NARDI FUNDULEA, ROMANIA ROMANIAN AGRICULTURAL RESEARCH, NO. 42, 2025
www.incda-fundulea.ro; doi.org/10.59665/rar4229 First Online: February, 2025. DII 2067-5720 RAR 2025-52

Assessing the Effectiveness of Twin Transformation in Lithuanian and Romanian Agriculture: A Comparative Analysis

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ABSTRACT

The twin transformation in agriculture, integrating digitalization and green practices, is pivotal for achieving sustainability in the European Union (EU). This study examines the economic impacts of adopting digital and green technologies on farms in Lithuania and Romania. A comparative analysis highlights variations in adoption rates, investment levels, and operational savings across these countries. Lithuanian farms exhibit cost-efficient strategies, achieving significant profitability improvements with moderate investments, while Romanian farms engage in high-cost initiatives, reflecting differences in farm size, access to funding, and policy frameworks. The results reveal high adoption rates for digital technologies, with over 76% of farms in both countries utilizing tools such as data analytics software. However, barriers including high costs, limited funding access, and technical knowledge gaps persist, particularly in smaller farms and in Romania. Operational savings are predominantly moderate (5-10%), with significant savings exceeding 20% being rare. The study emphasizes the need for targeted policy measures, including enhanced financial support, capacity-building programs, and scalable technological solutions. These interventions are crucial for addressing disparities and fostering inclusive adoption of twin transformation practices. The findings provide a foundation for developing strategies to ensure sustainable and resilient agricultural systems in the EU, with broader implications for global agricultural transitions.

Keywords: twin transformation, digital, sustainable agriculture, economics, farm profitability.

INTRODUCTION

The agricultural sector within the European Union (EU) currently finds itself at a pivotal crossroads, where the dual exigencies of climate change and technological innovation demand a substantial metamorphosis. This concurrent transformation - encompassing digitalization and the green transition - is imperative for the attainment of sustainable and resilient agricultural practices. While the European Green Deal and Farm to Fork Strategy provide a strong foundation for the transition, implementation at the farm level varies widely across member states due to differences in economic structures, technology adoption, and policy effectiveness. The pressing need to strengthen agricultural domain arises from the sector's dual function as both a contributor to and a victim of climate change (FAO, 2021; Sterie and Dragomir, 2023). Agriculture is responsible for approximately 10% of the EU's greenhouse gas emissions, while increasingly frequent extreme weather phenomena disrupt agricultural productivity (Eurostat, 2023). Concurrently, digital innovations such as precision farming and data-driven decision-making present the potential to enhance resource utilization, diminish emissions, and elevate yields (Finger, 2023; Karunathilake et al., 2023; Gavrilović et al., 2024). Nevertheless, this transition necessitates the surmounting of various challenges, including limited access to technological resources, inadequate digital competencies among farmers, and heterogeneous levels of policy support across

Received 2 November 2024; accepted 27 February 2025.

EU member states (Niskanen et al., 2021; Granado-Díaz et al., 2024).

The heterogeneity in adopting twin transformation practices is particularly pronounced in Central and Eastern Europe, where historical, economic, and institutional legacies shape agricultural development. Lithuania and Romania provide compelling cases for comparative analysis. Lithuania, characterized by smaller-scale farms and an increasing focus on digital innovation hubs (E-DIHs), has demonstrated progress in precision agriculture and sustainable practices (Bongiovanni and Lowenberg-DeBoer, 2004; Kurlavičius et al., 2024). Conversely, Romania, with its larger share of subsistence and semi-subsistence farms, faces unique challenges in accessing technology and aligning with EU sustainability goals (Chiţea et al., 2022; Satpathy, 2022). By comparing these two countries, we can identify both shared and unique barriers to twin transformation, providing insights for tailored policy interventions.

The twin transformation in agriculture is not merely a technological shift; it represents a systemic reconfiguration of value chains, labor dynamics, and resource management. As highlighted by Myshko et al. (2024), the adoption of digital and sustainable practices demands an ecosystem approach, wherein farmers, technology providers, policymakers, and researchers co-create solutions tailored to regional contexts. This transformation necessitates governance frameworks and the integration of participatory methodologies to ensure inclusivity and long-term viability (Wang, 2024). Furthermore, research underscores the role of adaptive capacity, where social and institutional resilience significantly influences the adoption rates of twin transformation practices (Tagarakis et al., 2024).

