ANALYSIS OF THE DISTRIBUTION AND USE OF THE TRACTOR AND AGRICULTURAL MACHINERY FLEET IN ROMANIA: REGIONAL AND COUNTY PERSPECTIVES

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ANALIZA DISTRIBUȚIEI ȘI UTILIZĂRII PARCULUI DE TRACTOARE ȘI MAȘINI AGRICOLE ÎN ROMÂNIA: PERSPECTIVE REGIONALE ȘI JUDEȚENE

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ABSTRACT

The study examined the distribution and use of tractors and agricultural machinery in Romania between 2014 and 2024 at national, regional, and county levels. Its objective was to identify territorial disparities in technical endowment and assess mechanization in relation to agricultural economic performance. Using standardized statistical data from the National Institute of Statistics, indicators such as technical endowment, mechanization level, economic efficiency, and composite mechanization indices were calculated. Results showed strong contrasts between the well-equipped western regions and the less mechanized eastern and southern areas. Projections to 2035 highlight the role of investment in reducing regional gaps and supporting agricultural modernization and competitiveness.

REZUMAT

Studiul a analizat distribuția și utilizarea parcului de tractoare și mașini agricole din România în perioada 2014–2024, la nivel național, regional și județean. Obiectivul a fost identificarea disparităților teritoriale în dotarea tehnică și evaluarea mecanizării în raport cu performanța economică agricolă. Pe baza datelor INS au fost calculați indicatori privind dotarea tehnică, gradul de mecanizare, eficiența economică și indici compoziți. Rezultatele arată contraste majore între regiunile vestice, bine echipate, și cele estice și sudice, slab mecanizate. Proiecțiile pentru 2035 evidențiază rolul investițiilor în reducerea decalajelor și modernizarea agriculturii românești.

INTRODUCTION

General considerations: Agricultural mechanization constitutes a fundamental pillar in the modernization of the agri-food sector, directly shaping labor productivity, resource efficiency, and territorial competitiveness. Agricultural mechanization—defined as the replacement of human labor with animal or mechanical power across agricultural, livestock, aquaculture, and agroforestry value chains—extends beyond simple farm-level motorization to include animal traction and a wide range of equipment, technologies, and processes; therefore, it should be understood as a broad concept encompassing the entire agricultural system, not merely motorized farm equipment *(Daum, 2023; FAO & AUC, 2018).* Beyond its frequent association with tractors and combines, mechanization encompasses a set of technical and managerial processes related to the selection, utilization, and management of agricultural equipment adapted to local conditions *(Özpınar et al., 2018; Telemans et al., 2024)*. The scholarly literature emphasizes its dynamic and context-dependent nature, influenced by farm structure, input costs, infrastructure, and access to services *(Özpınar et al., 2018; Zhang et al., 2020; CEMA, 2025; Binswanger, 1988).* Recent FAO reports reaffirm that sustainable mechanization is essential for food security and rural development, while disparities in equipment endowment largely explain global productivity gaps *(Telemans et al., 2024).*

Existing studies converge around three main research directions. The first concerns the definition and measurement of mechanization through physical indicators (machines per 100 ha, ha per machine) and composite indices integrating mechanical energy and the share of mechanized operations *(Singh, 2006; Maheshwari et al., 2019; Gebiso et al., 2024).* The second explores the relationship between mechanization, productivity, and economic efficiency.

Econometric analyses highlight positive impacts on land productivity and farm income, although effects vary with farm size, production stage, and labor costs *(Dokin et al., 2021; García-Arias et al., 2023; Cui, 2023; Shi, 2021; Zhou, X., & Ma, W., 2022; Binswanger, 1988)*. Other studies indicate that, at the regional scale, mechanization enhances total factor productivity, although profitability remains contingent on market structure and access to finance *(Cui, 2023)*.

The third direction focuses on optimizing the use of the machinery fleet through simulation models, linear programming, and outsourced mechanization services, which alleviate equipment shortages but may result in partial mechanization costs *(Dokin et al., 2021; García-Arias et al., 2023)*. Current trends embed mechanization within the "smart" paradigm, linking it to precision agriculture, digitalization, and sustainability objectives *(Zhang, Q., & Reid, J. F., 2020)*. Accordingly, FAO and European Union frameworks advocate for inclusive and climate-smart mechanization *(Telemans et al., 2024; European Commission, 2021)*.

Against this backdrop, the present study examines the mechanization of Romanian agriculture through relative and composite indicators of equipment endowment and machinery utilization at national, regional, and county levels. The primary objective is to assess the degree of mechanization and its relationship with the economic performance of Romanian agriculture *(Dokin et al., 2021; Zhou, 2022; Telemans et al., 2024; Zhang, & Reid, 2020; CEMA, 2025; Binswanger, 1988; European Commission, 2021)*.

MATERIALS AND METHODS

The analysis of the distribution and utilization of the tractor and agricultural machinery fleet in Romania was based on a statistical, comparative, and spatial approach aimed at identifying regional disparities and relationships between technical endowment and the economic performance of agriculture. The data were obtained from the TEMPO-Online statistical database of the National Institute of Statistics (INS) for the period 2014–2024, selected to capture recent trends in the modernization of the technical and material base in the context of national and European agricultural policies supporting investment.

The analysis was conducted at national, regional (eight development regions), and county levels (41 counties), with indicators standardized to ensure spatial and temporal comparability. The results were interpreted in the broader context of sustainable rural development and the technological modernization of Romanian agriculture.

Variables analyzed: **X1** – Physical agricultural tractors; **X2** – Tractor-drawn ploughs; **X3** – Mechanical cultivators; **X4** – Mechanical seeders; **X5** – Mechanical sprayers and dusters; **X6** – Self-propelled combine harvesters for cereals; **X7** – Self-propelled combine harvesters for fodder; **X8** – Combines and potato harvesting machines; **X9** – Self-propelled windrowers for harvesting fodder; **X10** – Straw and hay balers.

Main indicators used:

Degree of Technical Endowment (GTE): This indicator, calculated for each agricultural machinery category (X_1–X_{10}), expresses the number of machines per 100 hectares of arable land. It measures the level of technical equipment in agriculture relative to the available arable area:

$$GTE_{ik} = \frac{Number\ of\ machines_{ik}}{Arable\ land\ area_i}\ x\ 100 \quad (1)$$

where:

- GTE_{ik} = Degree of Technical Endowment for machinery category k in region or county i;
- $Number\ of\ machines_k$ = Number of units in category k;
- $Arable\ land\ area_i$ = Arable land area, expressed in hectares.

