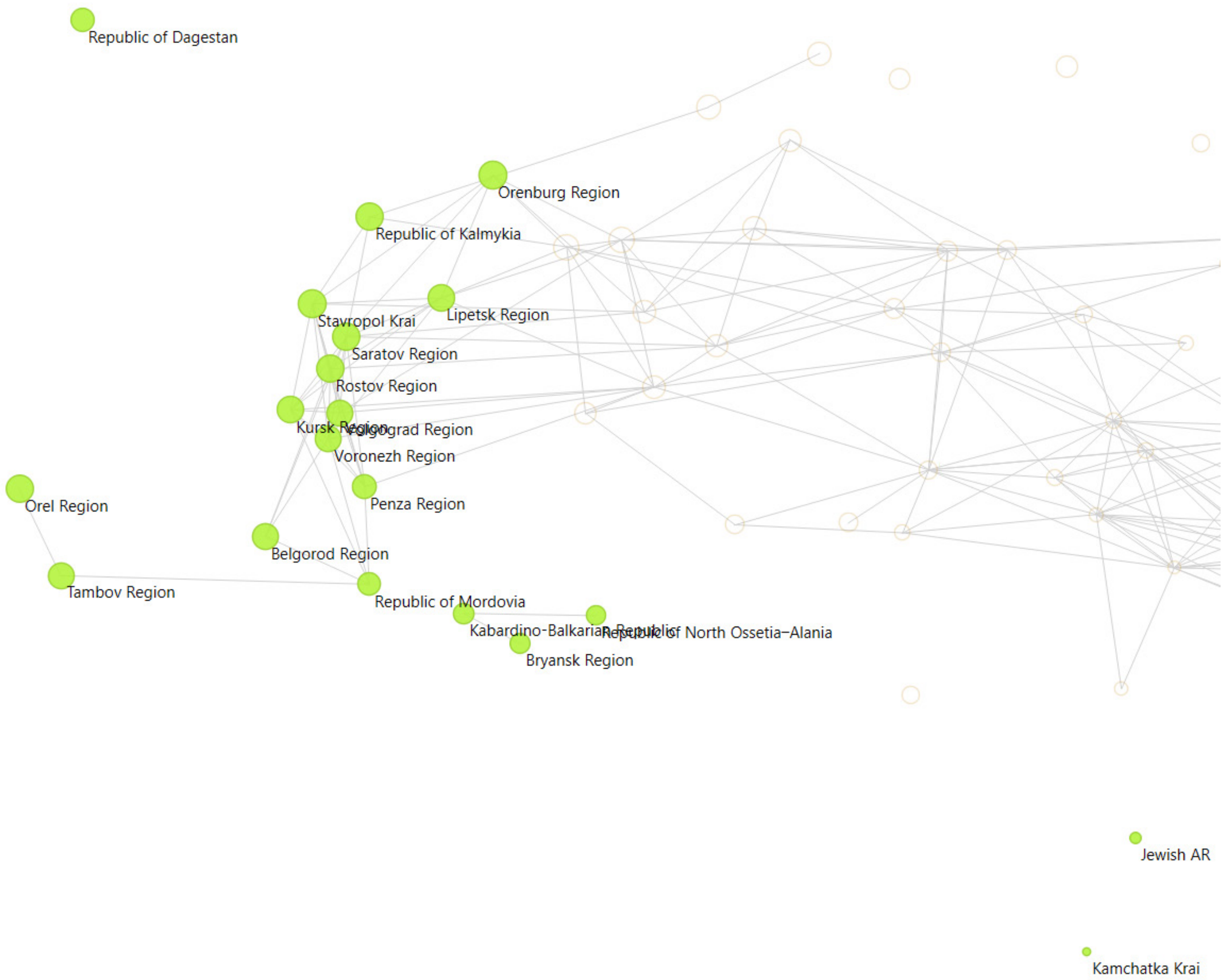

Figure 5. *Two-dimensional visualization of Cluster 3 regions*
Source: created by the authors.

by developing competencies in digital technologies and providing targeted training at the intersection of digital skills and agro-engineering. It is, therefore, necessary to stimulate cooperation between the IT sector and modern agricultural enterprises (agro-holdings) located in other regions.

The second cluster exhibits the most balanced profile as these regions combine solid agricultural infrastructure, adequate digital development, and potential for the growth of agribusiness. Regions in this cluster can serve as pilot sites for testing, refining, and subsequently scaling digital service solutions. Moreover, due to the low wear of fixed assets, faster results from implementation can be achieved here, which is strategically important for accelerated import substitution in sectors critical to national security.

The third cluster includes regions with agricultural specialization and generally low levels of digital infrastructure development. These regions can become recipients of digital services for the AIC. To implement digital servitization in these regions, it is necessary to address infrastructure and technology gaps and improve farmers' digital skills. Given the large share of farmland and aging agricultural machinery, it is critically important that solutions should be low-cost and supported with digital services, including remote monitoring, troubleshooting, and maintenance.

It should also be noted that the first and third clusters have greater heterogeneity, as outlier regions deviate from the general pattern of their clusters. This suggests that, in addition to the fac-

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tors considered in the study, there could be some unobserved factors related to the uniqueness of local economic structures that influence regions' digital readiness for AIC servitization projects.

These findings are broadly consistent with those of other research on the issues and prospects of digital development in the AIC across Russian regions (Baliants, 2024; Oborin, 2023; Pitel, 2023, et al.). Our conclusions largely align with those of Shestakov and Lovchikova (2023), who highlighted spatial heterogeneity and outlier regions in the development of Russia's AIC. By defining the functional roles of regions, the proposed approach allows us to move beyond simple comparisons and provide findings that support more precise government policy.

Conclusion

This study confirms the initial hypothesis that Russian regions show significant spatial heterogeneity, shaping the different roles they can play in the AIC's digital servitization ecosystem. By applying MDS, the study moves beyond simplistic indicators and rankings, creating a multi-dimensional map that highlights the factors differentiating regions, which determines its contribution to the field. Another novel aspect is the methodological shift from analyzing individual measures of regions' "digital readiness" to defining their functional roles in the national AIC ecosystem, thus recognizing that each region presents a unique combination of competencies and constraints.

The study's theoretical significance lies in demonstrating how an ecosystem-based approach enhances our understanding of digital servitization in the AIC, offering a more nuanced view of regions' participation. The study's practical contribution lies in providing findings and tools that policymakers can use to design targeted, region-specific digitalization strategies instead of one-size-fits-all measures.

The main limitation of the study is that the selected indicators do not capture all factors affecting the opportunities and effectiveness of digital servitization. Variation within clusters suggests additional factors, highlighting directions for future research.

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