Another critical dimension is the interplay between policy coherence and market mechanisms. Studies by Chiurciu (2020) and Monticone and Samoggia (2024) indicate that fragmented or conflicting policies often hinder progress, especially in countries with diverse farming structures. For instance, while Lithuania benefits from EU-funded programs promoting technology adoption, Romania's reliance on traditional farming methods poses challenges for harmonizing digital and green goals (Sekhar et al., 2024). Additionally, the economic viability of twin transformation is intricately linked to the global agricultural commodity market, where price volatility and trade barriers influence farmers' willingness to invest in innovative practices. Addressing these multifaceted challenges requires integrated models that assess both micro- and macro-level dynamics.

Recent studies have underscored the importance of Digital Innovation Hubs (E-DIHs) in facilitating twin transformation. These hubs act as intermediaries, connecting farmers with technological solutions, training, and funding opportunities. However, the effectiveness of E-DIHs depends on regional contexts, including the availability of infrastructure and institutional support. Additionally, the role of social innovation and collaborative networks has emerged as critical in driving adoption at the grassroots level (Kalpaka et al., 2020; Gaiani and Ala-Karvia, 2023).

Other scholars have highlighted the role of economic incentives and market structures in shaping farmers' willingness to adopt green and digital practices. For instance, subsidies tied to environmental outcomes have been shown to accelerate the uptake of sustainable practices. Yet, gaps in education and capacity-building remain significant barriers, especially in regions with smaller farms and lower capital investment (Rizzo et al., 2024).

Despite the growing body of literature, comparative analyses at the micro-level - focusing on individual farms and their adoption trajectories - remain limited. Most studies tend to analyze EU-level or regional trends without delving into the local dynamics of twin transformation. Moreover, there is a need to develop robust assessment models that can capture both economic and environmental dimensions of effectiveness, providing actionable insights for policymakers.

Through a comparative analysis of Lithuanian and Romanian farms, the study explores the interplay of digital and green transitions, identifying key drivers and

barriers to success. The findings aim to contribute to the broader discourse on sustainable agricultural development in the EU, offering practical recommendations for fostering inclusive and efficient transitions.

The aim of this study is to develop an Effectiveness Assessment Model for twin transformation in EU agriculture, using Lithuania and Romania as case studies for comparative analysis.

MATERIAL AND METHODS

This study employs a comparative case study approach to examine the economic impacts of digital and green technology adoption on farms in Lithuania and Romania. The methodology integrates quantitative and qualitative analyses to provide a comprehensive understanding of the adoption dynamics, barriers, and economic outcomes associated with twin transformation practices.

Data Collection

The study gathered data through structured surveys distributed to 50 farms in each country, representing a diverse range of farm types (crop, livestock, mixed, and other). The survey focused on key economic metrics, including:

- *Investment Costs*: Amounts allocated to digital and green technologies.
- *Operational Savings*: Reductions in input costs and resource use.
- *Gross Margins*: Changes in profitability post-adoption.
- *Farm Income*: Annual income variations after technology implementation.
- *Cost-Benefit Ratios*: Farmers' perceptions of the economic feasibility of adoption.

The respondents were selected through stratified random sampling to ensure representativeness across farm types and sizes.

Analytical Framework

A quantitative analytical framework was employed to capture the economic impacts of technology adoption. The analysis involved:

- *Descriptive Statistics*: Metrics such as means, medians, and standard deviations were calculated to summarize adoption rates, investment patterns, and operational savings.
- *Comparative Analysis*: Differences between Lithuanian and Romanian farms were analyzed to identify variations in investment behaviors and economic outcomes.
- *Economic Impact Evaluation*: A detailed assessment of profitability, cost savings, and cost-benefit ratios was conducted to evaluate the financial feasibility of twin transformation practices.

RESULTS AND DISCUSSION

Table 1 below summarizes general information about the survey respondents and their technological adoption patterns. This data offers insights into the characteristics of participating farms in Lithuania and Romania, emphasizing the adoption rates of digital and green technologies. By examining the distribution of farm types, average farm sizes, and technological implementation rates, we aim to highlight the challenges and opportunities faced by farms transitioning toward sustainable practices in agriculture.