Degree of Mechanization (GM), expressed in hectares per machine, this indicator represents the ratio between the arable land area and the total number of machines of a given type:

$$GM_{ik} = \frac{Arable\ land\ area_i}{Number\ of\ machines_{ik}} \quad (2)$$

where:

- GM_{ik} - Degree of Mechanization = representing the average area served by one machine of category k;
- $Arable\ land\ area_i$ = Arable land area, expressed in hectares.
- $Number\ of\ machines_k$ = Number of units in category k;

Economic Efficiency of Mechanization (EE): This indicator expresses the economic performance associated with the use of agricultural equipment and is calculated as the ratio between regional agricultural gross value added (GVA_a) and the number of tractors in use:

$$EE_i = \frac{Agricultural\ GVA_i}{Number\ of\ tractors_i} \quad (3)$$

where:

- EE_i - Economic Efficiency of Mechanization in region or county *i*, expressed in *lei per tractor*;
- *Agricultural* GVA_i – Regional agricultural gross value added (millions lei);
- *Number of tractors*$_i$ – Total number of tractors in region or county *i;*

Regional Mechanization Index (RMI): The RMI is a relative indicator calculated separately for each machinery category (X_1–X_{10}). It compares the degree of technical endowment of each region with the national average:

$$RMI_{ik} = \frac{GTE_{ik}}{GTE_{k,RO}}\ x\ 100 \quad (4)$$

where:

- RMI_{ik} = Regional Mechanization Index for machinery category *k* in region or county i;
- GTE_{ik} = Degree of Technical Endowment for category *k* in region or county i;
- $GTT_{k,RO}$ = National average value of the Degree of Technical Endowment for category k.

Composite Regional Mechanization Index (CRMI): The multivariable Composite Regional Mechanization Index integrates the levels of equipment across all categories of machinery through a weighted average of the partial indices:

$$CRMI_i = \frac{\sum_{k=1}^{10} w_k\ x\ RMI_{ik}}{\sum_{k=1}^{10} w_k} \quad (5)$$

where:

- $CRMI_i$ = Composite mechanization index for region or county i;
- RMI_{ik} = Partial mechanization index for machinery category k;
- w_k = Weight assigned to each machinery category within the total agricultural machinery fleet.

Overall Dynamics Index (I_t): This index expresses the percentage change between the value of a given indicator in the final year and its value in the base year:

$$I_{t/0} = \frac{X_t}{X_0}\ x\ 100 \quad (6)$$

where:

- X_t - Value of the indicator in the final year (2024);
- X_0 − Value of the indicator in the base year (2014)

Annual Growth Rate (r): The annual rate of change was determined according to the following expression:

$$r = \left(\frac{X_t}{X_0}\right)^{\frac{1}{n-1}}\ x\ 100 \quad (7)$$

where n represents the number of years in the analyzed period.

Projection of the composite regional mechanization index for 2035

Based on these indicators, three evolution scenarios were developed for the year 2035: a pessimistic scenario (r = 0.5%), corresponding to investment stagnation and slow renewal of the machinery fleet; a moderate scenario (r = 1.8%), reflecting the continuation of the current average growth rate; and an optimistic scenario (r = 4.5%), corresponding to accelerated modernization driven by investments and European funding. The results are presented in both tabular and graphical form, using relative indices and territorial comparisons.

Their interpretation highlights general trends, regional disparities, and the relationships between mechanization and the economic performance of the agricultural sector.

RESULTS

The analysis of the distribution and utilization of the tractor and agricultural machinery fleet in Romania for the period 2014–2024 reveals significant differences among the country's development regions and counties. The results were derived from the processing of indicators related to technical endowment, mechanization, and economic efficiency, following the methodology described above. The data are expressed as multi-annual averages and report the number of machines per 100 hectares of arable land.

The initial assessment was conducted at the regional level, using the main categories of agricultural machinery (X_1–X_{10}) as defined in the methodological framework.

Table 1

Degree of technical endowment – Tractors and agricultural machines per 100 hectares of arable land (average 2014–2024)

No.	Region	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	Romania	2.70	1.96	0.35	0.90	0.06	0.32	0.01	0.07	0.20	0.02
2	North-West	5.63	4.02	0.40	1.19	0.06	0.50	0.02	0.10	0.43	0.01
3	Center	5.83	3.88	0.78	1.43	0.16	0.56	0.05	0.46	0.60	0.04
4	North-East	2.23	1.66	0.21	0.76	0.03	0.25	0.01	0.06	0.18	0.01
5	South-East	1.19	0.92	0.20	0.51	0.06	0.18	0.01	0.00	0.09	0.02
6	South-Muntenia	1.93	1.40	0.35	0.82	0.10	0.29	0.01	0.05	0.13	0.01
7	Bucharest - Ilfov	2.27	1.83	0.34	1.14	0.03	0.36	0.03	0.00	0.18	0.04
8	South-West Oltenia	2.55	1.96	0.37	1.15	0.02	0.37	0.00	0.00	0.10	0.01
9	West	3.45	2.52	0.46	1.07	0.03	0.38	0.02	0.06	0.21	0.01

Source: *Author's calculations based on data from the National Institute of Statistics (INS), TEMPO-Online database*

Degree of technical endowment at the Regional level

Compared to the national average of 2.7 tractors and 1.96 plows per 100 hectares of arable land, the regional distribution of the Degree of Technical Endowment (GTE) reveals significant differences across Romania's development regions.

The North-West region shows one of the highest endowment levels, with 5.63 tractors and 4.02 plows per 100 ha. It benefits from medium and commercial farms, modernized agricultural infrastructure, and balanced mechanization across all technological stages.

The Center region records the highest national values (5.83 tractors and 3.88 plows per 100 ha), making it the national leader in technical equipment. A mixed farm structure and continuous investment in high-performance machinery support an advanced level of mechanization.

The West region stands above the national average (3.45 tractors and 2.52 plows per 100 ha), with a balanced technical endowment adapted to large, well-capitalized commercial farms.

The South-Muntenia region shows values close to the national average (2.3 tractors per 100 ha), with good endowment in spraying and dusting equipment but deficits in harvesting machinery.

South-West Oltenia records an intermediate level (2.5 tractors per 100 ha), compensated by a higher density of grain combines due to its lowland agricultural profile.

The North-East and South-East regions fall well below the national average (under 2 tractors per 100 ha), with low endowment across all equipment categories and limited mechanization, reflecting the prevalence of small and fragmented farms.

Although agriculturally less significant, the Bucharest–Ilfov region shows a relatively good density (2.3 tractors per 100 ha), characteristic of intensive and horticultural farms.

Overall, the GTE confirms a clear west–east divide linked to farm capitalization levels and structural typologies.