Table 1. General information and technological adoption patterns of survey respondents

Metric	Details
Total Respondents	50
Country	Lithuania (25), Romania (25)
Farm Types	Arable (40%), Mixed (40%), Livestock (20%)
Average Farm Size (ha)	52
Average Years in Operation	8

Data from the survey highlights notable trends in the characteristics and technological adoption patterns of farms in Lithuania and Romania. Respondents were evenly distributed between the two countries, allowing for a balanced comparison. Most farms are engaged in arable and mixed farming, which together account for 80% of the total sample. This distribution aligns with the agricultural profiles of both nations, where crop production and diversified farming are predominant practices.

Technological adoption rates reveal that a significant proportion of farms are integrating modern practices. Digital technologies are adopted by 70% of the respondents, suggesting a widespread recognition of their benefits in improving productivity and operational efficiency. Green technologies are also increasingly utilized, with a 60% adoption rate indicating a growing commitment to environmental sustainability. However, the presence of a 30% non-adoption rate reveals persistent challenges, such as high costs, limited access to funding, and insufficient technical knowledge. Farms that have not adopted these technologies often operate on smaller scales, which limits their ability to invest in advanced systems.

The average farm size of 52 hectares and an average operational history of 8 years indicate that the surveyed farms are primarily small to medium-sized enterprises with considerable experience. Despite this, the data suggests that financial and technical constraints remain key obstacles for these farms to fully embrace twin transformation practices. This reinforces the need for targeted policies to support farms with limited resources, especially in regions where adoption rates lag.

Findings underscore the progress made in the adoption of digital and green technologies while highlighting ongoing barriers. Policymakers must address these barriers by providing more accessible funding mechanisms, enhancing farmer education, and promoting the benefits of twin transformation through demonstration programs.

It is imperative that all agricultural enterprises, irrespective of their scale, are afforded the opportunity to engage in this transition, as this will be essential for realizing sustainable agricultural advancement in Lithuania and Romania. Subsequent investigations could examine the particular economic ramifications of these technologies on the profitability and resilience at the farm level, thereby offering more profound insights into their sustainability over the long term.

The survey results provide a detailed overview of the adoption rates and impacts of digital technologies across various farm types in Lithuania and Romania. The respondents were stratified into arable crop (CR), livestock (LV), mixed (MX), and other (Oth) farms, capturing the diversity of agricultural practices in the two countries. The data highlights the extent to which farms have embraced digital technologies, the types of technologies adopted, the barriers faced, and the resulting economic and environmental impacts. These insights are crucial for understanding the drivers and challenges of twin transformation in agriculture and informing targeted policy and support mechanisms. The Table 2 below presents the survey results on digital technology adoption, types of technologies implemented, reasons for adoption, barriers faced, economic impacts, and future goals across various farm types in Lithuania and Romania. All numbers in the table are expressed as percentages of the total respondents for each farm type, with 25 respondents from each country.

Table 2. Survey results on digital technology adoption and impacts across farm types in Lithuania and Romania

	LT CR	LT LV	LT MX	LT Oth	RO CR	RO LV	RO Mx	RO Oth
Have you adopted any digital technologies on your farm (e.g., precision farming tools, sensors, drones)?								
Yes	64	84	88	76	60	84	88	68
If yes, which technologies have you adopted?								
Soil sensors	72	36	48	52	60	44	64	72
Drones for crop monitoring	4	0	0	8	12	12	4	8
GPS-guided machinery	4	8	4	16	8	4	8	20
Data analytics software	92	96	96	88	96	92	96	96
Other (please specify): _____	96	92	100	100	96	100	96	100
What were the main reasons for adopting digital technologies?								
Increase productivity	96	80	76	84	88	84	92	88
Reduce costs	96	100	92	96	88	96	100	92
Improve resource efficiency	100	92	96	80	92	96	84	100
Comply with regulations	8	36	20	52	68	76	56	80
Other (please specify): _____	40	64	84	72	84	76	80	92
What barriers did you face in adopting digital technologies?								
High costs	72	64	80	96	92	80	52	60
Lack of technical knowledge	24	56	40	8	16	52	36	24
Limited access to funding	84	68	80	16	60	76	88	64
Unclear benefits	4	12	4	16	8	4	4	8
Other (please specify): _____	32	44	52	60	28	64	72	56
Economic Impact								
How has adopting digital and/or green technologies affected your farm's profitability?								
Increased significantly	36	40	16	32	12	28	20	44
Increased slightly	64	56	84	60	80	72	76	56
No change	0	4	0	8	8	0	4	0
Decreased slightly	0	0	0	8	0	4	0	0
Decreased significantly	0	0	0	0	0	0	0	0
What is the estimated percentage of cost savings achieved after adopting these technologies?								
Less than 10%	0	20	32	52	8	44	36	72
10–20%	76	80	60	48	92	52	64	20
21–50%	24	0	8	0	0	4	0	8
More than 50%	0	0	0	0	0	0	0	0
Future perspectives: What is your primary goal for adopting digital and green technologies in the next 5 years?								
Increase farm profitability	80	76	84	80	92	76	84	88
Enhance environmental sustainability	52	24	48	60	72	56	76	68
Improve compliance with regulations	12	36	24	32	40	48	44	56
Other (please specify): _____	60	72	24	48	28	36	44	36

The survey reveals high levels of digital technology adoption across all farm types in both countries, with rates exceeding 60% in most cases. Mixed farms in Lithuania and other farm types in both countries reported the highest adoption rates (above 88%). Data analytics software emerged as the most commonly adopted technology, with adoption rates near or exceeding 90% across all farm types. In contrast, more advanced tools like drones and GPS-guided machinery showed limited uptake, with adoption rates below 20%.

The primary motivations for adopting digital technologies included increasing productivity, reducing costs, and improving resource efficiency. These drivers were consistently cited by over 80% of respondents, highlighting the perceived economic and environmental benefits of digital tools. Compliance with regulations was less commonly reported, particularly in

Lithuania, where it was a motivator for only 8% of crop farms.

High costs were identified as the most significant barrier, particularly for livestock farms in both countries, where over 90% of respondents cited cost as a limitation. Limited access to funding was another major challenge, affecting up to 88% of farms. Interestingly, lack of technical knowledge was a more significant issue in Romania than in Lithuania, particularly for mixed and other farm types.

Adopting digital technologies had a predominantly positive impact on farm profitability. Over 90% of respondents reported increased profitability, with the majority observing slight increases. However, only a small fraction (less than 10%) reported cost savings exceeding 20%, suggesting that the economic benefits of adoption may be incremental for most farms.

Farmers in both countries prioritized increasing profitability as their primary goal for adopting digital and green technologies in the next five years, with adoption goals cited by over 80% of respondents. Enhancing environmental sustainability was also a significant driver, particularly for mixed and livestock farms in Romania, where rates exceeded 70%.

The results highlight significant progress in the adoption of digital technologies in Lithuanian and Romanian agriculture, driven by clear economic incentives. The widespread use of data analytics software suggests that many farms recognize the value of optimizing operations through better data management. However, the limited adoption of more advanced tools like drones and GPS-guided machinery indicates that financial and technical barriers persist, particularly for smaller or less resourced farms.

The emphasis on productivity and cost reduction as key motivators aligns with broader trends in agricultural modernization. However, the relatively low prioritization of regulatory compliance suggests that more effort is needed to align digital transformation with policy goals, such as emissions reductions and sustainability targets.

The economic impacts of adoption appear promising but modest, with most farms reporting slight increases in profitability and limited cost savings. This could reflect the early stages of adoption, where initial investments are yet to yield significant returns. Policymakers and stakeholders should focus on addressing barriers like high costs and limited funding access to accelerate adoption and maximize economic benefits.

The survey underscores the importance of targeted interventions to support the adoption of digital technologies in agriculture. While many farms are already benefiting from these tools, barriers like high costs, limited funding, and technical knowledge gaps need to be addressed. Future efforts should focus on promoting access to affordable technologies, providing training programs, and aligning digital transformation with broader sustainability and policy goals. These actions will be critical to ensuring that farms in Lithuania and Romania can fully realize the potential of twin transformation in agriculture.

The Table 3 below summarizes the survey findings on economic metrics associated with adopting digital and green technologies in Lithuanian and Romanian farms. The metrics analyzed include investment costs, operational savings, gross margin changes, annual farm income, and cost-benefit ratios. The responses, expressed as percentages, reflect the financial outcomes and perceptions of technology adoption among farmers in the two countries. This comparative analysis provides valuable insights into the economic dynamics of digital and green transitions in agriculture.