Degree of technical endowment at the County level

The county-level analysis allows for a more detailed interpretation of the territorial distribution of the Degree of Technical Endowment (GTE) in agriculture, providing a finer depiction of the spatial contrasts observed at the regional scale. The average values for the period 2014–2024, expressed as the number of machines per 100 hectares of arable land, are presented in **Table 2.**

Table 2

Degree of Technical Endowment – Tractors and agricultural machinery per 100 hectares of arable land, 2014–2024 (county averages)

No.	County	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	Bihor	4.27	3.04	0.43	1.27	0.09	0.49	0.02	0.05	0.38	0.02
2	Bistrița-Năsăud	0.96	0.75	0.07	0.18	0.01	0.05	0.00	0.02	0.12	0.00
3	Cluj	2.12	1.45	0.16	0.51	0.02	0.20	0.02	0.05	0.20	0.01
4	Maramureș	3.44	1.97	0.09	0.34	0.02	0.11	0.01	0.11	0.26	0.01
5	Satu Mare	2.60	2.07	0.23	0.63	0.02	0.38	0.01	0.02	0.16	0.01
6	Sălaj	2.05	1.74	0.11	0.34	0.02	0.15	0.00	0.01	0.06	0.00
7	Alba	1.43	1.18	0.20	0.55	0.06	0.21	0.01	0.02	0.08	0.01
8	Brașov	1.64	1.19	0.31	0.35	0.04	0.15	0.01	0.29	0.14	0.01
9	Covasna	1.77	1.10	0.30	0.35	0.02	0.12	0.02	0.33	0.16	0.02
10	Harghita	2.22	1.02	0.20	0.22	0.03	0.14	0.02	0.11	0.22	0.01
11	Mureș	2.40	1.94	0.29	0.90	0.11	0.35	0.03	0.05	0.31	0.02
12	Sibiu	1.80	1.07	0.21	0.39	0.04	0.11	0.01	0.10	0.25	0.01
13	Bacău	1.60	1.06	0.06	0.47	0.01	0.13	0.00	0.01	0.07	0.01
14	Botoșani	1.63	1.19	0.17	0.60	0.01	0.21	0.01	0.02	0.18	0.01
15	Iași	1.44	1.09	0.24	0.64	0.07	0.17	0.01	0.01	0.12	0.01
16	Neamț	0.92	0.86	0.11	0.44	0.01	0.16	0.01	0.03	0.09	0.01
17	Suceava	2.46	1.73	0.15	0.45	0.01	0.21	0.01	0.20	0.19	0.01
18	Vaslui	1.36	1.06	0.15	0.60	0.02	0.17	0.01	0.00	0.09	0.01
19	Brăila	0.79	0.69	0.28	0.55	0.01	0.20	0.00	0.00	0.08	0.03
20	Buzău	1.10	1.10	0.18	0.39	0.07	0.15	0.01	0.00	0.08	0.02
21	Constanta	1.15	0.98	0.28	0.77	0.06	0.29	0.01	0.00	0.08	0.02
22	Galați	1.07	0.87	0.20	0.49	0.05	0.15	0.00	0.01	0.10	0.00
23	Tulcea	1.01	0.71	0.17	0.40	0.04	0.19	0.01	0.00	0.12	0.02
24	Vrancea	1.93	1.14	0.09	0.41	0.14	0.11	0.01	0.00	0.09	0.01
25	Argeș	1.99	1.68	0.23	0.67	0.09	0.22	0.00	0.01	0.09	0.01
26	Călărași	1.72	1.35	0.41	1.00	0.06	0.41	0.01	0.00	0.16	0.03
27	Dâmbovița	2.78	1.56	0.43	0.72	0.29	0.20	0.00	0.32	0.10	0.01
28	Giurgiu	1.25	1.10	0.35	0.85	0.03	0.23	0.00	0.00	0.18	0.01
29	Ialomița	1.36	0.85	0.22	0.59	0.02	0.23	0.01	0.00	0.13	0.01
30	Prahova	0.85	0.47	0.09	0.27	0.06	0.09	0.01	0.00	0.06	0.01
31	Teleorman	2.30	1.88	0.48	1.11	0.07	0.42	0.00	0.01	0.14	0.01
32	Ilfov	0.49	0.40	0.07	0.25	0.00	0.08	0.01	0.00	0.04	0.01
33	Bucharest Mun.	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	Dolj	2.64	2.12	0.55	1.55	0.05	0.47	0.01	0.00	0.14	0.02
35	Gorj	1.69	1.23	0.17	0.42	0.01	0.14	0.00	0.00	0.08	0.00
36	Mehedinți	1.28	1.00	0.37	0.61	0.00	0.19	0.00	0.00	0.01	0.00
37	Olt	2.36	2.13	0.27	1.39	0.01	0.54	0.00	0.00	0.13	0.01
38	Vâlcea	1.81	1.05	0.06	0.45	0.00	0.11	0.00	0.00	0.04	0.00
39	Arad	2.58	1.79	0.46	0.94	0.04	0.53	0.02	0.02	0.25	0.02
40	Caras-Severin	2.53	2.04	0.14	0.57	0.02	0.10	0.00	0.04	0.12	0.00
41	Hunedoara	2.36	1.65	0.16	0.37	0.01	0.12	0.01	0.11	0.09	0.00
42	Timiș	2.98	2.15	0.63	1.35	0.02	0.40	0.01	0.02	0.16	0.01

Source: *Author's calculations based on data from the National Institute of Statistics (INS), TEMPO-Online database*

The county-level analysis (Table 2) confirms the presence of major disparities between the western and eastern parts of the country. Compared with the national average of 2.7 tractors per 100 hectares, only a few counties consistently exceed this threshold.

Bihor, Timiș, Dolj, Arad, Olt, Teleorman, and Dâmbovița record the highest levels of technical endowment, reflecting a modern and well-developed technical base. Bihor stands out with 4.27 tractors, 3.04 plows, and 1.27 seeders per 100 ha, followed by Timiș and Dolj, where endowment exceeds 2.5 tractors per 100 ha and includes a high number of combines and plows. These territories are characterized by large, well-capitalized farms oriented toward cereal cultivation and modern technologies.

An intermediate level of mechanization is found in Arad, Mureș, Cluj, Maramureș, and Satu Mare, with 2–3.5 tractors per 100 ha, indicating a balanced endowment typical of mixed farming systems.

At the opposite end, Brăila, Tulcea, Vaslui, Prahova, Ilfov, and Bucharest Municipality register values below 1.5 tractors per 100 ha, with pronounced deficits in harvesting and processing equipment. In mountainous counties (e.g., Bistrița-Năsăud, Neamț), endowment drops below 1 tractor per 100 ha, constrained by terrain conditions and land fragmentation.

The overall territorial pattern shows: western and central counties with high endowment and diversified mechanization; southern and eastern regions with low endowment and predominantly small farms; and northern counties with low equipment density determined by natural constraints.

The spatial distribution of the GTE highlights persistent modernization gaps and underscores the need for differentiated agricultural policies aligned with the structural and economic characteristics of each county.

Degree of mechanization and intensity of agricultural equipment mechanization

Following the assessment of technical endowment, the next methodological step consists of analyzing the degree of mechanization, expressed as the average area served by one machine (ha/machine). This indicator reflects the intensity of equipment utilization and provides an indirect measure of technical efficiency within agricultural holdings.

Lower indicator values suggest a high density of machinery and an advanced level of mechanization, whereas higher values indicate insufficient equipment endowment or extensive use of technical resources.

Table 3

Degree of mechanization (ha/machine) and intensity of agricultural equipment utilization, 2014–2024 (regional averages)

No.	Region	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
1	Romania	37	51	288	111	1.595	310	7.744	1.447	512	6.480
2	North-West	18	25	250	84	1.559	198	4.461	1.020	234	6.805
3	Center	17	26	128	70	631	179	1.923	216	166	2.783
4	North-East	45	60	480	132	3.160	396	8.517	1.656	567	7.145
5	South-East	84	108	496	197	1.627	541	12.820	42.301	1.101	5.478
6	South-Muntenia	52	71	287	121	1.030	350	15.420	1.902	748	7.801
7	Bucharest - Ilfov	44	55	294	88	3.399	275	3.680	64.893	543	2.496
8	South-West Oltenia	39	51	268	87	4.963	267	28.598	55.656	987	11.324
9	West	29	40	217	93	3.317	262	6.505	1.685	486	8.683

Source: *Author's calculations based on data from the National Institute of Statistics (INS), TEMPO-Online database*

At the national level, one tractor serves an average of 37 hectares of arable land, corresponding to a medium level of mechanization relative to European standards.

High-mechanization regions — the Center and North-West — register the lowest values (17–18 ha per tractor; 25–26 ha per plow), reflecting a high density of equipment and superior technical endowment typical of medium and commercial farms.

Medium-mechanization regions — South-Muntenia, North-East, West, and Bucharest–Ilfov — show values between 40 and 60 ha per tractor. In these areas, mechanization is functional, but equipment utilization is intensive, particularly for harvesting combines, which serve between 8,000 and 15,000 hectares per unit.

Low-mechanization regions — South-East and South-West Oltenia — exceed 80 ha per tractor, indicating acute equipment shortages and extensive use of technical resources. In these territories, a single specialized machine may serve more than 25,000 hectares, signaling major functional imbalances.

The spatial distribution of the Degree of Mechanization confirms a clear west–east contrast in technical and material development: Transylvania and western Romania benefit from advanced and diversified mechanization, while the southern and eastern regions remain dependent on an undersized machinery fleet.

Composite Regional Mechanization Index (CRMI)

For an integrated assessment of agricultural mechanization, the Composite Regional Mechanization Index (CRMI) was calculated, aggregating information on the technical endowment across the ten categories of machinery (X_1–X_{10}). This indicator enables comparison of the overall level of mechanization between regions relative to the national average (100).

Table 4

Composite Regional Mechanization Index (CRMI) – comparative values, 2014–2024 (national average = 100)

Region	RMI_{X_1}	RMI_{X_2}	RMI_3	RMI_{X_4}	RMI_{X_5}	RMI_6	RMI_7	RMI_8	RMI_9	RMI_{10}	$CRMI_{C_t}$
Romania	209	205	116	133	102	156	174	142	219	95	**155**
North-West	216	198	225	160	253	173	403	670	309	233	**284**
Center	83	84	60	85	50	78	91	87	90	91	**80**
North-East	44	47	58	56	98	57	60	3	46	118	**59**
South-East	72	71	101	92	155	89	50	76	68	83	**86**
South-Muntenia	84	93	98	127	47	113	210	1	94	260	**113**
Bucharest - Ilfov	95	100	108	128	32	116	27	3	52	57	**72**
South-West Oltenia	128	128	133	119	48	118	119	86	105	75	**106**
West	209	205	116	133	102	156	174	142	219	95	**155**

Source: Author's calculations based on data from the National Institute of Statistics (INS), TEMPO-Online database

Nota: RMI_{X_1}- Physical agricultural tractors; RMI_{X_2}– Tractor-drawn ploughs; RMI_3 – Mechanical cultivators; RMI_{X_4} – Mechanical seeders; RMI_{X_5} – Mechanical sprayers and dusters; IMR_6 – Self-propelled combine harvesters for cereals; RMI_7 – Self-propelled combine harvesters for fodder; RMI_8 – Combines and potato harvesting machines; RMI_9 – Straw and hay balers; RMI_{10} – Self-propelled windrowers for harvesting fodder

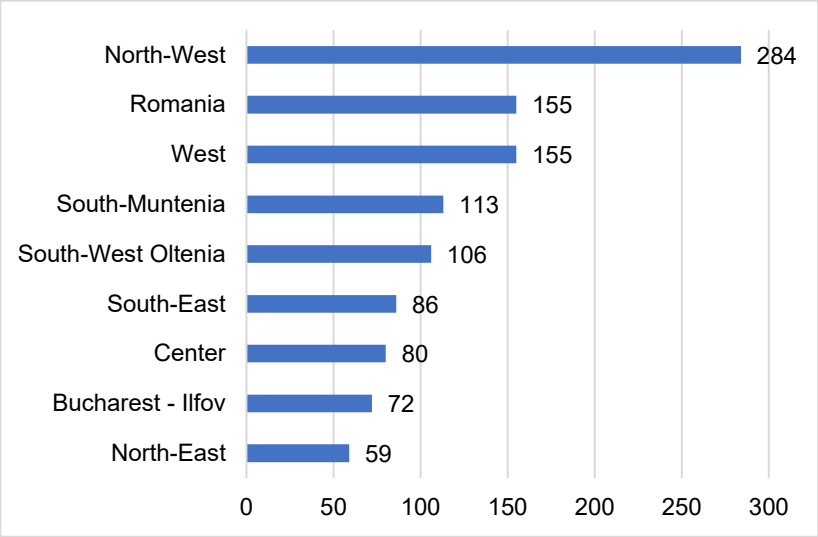


Fig. 1 - Distribution of the composite mechanization index (CMRI) by development regions in Romania

In Table 4 and in Figure 1, the composite regional mechanization index is presented, highlighting significant differences among Romania's regions. The North-West stands out clearly with a value of 284, followed by Romania and the West (155), while the North-East records the lowest level (59). The distribution confirms a pronounced west–east divide in the technical endowment of agriculture.

Building on these regional differences, the composite mechanization index can be grouped into three categories: high, medium, and low mechanization, which allows for a more structured interpretation of territorial disparities.

Regions with high mechanization (CRMI > 150): North-West (284) and West (155). These regions significantly exceed the national average, reflecting a modern technical infrastructure and efficient resource use. The North-West stands out with the highest index value - nearly three times the national average - confirming the presence of a diversified machinery fleet and advanced mechanization. In the West, the consolidation of agricultural holdings and the steady absorption of European funds support equipment modernization and strong adaptation to current technological requirements.

Regions with medium mechanization (CRMI = 90–130): South-Muntenia (113), South-West Oltenia (106), and South-East (86). These regions exhibit technical endowment levels close to the national average, reflecting partial mechanization. Although their machinery fleets are relatively balanced, equipment-use efficiency remains limited by land fragmentation and the predominance of small farms.

Regions with low mechanization (CRMI < 80): Center (80), Bucharest–Ilfov (72), and North-East (59). These territories are characterized by low mechanization levels, persistent deficits in technical equipment, and limited investment in agricultural infrastructure.

Overall, CRMI values confirm a clear west–east divide in mechanization levels, with technical resources concentrated in the western and southern parts of the country and substantially lower values in the north-eastern regions.

County Composite Mechanization Index (CRMI)

To highlight detailed spatial disparities, the analysis was extended to the county level using the same calculation model as for the composite mechanization index (RMIj). This indicator was determined for each of Romania's 42 counties by comparing the local degree of technical endowment to the national average (100).