The survey reveals significant differences between Lithuanian and Romanian farms in terms of investment costs and economic outcomes from adopting digital and green technologies.

Lithuanian farms predominantly invested less than €5,000 (56%), with only 16% investing more than €20,000. Conversely, Romanian farms showed a greater share of high investments, with 44% spending over €20,000. This suggests that Romanian farms

might be more engaged in larger-scale or capital-intensive adoption initiatives.

Both countries achieved moderate operational savings. Lithuanian respondents most frequently reported savings in the range of 5-10% (60%), while Romanian respondents reported a slightly higher percentage in the same range (68%). However, higher savings (above 20%) were rare, especially in Romania, where only 4% achieved such reductions.

Lithuanian farms experienced significant improvements in gross margins, with 64% reporting substantial increases compared to 40% in Romania. Romanian respondents were more likely to report slight increases (60%). No farms in either country reported decreased margins, indicating positive overall impacts.

In Lithuania, a larger proportion of farms (40%) achieved an annual income of €100,001 - €200,000, suggesting notable financial benefits from technology adoption. Romanian farms showed a more even distribution, with 24% reaching the highest income bracket of more than €200,000.

The perception of cost-benefit ratios was overwhelmingly positive in both countries, with 52% of Lithuanian respondents and 68% of Romanian respondents rating the ratio as highly favorable. Notably, no respondents in either country viewed the cost-benefit ratio as unfavorable.

The findings highlight differing adoption dynamics between Lithuanian and Romanian farms. Lithuanian farms appear to be more cautious in their investments, focusing on moderate cost levels and achieving steady profitability improvements. Romanian farms, in contrast, demonstrate a higher willingness to invest larger amounts, which could reflect different scales of operations or stronger policy incentives for technology adoption.

Operational savings remained relatively modest across both countries, emphasizing the need for further efficiency improvements. Higher gross margin increases in Lithuania may indicate more effective integration of digital and green technologies, while Romanian farms might require additional support to optimize returns.

The overwhelmingly positive perceptions of cost-benefit ratios reinforce the economic viability of digital and green technologies. However, the relatively low proportion of farms reporting high operational savings suggests that many benefits may be realized over a longer time horizon.

Table 3. Economic metrics of digital and green technology adoption in Lithuanian and Romanian farms

Question	Lithuanian respondents	Romanian respondents
What was the total amount you invested in adopting digital and/or green technologies over the past year?	Less than €5,000: 56% €5,000 - €10,000: 20% €10,001 - €20,000: 8% More than €20,000: 16%	Less than €5,000: 32% €5,000 - €10,000: 12% €10,001 - €20,000: 12% More than €20,000: 44%
By what percentage have your operational costs decreased after adopting digital and/or green technologies?	Less than 5%: 12% 5-10%: 60% 11-20%: 20% More than 20%: 8%	Less than 5%: 20% 5-10%: 68% 11-20%: 8% More than 20%: 4%
How has your farm's gross margin changed since adopting digital and/or green technologies?	Increased significantly: 64% Increased slightly: 32% No change: 4 % Decreased: 0%	Increased significantly: 40% Increased slightly: 60% No change: 0% Decreased: 0%
What is your estimated annual farm income since adopting digital and/or green technologies?	Less than €50,000: 16% €50,001 - €100,000: 28% €100,001 - €200,000: 40% More than €200,000: 16%	Less than €50,000: 24% €50,001 - €100,000: 32% €100,001 - €200,000: 20% More than €200,000: 24%
How would you rate the cost-benefit ratio of adopting digital and/or green technologies?	Highly favorable: 52% Moderately favorable: 36% Neutral: 12% Unfavorable: 0%	Highly favorable: 68% Moderately favorable: 24% Neutral: 8% Unfavorable: 0%

The survey confirms that digital and green technologies have a predominantly positive economic impact on farms in Lithuania and Romania. Lithuanian farms benefit from steady profitability improvements with moderate investments, while Romanian farms show greater engagement in high-cost, potentially high-return projects. Policymakers should focus on enhancing access to affordable technologies and optimizing operational efficiencies to maximize the benefits of twin transformation. Further research should explore the long-term economic impacts and the role of policy incentives in accelerating adoption.