Table 5

County Composite Mechanization Index (CRMIj) – comparative values, 2014–2024 (national average = 100)

No.	County	RMI_{X_1}	RMI_{X_2}	RMI_3	RMI_{X_4}	RMI_{X_5}	RMI_6	RMI_7	RMI_8	RMI_9	RMI_{10}	$CRMI_{C_t}$
1	Bihor	158.6	112.9	16.1	47.3	3.3	18.2	0.7	1.8	13.9	0.6	**37**
2	Bistrita-Nasaud	35.7	27.7	2.6	6.6	0.5	1.8	0.2	0.8	4.3	0.0	**8**
3	Cluj	78.7	53.9	5.9	18.8	0.7	7.6	0.6	2.0	7.6	0.4	**18**
4	Maramures	127.7	73.2	3.5	12.6	0.6	4.0	0.2	4.1	9.6	0.2	**24**

No.	County	RMI_{X_1}	RMI_{X_2}	RMI_3	RMI_{X_4}	RMI_{X_5}	RMI_6	RMI_7	RMI_8	RMI_9	RMI_{10}	$CRMI_{C_t}$
5	Satu Mare	96.3	76.9	8.5	23.4	0.7	14.2	0.5	0.8	5.9	0.2	**23**
6	Salaj	76.2	64.5	4.1	12.8	0.8	5.5	0.0	0.5	2.1	0.1	**17**
7	Alba	53.1	43.7	7.3	20.5	2.3	7.9	0.4	0.8	3.0	0.3	**14**
8	Brasov	60.7	44.0	11.6	13.1	1.5	5.4	0.4	10.7	5.3	0.3	**15**
9	Covasna	65.6	40.7	11.0	13.2	0.8	4.5	0.9	12.1	6.1	0.6	**16**
10	Harghita	82.3	38.0	7.5	8.3	1.1	5.2	0.7	4.1	8.2	0.3	**16**
11	Mures	88.9	71.9	10.9	33.4	4.1	12.9	1.0	1.8	11.4	0.9	**24**
12	Sibiu	66.8	39.9	7.8	14.3	1.6	4.0	0.4	3.8	9.3	0.2	**15**
13	Bacau	59.4	39.4	2.2	17.4	0.3	4.9	0.2	0.2	2.8	0.4	**13**
14	Botosani	60.3	44.0	6.1	22.3	0.5	7.9	0.4	0.8	6.7	0.5	**15**
15	Iasi	53.5	40.3	8.9	23.7	2.5	6.3	0.4	0.2	4.3	0.4	**14**
16	Neamt	34.2	31.8	4.2	16.5	0.4	6.0	0.3	1.0	3.4	0.3	**10**
17	Suceava	91.3	64.2	5.7	16.8	0.4	7.8	0.4	7.2	7.1	0.4	**20**
18	Vaslui	50.3	39.2	5.5	22.1	0.9	6.5	0.2	0.0	3.3	0.3	**13**
19	Braila	29.2	25.6	10.2	20.4	0.6	7.6	0.1	0.1	2.9	1.2	**10**
20	Buzau	40.9	40.9	6.7	14.5	2.5	5.7	0.3	0.1	2.8	0.7	**12**
21	Constanta	42.5	36.3	10.5	28.6	2.3	10.6	0.5	0.1	2.9	0.8	**14**
22	Galati	39.5	32.4	7.4	18.2	1.7	5.6	0.2	0.2	3.7	0.2	**11**
23	Tulcea	37.5	26.4	6.4	14.7	1.4	7.0	0.2	0.0	4.3	0.8	**10**
24	Vrancea	71.6	42.2	3.2	15.1	5.1	4.3	0.5	0.0	3.5	0.3	**15**
25	Arges	73.7	62.2	8.5	25.0	3.4	8.1	0.2	0.2	3.2	0.2	**18**
26	Calarasi	63.6	50.1	15.3	37.1	2.4	15.3	0.5	0.1	5.8	1.0	**19**
27	Dambovita	103.3	57.9	15.9	26.6	10.6	7.6	0.2	11.7	3.7	0.3	**24**
28	Giurgiu	46.5	40.9	12.8	31.7	1.0	8.5	0.1	0.0	6.7	0.2	**15**
29	Ialomita	50.4	31.4	8.2	21.7	0.8	8.7	0.2	0.0	4.8	0.5	**13**
30	Prahova	31.4	17.6	3.4	10.0	2.2	3.3	0.2	0.1	2.1	0.2	**7**
31	Teleorman	85.3	69.9	17.8	41.3	2.5	15.6	0.1	0.2	5.1	0.5	**24**
32	Ilfov	18.1	14.7	2.7	9.2	0.2	3.0	0.2	0.0	1.5	0.3	**5**
33	Bucharest Mun.	0.5	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	**0**
34	Dolj	98.1	78.5	20.5	57.4	1.9	17.5	0.2	0.2	5.2	0.7	**28**
35	Gorj	62.8	45.6	6.5	15.6	0.2	5.1	0.1	0.0	2.9	0.1	**14**
36	Mehedinti	47.4	37.1	13.8	22.6	0.2	6.9	0.0	0.0	0.3	0.0	**13**
37	Olt	87.6	79.1	10.0	51.7	0.5	19.9	0.1	0.0	4.6	0.4	**25**
38	Valcea	67.1	39.0	2.2	16.8	0.1	3.9	0.1	0.0	1.3	0.1	**13**
39	Arad	95.7	66.2	17.0	34.7	1.6	19.6	0.8	0.6	9.4	0.8	**25**
40	Caras-Severin	93.8	75.7	5.3	21.3	0.7	3.7	0.2	1.3	4.3	0.2	**21**
41	Hunedoara	87.4	61.0	6.0	13.9	0.5	4.6	0.3	4.1	3.5	0.1	**18**
42	Timis	110.5	79.6	23.4	50.0	0.6	14.9	0.4	0.7	5.9	0.2	**29**