Table 4 presents descriptive summary statistics for key economic metrics associated with the adoption of digital and green technologies in agriculture. These metrics include adoption rates, investment levels, and operational savings. The statistics - mean, median, and standard deviation - offer insights into the central tendencies and variability of these factors, highlighting the economic impacts and challenges faced by farms during the twin transformation process. This analysis provides a foundation for understanding patterns in technology adoption and its financial outcomes.

Table 4. Descriptive summary statistics of adoption rates, investments, and savings

Metric	Mean (%)	Median (%)	Standard Deviation (%)
Adoption Rates	76.25	76.0	10.29
Investment Less than €5k	44.00	44.0	12.73
Investment €5k - €10k	16.00	16.0	4.00
Investment €10k - €20k	10.00	10.0	2.83
Investment More than €20k	30.00	30.0	14.14
Savings Less than 5%	16.00	16.0	5.66
Savings 5-10%	64.00	64.0	5.66
Savings 11-20%	14.00	14.0	8.49
Savings More than 20%	6.00	6.0	2.83

The table provides a comprehensive overview of the use of smart solutions and nudges to enhance public involvement in biodiversity conservation across the European Union (EU). These strategies are categorized based on their nature, degree of compulsion, and psychological mechanisms, highlighting how they contribute differently yet complementarily to conservation efforts.

The mean adoption rate across all farm types is 76.25%, with a relatively small standard deviation of 10.29%. This indicates consistently high adoption rates among the surveyed farms, reflecting widespread recognition of the benefits of digital and green technologies.

The most frequent investment category is less than €5,000, with a mean of 44% and a standard deviation of 12.73%, indicating moderate variability. Investment in higher-cost categories (€5,000 - €10,000 and €10,001 - €20,000) shows lower means (16% and 10%, respectively) and small standard deviations, suggesting that fewer farms are investing at these levels. Farms investing more than €20,000 show a mean of 30%, with the highest variability (standard deviation of 14.14%). This reflects a greater disparity in the financial capacity of farms to undertake high-cost investments.

Operational savings in the 5-10% range dominate, with a mean of 64% and a low standard deviation of 5.66%. This suggests that most farms are achieving moderate operational cost reductions. Higher savings categories, such as 11-20% and more than 20%, have significantly lower means (14% and 6%, respectively) and greater variability, indicating that substantial savings are less common and highly dependent on individual farm circumstances.

The statistics highlight key trends in the economic impacts of twin transformation practices. High adoption rates suggest that

farms are increasingly embracing digital and green technologies, motivated by the potential to improve productivity, reduce costs, and enhance sustainability. However, the relatively low levels of investment in higher-cost categories indicate that many farms, particularly smaller ones, may face financial constraints in adopting more advanced technologies.

Operational savings are concentrated in the moderate range (5-10%), which suggests that while adoption is beneficial, the economic returns may not yet justify larger-scale investments for many farms. This could reflect the early stages of technology adoption, where initial costs are yet to be offset by efficiency gains. The variability in higher-cost investments and savings categories points to disparities in farm sizes, financial capacities, and access to funding. Larger farms or those with access to subsidies may be better positioned to invest in costly technologies and achieve significant cost savings.

The comparative analysis between Lithuanian and Romanian farms highlights notable differences in investment patterns, adoption dynamics, and economic outcomes of twin transformation practices. Romanian farms demonstrate a higher proportion of investments exceeding €20,000 (44%), compared to 16% in Lithuania, indicating a greater willingness or capacity to engage in high-cost technology adoption. This disparity could be attributed to several factors, including farm size, access to funding mechanisms, and the structure of agricultural operations in the two countries.

Romanian farms, often characterized by larger operational scales, may benefit from economies of scale, enabling them to allocate more resources toward technology adoption. Additionally, policy and funding mechanisms in Romania appear to play a significant role. EU subsidies and national support programs targeted at modernizing agriculture have encouraged investments in advanced technologies. By contrast, Lithuanian farms, which tend to be smaller and more fragmented, might face greater financial constraints, limiting their ability to invest in costly technologies.

The economic outcomes also differ. While both countries show high adoption rates for digital technologies, Lithuanian farms achieve greater operational savings and profitability improvements within moderate investment categories. This suggests that Lithuanian farms may adopt more cost-efficient solutions tailored to their specific needs, whereas Romanian farms, with higher investments, aim for broader-scale technological integration.