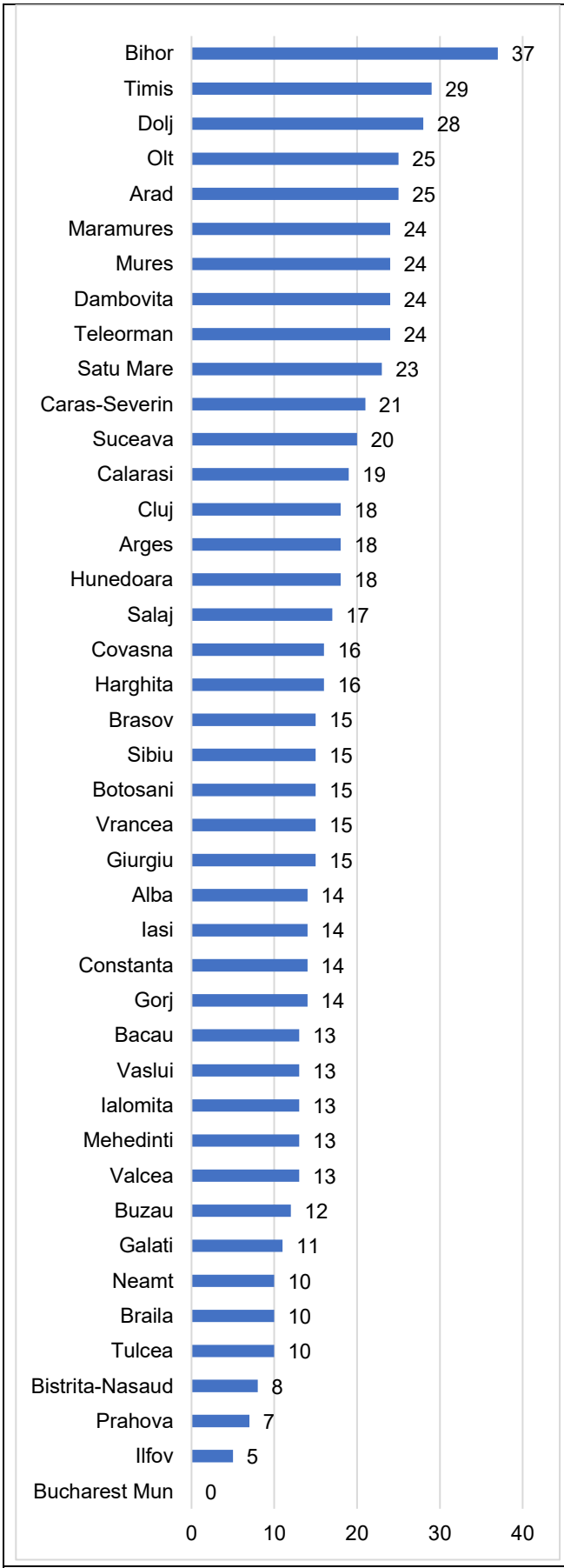
Source: *Author's calculations based on data from the National Institute of Statistics (INS). TEMPO-Online database*
Nota: RMI_{X_1}- Physical agricultural tractors; RMI_{X_2}– Tractor-drawn ploughs; RMI_3 – Mechanical cultivators; RMI_{X_4} – Mechanical seeders; RMI_{X_5} – Mechanical sprayers and dusters; IMR_6 – Self-propelled combine harvesters for cereals; RMI_7 – Self-propelled combine harvesters for fodder; RMI_8 – Combines and potato harvesting machines; RMI_9 – Straw and hay balers; RMI_{10} – Self-propelled windrowers for harvesting fodder

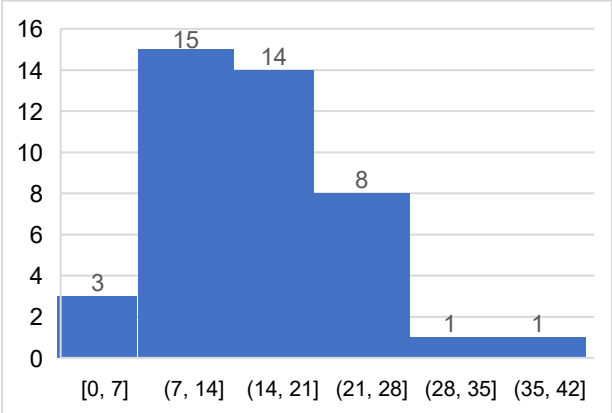
Counties with high mechanization (IMRj > 22): Timiș (29), Dolj (28), Olt and Arad (25), Dâmbovița, Mureș, Teleorman (24), and Satu Mare (23). These territories are characterized by advanced technical capacity, high machinery density, and predominantly commercial agriculture. Counties in the Western Plain and southern Oltenia, in particular, benefit from consistent investment and effective absorption of European funds for modernizing the agricultural machinery fleet.

Counties with medium mechanization (IMRj = 15–20): Cluj, Brașov, Harghita, Bacău, Giurgiu, Constanța, Gorj, Vaslui, Vrancea, and Vâlcea. These areas combine commercial farms with subsistence-oriented households. Although machinery endowment is relatively balanced, land fragmentation and inadequate infrastructure limit equipment-use efficiency.

Counties with low mechanization (IMRj < 12): Ilfov (5), Bucharest (0), Prahova (7), Bistrița-Năsăud (8), and Brăila, Neamț, and Tulcea (10–11). These counties have a low agricultural share, insufficient technical endowment, and minimal mechanization, especially in mountainous or peri-urban zones.

The county-level distribution confirms a dual spatial pattern: a high-performing core in the western and southern parts of the country, contrasted by modest values in the north-east. This reflects the direct correlation between agricultural capitalization and territorial economic performance.





Histogram 1: Frequency Distribution of County-Level Mechanization (IMRj)

The histogram displays the distribution of the composite county-level mechanization index (IMRj), grouped into equal-value intervals. The horizontal axis shows the six class intervals: (0–7), (7–14), (14–21), (21–28), (28–35), and (35–42), while the vertical axis indicates the frequency of counties falling within each range. The distribution reveals a strong concentration in the (7–14] and (14–21] intervals, which contain the majority of counties, whereas very low and very high values are rare.

The class interval (35–42): 1 county – Bihor.
The class interval (28–35): 1 county – Timis.
The class interval (21–28): 8 counties – Dolj, Olt, Arad, Maramureș, Mureș, Dambovița, Teleorman, Satu Mare.
The class interval (14–21): 14 counties – Caraș-Severin, Suceava, Călărași, Cluj, Argeș, Hunedoara, Sălaj, Covasna, Harghita, Brașov, Sibiu, Botoșani, Vrancea, Giurgiu.
The class interval (7–14): 15 counties – Alba, Iași, Constanța, Gorj, Bacău, Vaslui, Ialomița, Mehedinți, Vâlcea, Buzău, Galați, Neamț, Brăila, Tulcea, Bistrița-Năsăud.
The class interval (0–7): 3 counties – Prahova, Ilfov, Bucharest Mun.

Fig. 2 - Distribution of the composite mechanization index (CMRI) by county in Romania

Economic efficiency of mechanization

To assess the economic performance associated with the degree of mechanization.

The economic efficiency (EE) indicator was calculated, defined as the ratio between the regional agricultural gross value added (GVA_a) and the total number of tractors in operation.

The indicator expresses the average value generated per tractor (lei/tractor) and provides an overview of the productivity of the technical capital employed in agriculture.

The data in Table 6 and Figure 3 present the economic efficiency of mechanization across the development regions, highlighting territorial differences in the productivity of agricultural technical capital.

Table 6

Economic efficiency of mechanization – regional agricultural GVA relative to the number of tractors (lei/tractor)

No.	Region	Arable land area (ha)	Number of tractors	Regional agr. GVA (million lei)	GVA/tractor (lei)	EMI (100=national average)
1	Romania	8.303.556	223.863	41.676	186.167	100.0
2	North-West	806.666	45.438	4.803	105.704	56.8
3	Center	567.944	33.086	4.890	147.797	79.4
4	North-East	1.238.073	27.666	6.972	252.006	135.4
5	South-East	1.745.875	20.710	6.834	329.986	177.3
6	South-Muntenia	1.862.959	36.004	7.655	212.615	114.2
7	Bucharest - Ilfov	64.893	1.476	1.286	871.274	468.0
8	South-West Oltenia	1.128.302	28.773	4.849	168.526	90.5
9	West	888.843	30.709	4.387	142.857	76.7

Source: Author's calculations based on data from the National Institute of Statistics (INS). TEMPO-Online database
Note: EMI – Economic Mechanization Index

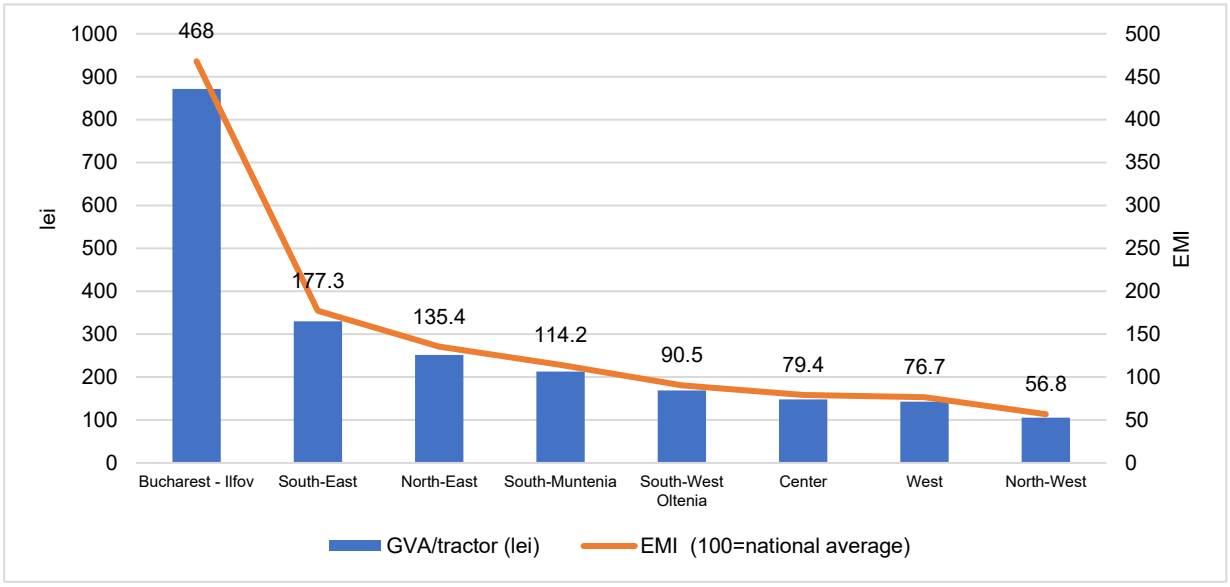


Fig. 3 - Economic efficiency of mechanization – regional agricultural GVA relative to the number of tractors (lei/tractor)

Based on the calculated data, the regions were grouped into three categories: regions with high, medium, and low economic efficiency.

Regions with high economic efficiency (EE > 250,000 lei/tractor): Bucharest–Ilfov (871,274 lei/tractor, CRMI = 468), South-East (329,986 lei/tractor, CRMI = 177), and North-East (252,006 lei/tractor, CRMI = 135). These regions stand out for their superior utilization of the machinery fleet, even under relatively modest mechanization levels. Bucharest–Ilfov shows an exceptionally high value due to its limited agricultural area and the prevalence of intensive, high-value activities. The exceptionally high economic efficiency observed in Bucharest–Ilfov is explained by the region's small agricultural area and very low number of tractors, combined with the prevalence of high-value, intensive agricultural activities, which statistically amplifies the GVA-per-tractor indicator.

Regions with medium efficiency (EE = 160,000–220,000 lei/tractor): South-Muntenia (212,615 lei/tractor), South-West Oltenia (168,526 lei/tractor), and the Center (147,797 lei/tractor). These territories display a balanced agricultural structure, combining commercial farms with medium-sized holdings, stable capitalization, and efficient—but not maximal—equipment use.

Regions with low efficiency (EE < 140,000 lei/tractor): West (142,857 lei/tractor) and North-West (105,704 lei/tractor). Although they have high mechanization levels, land fragmentation and the predominance of small-capacity machinery limit productivity per unit of equipment.

Overall, the analysis highlights a partial correlation between technical endowment and economic performance: high efficiency does not depend solely on machinery density but on the way equipment is used and integrated into production systems.

Dynamics and annual growth rate of the agricultural machinery fleet

To assess the temporal evolution of technical endowment in agriculture, the overall dynamics index (I_t) and the average annual growth rate (r) were calculated for the main categories of machinery. The analysis covers the period 2014–2024 and enables the identification of modernization, stagnation, or decline trends at the regional level.

Table 7

Overall dynamics index - DI (%) and annual growth rate - AGR (%) of the tractor and agricultural machinery fleet, 2014–2024

Type of machinery	Indicator	Romania (Total)	North-West	Center	North-East	South-East	South-Muntenia	Bucharest - Ilfov	South-West Oltenia	West
X1	DI (%)	130	152	166	144	97	118	95	125	107
	AGR (%)	2.7	4.3	5.2	3.7	-0.3	1.6	-0.6	2.3	0.7
X2	DI (%)	104	117	116	128	85	79	100	114	93
	AGR (%)	0.4	1.6	1.5	2.5	-1.6	-2.3	0.0	1.3	-0.8
X3	DI (%)	90	106	121	105	74	74	101	132	55
	AGR (%)	-1.1	0.6	1.9	0.5	-3.0	-3.0	0.1	2.8	-5.9
X4	DI (%)	91	99	116	112	87	74	100	106	62
	AGR (%)	-0.9	-0.1	1.5	1.2	-1.4	-3.0	0.0	0.6	-4.7
X5	DI (%)	81	82	81	53	69	95	74	118	86
	AGR (%)	-2.0	-1.9	-2.1	-6.2	-3.7	-0.5	-3.0	1.6	-1.5
X6	DI (%)	102	80	106	131	108	102	107	123	77
	AGR (%)	0.2	-2.1	0.6	2.7	0.7	0.2	0.7	2.1	-2.5
X7	DI (%)	149	101	128	167	265	191	94	118	154
	AGR (%)	4.1	0.1	2.5	5.3	10.3	6.7	-0.6	1.7	4.4
X8	DI (%)	112	376	80	101	65	108	0	456	212
	AGR (%)	1.2	14.2	-2.2	0.1	-4.2	0.8	0.0	16.4	7.8
X9	DI (%)	196	298	285	196	145	87	103	229	214
	AGR (%)	7.0	11.6	11.0	7.0	3.8	-1.4	0.3	8.6	7.9
X10	DI (%)	101	119	163	112	79	79	96	79	122
	AGR (%)	0.1	1.7	5.0	1.1	-2.3	-2.4	-0.4	-2.3	2.0

Source: *Author's calculations based on data from the National Institute of Statistics (INS). TEMPO-Online database*

The analysis of the evolution of the agricultural machinery fleet between 2014 and 2024 indicates moderate growth at the national level, with an overall index of 130% for tractors and an average annual rate of 2.7%. The results show significant differences between regions and equipment categories, outlining three distinct evolution patterns.