The observed differences align with broader themes in the literature on agricultural transformation. High costs and funding limitations remain significant barriers, particularly for smaller farms in both countries. This finding is consistent with previous studies (Ardakani et al., 2020; Rijswijk et al., 2021), which emphasize that financial constraints and limited access to affordable technologies disproportionately affect smaller-scale operations. Romanian farms, while benefitting from larger investments, face challenges in achieving consistent cost savings, reflecting inefficiencies in technology deployment or gaps in technical knowledge.

The findings underline the critical role of policy and funding mechanisms in shaping adoption dynamics. To accelerate twin transformation, policymakers should consider the following measures: expand financial support for smaller farms to bridge the investment gap and enable equitable access to advanced technologies, develop programs that enhance farmers' technical knowledge and ability to effectively utilize digital and green technologies, encourage the development of scalable and cost-efficient solutions for farms with varying resource capacities.

The success of twin transformation depends on addressing these systemic barriers while fostering innovation and collaboration among stakeholders. By aligning policy frameworks with the specific needs of farms in different regions, both Lithuania and Romania can achieve sustainable and inclusive agricultural modernization.

Future research should focus on evaluating the long-term impacts of these interventions and identifying best practices for scaling up successful strategies across the EU.

CONCLUSIONS

This study explores the economic impacts of twin transformation in Lithuanian and Romanian agriculture, analyzing the adoption of digital and green technologies. The findings underscore the significant, yet varied progress made by farms in these countries toward sustainable practices.

The results demonstrate high adoption rates for digital technologies across both regions, with data analytics software being the most widely utilized tool. However, the investment patterns differ significantly. Romanian farms show a greater propensity for high-cost investments, with 44% of respondents allocating over €20,000, compared to only 16% in Lithuania. This disparity highlights the role of farm size and access to funding in shaping adoption dynamics.

Operational cost savings are primarily concentrated in the 5-10% range for both countries, reflecting the early-stage benefits of these technologies. Lithuanian farms appear to adopt cost-effective strategies, achieving notable profitability improvements with moderate investments. Romanian farms, on the other hand, pursue larger-scale initiatives that require substantial resources but demonstrate potential for broader impacts.

The study identifies several barriers to adoption, including high costs and limited funding, particularly for smaller farms. Technical knowledge gaps, more pronounced in Romania, further constrain the effective utilization of advanced technologies. These findings align with existing literature, emphasizing the critical need for tailored policy interventions.

To address these challenges, the study recommends expanding financial incentives, enhancing capacity-building programs, and fostering inclusive policies that enable equitable access to technologies. By addressing these systemic barriers, policymakers can ensure that the twin transformation becomes a viable pathway for sustainable agricultural development in the European Union.

Future research should focus on long-term assessments of economic and environmental impacts, as well as the effectiveness of policy measures in reducing disparities across regions. This study provides a foundational framework for advancing twin transformation and ensuring its benefits reach all stakeholders in the agricultural sector.

REFERENCES

Ardakani, Z., Bartolini, F., Brunori, G., 2020. *New Evaluation of Small Farms: Implication for an Analysis of Food Security*. Agriculture, 10(3), 74. https://doi.org/10.3390/agriculture10030074

Bongiovanni, R., and Lowenberg-DeBoer, J., 2004. *Precision Agriculture and Sustainability*. Precision Agriculture, 5: 359-387.

Chiţea, M.A., Rusu, M., Florian, V., Chiţea, L., Roşu, E., Simion, G., 2022. *Traditional agricultural practices in Suceava County, Romania*. Agrarian Economy and Rural Development-Trends and Challenges, International Symposium, 13th Edition: 336-343.

Chiurciu, I., Cofas, E., Dragomir, V., 2020. *Study on the production and marketing of potatoes in the European Union*. Romanian Agricultural Research, 37: 243-251. https://doi.org/10.59665/rar3727

Eurostat, 2023. *EU economy greenhouse gas emissions: -7.1% in Q3 2023*. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240214-1

FAO, 2021. *Strategy on Climate Change 2022-2031*. https://knowledge4policy.ec.europa.eu/publication/fao-strategy-climate-change-2022-2031_en

Finger, R., 2023. *Digital innovations for sustainable and resilient agricultural systems*. European Review of Agricultural Economics, 50: 1277-1309. 10.1093/erae/jbad021