Regions with high growth (r > 4 %): the Center (5.2%) and North-West (4.3%). These regions recorded the strongest progress in machinery renewal, supported by investments financed through European programs (PNDR). The marked increase reflects rapid farm modernization and a shift toward high-performance equipment.

Regions with moderate growth (r = 2-3 %): North-East and South-West Oltenia, where modernization continued steadily but unevenly across equipment types. Although these areas have benefited from recent investments, land fragmentation limits the overall pace of renewal.

Regions with low growth or stagnation (r < 1%): the West, South-Muntenia, and South-East, characterized by farm restructuring, aging machinery, and low absorption of investment funds.

Across equipment categories, the largest increases were recorded for hay and straw balers (196 %), forage harvesters (149%), and potato harvesters (112%), indicating a trend toward technological diversification. By contrast, mechanical cultivators (90%), spraying and dusting machines (81%), and seeders (91%) showed weak evolution, suggesting slow renewal of basic equipment.

Overall, the period reflects partial and uneven modernization, with clear technological advances in the western and central regions and persistent stagnation in the south and east.

Projection of the Composite Regional Mechanization Index for 2035

To estimate the future evolution of agricultural mechanization in Romania. three projection scenarios of the Composite Regional Mechanization Index (CRMI) were developed, corresponding to the annual growth rates previously determined (see section 8 of the methodology): the pessimistic scenario (r = 0.5%), the moderate scenario (r = 1.8%), and the optimistic scenario (r = 4.5%).

Table 8

Projection of the Composite Regional Mechanization Index (CRMI) for 2035 according to the evolution scenarios (%)

No.	Region	CRMI 2024	Pessimistic scenario (r = 0.5%)	Moderate scenario (r = 2.5%)	Optimistic scenario (r = 4.5%)
1	North-West	155	164	198	240
2	Center	284	300	383	491
3	North-East	80	84	102	131
4	South-East	59	62	75	95
5	South-Muntenia	86	91	110	140
6	Bucharest - Ilfov	113	119	144	184
7	South-West Oltenia	72	76	92	117
8	West	106	111	135	171

Source: *Author's calculations based on data from the National Institute of Statistics (INS). TEMPO-Online database.*
Note: CRMI – Composite Regional Mechanization Index; *r* – average annual growth rate, expressed as a percentage.

The projections for 2035 indicate a general increase in the level of mechanization across all Romanian regions, although with different growth rates depending on the evolution scenario adopted.

The pessimistic scenario (r = 0.5 %) anticipates slow progress of only 5–10%, maintaining the current gaps between well-equipped regions such as the Center and North-West and those with low mechanization, including the South-East and North-East. In this case, modernization would stagnate, and technological convergence would remain minimal.

The moderate scenario (r = 1.8 %) suggests a more substantial evolution, with increases of 20–35 percent in the Composite Mechanization Index (IMR). This scenario reflects the continuation of current investment trends supported by PNDR and PNS programs, as well as broader access to modern equipment and technologies.

The optimistic scenario (r = 4.5 %) assumes a significant acceleration of modernization driven by full absorption of European funds and increased private investment. Under this scenario, the Center (IMR = 491) and North-West (IMR = 240) regions could more than double their current levels, approaching the standards of Central European countries. Less developed regions, such as the South-East and North-East, would achieve values between 95 and 131, marking notable improvements but still falling short of full convergence.

Overall, Romania could attain a competitive average level of mechanization by 2035, but the persistence of regional imbalances requires differentiated policies and strategically targeted investments in under-equipped areas.

CONCLUSIONS AND DISCUSSION

Discussion

The results confirm the hypothesis of an uneven distribution of mechanization in Romanian agriculture, shaped by regional economic potential, farm structure, and the level of technological capitalization. The Center and North-West regions record the highest values of the Composite Mechanization Index (IMR), supported by high machinery density and sustained investment in agricultural infrastructure. In contrast, the South-East and North-East remain low-mechanization areas, characterized by small farms, excessive fragmentation, and insufficient technical resources.

Comparing the composite mechanization index with the economic efficiency index reveals an inverse relationship between the two indicators, as regions with low mechanization levels, such as Bucharest-Ilfov, South-East, and North-East, record the highest economic efficiency per tractor, while highly mechanized

regions like the North-West and West exhibit lower efficiency, suggesting technical overcapacity, underutilization of equipment due to farm fragmentation, and structural differences that limit productivity per machine.

These findings align with recent analyses of territorial disparities in agricultural development (PNDR 2014-2020; PNS 2023-2027; Eurostat, 2022), which highlight the direct correlation between technical infrastructure, land productivity, and regional competitiveness. Dynamics and growth-rate indicators confirm a general trend toward modernization, although the pace of renewal remains modest compared with Central and Eastern European countries.

The economic interpretation of the data shows higher mechanization efficiency (GVA/tractor) in regions dominated by medium and large farms, where a positive relationship emerges between farm size, equipment density, and economic productivity. Conversely, areas dominated by small, non-cooperative farms demonstrate suboptimal equipment use and low investment returns.

Projections for 2035 indicate a gradual increase in mechanization, with partial reduction of regional disparities under the moderate and optimistic scenarios. However, full convergence depends on consistent agricultural policies, improved access to financing, and the integration of digital and sustainable technologies, including precision agriculture.

Future research should address the interdependence between mechanization, digitalization, and energy efficiency; assess the impact of European funding on technological modernization; develop spatial models of mechanization performance at the farm level; and incorporate ecological and sustainability dimensions into evaluations of the technical and material base.

Conclusions

The analysis of the distribution and use of tractors and agricultural machinery in Romania revealed significant territorial disparities in the degree of mechanization, shaped by structural and economic differences within the agricultural system. The Center and North-West regions display superior technical endowment and high economic efficiency, while the South-East and North-East face equipment shortages and low productivity.

The results confirm that machinery density directly influences farm economic performance and that regional variations are closely linked to average farm size, capitalization levels, and access to financing. The period 2014–2024 reflects a slow but steady modernization process, supported by public investment and European funds; however, the pace of renewal remains below the level required to converge with the European average.

Projections for 2035 anticipate a general increase in mechanization, more pronounced under the optimistic scenario, which assumes active investment policies and full absorption of dedicated funds. Reducing territorial disparities will depend on the integration of digital technologies, the consolidation of medium-sized farms, and the adaptation of agricultural policies to regional specificities.

To enhance the competitiveness of Romanian agriculture, strategic priorities should focus on supporting regions with low technical endowment, stimulating investment in modern and energy-efficient machinery, and promoting sustainable mechanization and precision agriculture.

The study's limitations arise from the exclusive use of INS Tempo-Online statistical data, which may contain reporting errors and time lags. The indicators reflect average levels without distinguishing the quality or age of equipment, and the composite index does not account for factors such as automation or technological adaptability.

Despite these limitations, the study provides a coherent picture of territorial disparities and modernization prospects, offering a solid empirical basis for designing technological development policies and supporting the convergence of Romanian agriculture with European standards.

ACKNOWLEDGEMENT

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