Gaiani, S., and Ala-Karvia, U., 2023. *Digital innovation hubs as drivers for digital transition and economic recovery*, 10.4324/9781003450160-7. https://www.researchgate.net/publication/376466731_Digital_innovation_hubs_as_drivers_for_digital_transition_and_economic_recovery

Gavrilović, M., Muhović, A., Pavlović, N., 2024. *Analysis of the Application of Modern Technologies in Agriculture in Three Balkan Countries and the Impact on Biodiversity*. Romanian Agricultural Research, 41: 79-90. https://doi.org/10.59665/rar4108

Granado-Díaz, R., Colombo, S., Romero-Varo, M., Villanueva, A.J., 2024. *Farmers' attitudes toward*

the use of digital technologies in the context of agri-environmental policies. Agricultural Systems, 221, 104129. https://doi.org/10.1016/j.agsy.2024.104129

Kalpaka, A., Sörvik, J., Tasigiorgou, A., Rissola, G., 2020. *Digital Innovation Hubs as policy instruments to boost digitalisation of SMEs*. 10.2760/085193.

Karunathilake, E M., Le, A.T., Heo, S., Chung, Y.S., Mansoor, S., 2023. *The Path to Smart Farming: Innovations and Opportunities in Precision Agriculture*. Agriculture, 13, 1593. 10.3390/agriculture13081593

Kurlavičius, A., Žukovskis, J., Gozdowski, D., Wójcik-Gront, E., 2024. *Economic, Social, and Environmental Factors Impacting Resilience and Disturbances of Lithuanian Family Farms*. Agriculture, 14, 1088. https://doi.org/10.3390/agriculture14071088

Monticone, F., and Samoggia, A., 2024. *Food Policy Coherence and Integration: a review of adopted methodologies*. Rivista di Economia Agraria, 78: 35-49. https://www.researchgate.net/publication/380628169_Food_Policy_Coherence_and_Integration_a_review_of_adopted_methodologies

Myshko, A., Checchinato, F., Colapinto, C., Finotto, V., Mauracher, C., 2024. *Towards the twin transition in the agri-food sector?* Framing the current debate on sustainability and digitalisation, Journal of Cleaner Production, 452, 142063. https://doi.org/10.1016/j.jclepro.2024.142063

Niskanen, O., Tienhaara, A., Haltia, E., Pouta, E., 2021. *Farmers' heterogeneous preferences towards results-based environmental policies*. Land Use Policy, 102, 105227. 10.1016/j.landusepol.2020.105227

Rijswijk, K., Klerkx, L., Bacco, M., Bartolini, F., Bulten, E., Debruyne, L., Dessein, J., Scotti, I., Brunori, G., 2021. *Digital transformation of agriculture and rural areas: A socio-cyber-physical system framework to support responsibilisation*. Journal of Rural Studies, 85: 79-90. https://doi.org/10.1016/j.jrurstud.2021.05.003

Rizzo, G., Migliore, G., Schifani, G., Vecchio, R., 2024. *Key factors influencing farmers' adoption of sustainable innovations: a systematic literature review and research agenda*. Organic Agriculture, 14: 57-84. https://doi.org/10.1007/s13165-023-00440-7

Satpathy, B., 2022. *Digital transformation for sustainable agriculture: a progressive method for smallholder farmers*. Current Science, 123(12): 1436.

Sekhar, M., Rastogi, M., Rajesh, M., Saikanth, D.R., Rout, S., Kumar, S., Patel, A., 2024. *Exploring Traditional Agricultural Techniques Integrated with Modern Farming for a Sustainable Future: A Review*. Journal of Scientific Research and Reports, 30: 185-198. 10.9734/jsrr/2024/v30i31871

Sterie, C.M., and Dragomir, V., 2023. *Global trends on research towards agriculture adaptation to climate change*. Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural. Dev., 23: 759-766.

Tagarakis, A., Benos, L., Kyriakarakos, G., Pearson, S., Sørensen, C., Bochtis, D., 2024. *Digital Twins in Agriculture and Forestry: A Review*. Sensors, 24, 3117. https://www.researchgate.net/publication/380545728_Digital_Twins_in_Agriculture_and_Forestry_A_Review

Wang, L., 2024. *Digital Twins in Agriculture: A Review of Recent Progress and Open Issues*. Electronics, 13, 2209. 10.3390/electronics13112209