# MARKET INCLUSION AND SUSTAINABLE PRACTICE IN SERBIAN AGRITOURISM

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ABSTRACT

This study examines how market integration affects the adoption of sustainable production practices among agritourist households in Serbia. Using a Propensity Score Matching approach supported by endogeneity tests, mediation analysis, and Double Machine Learning, data from 148 households were analyzed. Results show that participation in modern market channels significantly increases the use of green technologies, particularly drip irrigation, biological pest control, and crop residue management. The mediation model confirms that market integration fosters adoption partly by enhancing producers' cognitive awareness of sustainability. Findings remain robust across different estimation methods. The study offers policy insights into promoting sustainable agritourism through support for market access and digital competencies.

## Introduction

Agricultural production is undergoing major shifts under the combined pressure of climate change, stricter environmental regulations, and rising market expectations, positioning sustainability as a key principle for future systems (Datta & Behera, 2022; Elnahal et al., 2022). Traditional intensive models are increasingly inadequate for protecting resources, adapting to climate risks, and ensuring household viability. Farmers'

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perceptions play a central role in this transition. Jha et al. (2020) emphasize that attitudes and willingness to adopt innovations are crucial, especially in developing countries with limited adaptive capacity. Zhang et al. (2025) further highlight the importance of market incentives and cognitive mechanisms in shaping sustainable behavior. Broader climate perceptions also matter, Torres et al. (2020) stress that recognizing climate risks is vital for adopting mitigation technologies. In Serbia, financial constraints remain a barrier (Petrović et al., 2021), yet education and market integration, especially through tourism and gastronomy, can improve household sustainability (Vuksanović et al., 2024). Despite the considerable body of research analyzing perceptions, adaptation, and market positioning in the context of sustainable agriculture, there remains a lack of integrated studies examining how market engagement and opportunities directly influence farmers' decisions to adopt sustainable production practices, particularly through the mediating role of cognitive awareness regarding ecological benefits (Datta & Behera, 2022; Zhang et al., 2025). Building on these findings, this study aims to investigate the effects of market engagement on the adoption of sustainable production technologies among agricultural households involved in agritourism in Serbia, with a specific focus on the role of farmers' perceptions and knowledge as mediating mechanisms in decision-making processes. In doing so, the study contributes to filling identified theoretical gaps and offers a comprehensive analytical framework for understanding the transition toward sustainable production practices under conditions of market diversification.

## Conceptual background and hypotheses formulation

The link between sustainability and rural diversification through agritourism has gained prominence, yet many studies remain conceptually limited. Brandano et al. (2018) discuss supply-demand balance in agritourism but offer little on household-level adoption. Shen et al. (2020) focus on sustainability indicators at the macro level, while Cavalleri (2021) reveals regional disparities that hinder broader generalizations. More recent research shifts toward household decisions. Pehin Dato Musa and Chin (2022) confirm the role of farm-to-table models but narrowly frame sustainability through gastronomic practices. Cavalleri, Tanwattana, and Grünbühel (2022) highlight market knowledge as vital, though evidence on how integration drives ecological investments is lacking. Stankulova et al. (2024) critique conventional metrics for ignoring ecological dimensions. In Serbia, Gajić et al. (2024) and Ristić et al. (2019) show agritourism's sustainability potential, yet causal pathways between market engagement and technology adoption remain unclear. Bibliometric reviews (Yasin & Bacsi, 2025; Yuan, 2025) confirm this gap, calling for empirically grounded, mechanism-focused studies. The role of agritourism in sustainable rural development has drawn increasing scholarly interest, particularly regarding its potential to strengthen rural economies and living standards. Ciolac et al. (2019) show how activity diversification revitalizes Romanian villages, yet without addressing market participation or production technologies. Ammirato et al. (2020) emphasize the strategic role of market positioning for agritourism sustainability, though they note a lack of focus on household-level decision-making.

Similarly, Paniccia and Baiocco (2020) underline how market, institutional, and social co-evolution fosters modernization, but evidence on technology uptake remains limited. Wang et al. (2025) find that stronger market structures in China boost ecological innovation, though regional disparities mediate the effect. Baipai et al. (2023) argue that market access enables reinvestment in green practices, but institutional and educational gaps weaken outcomes. Studies from Slovenia (Cigale & Lampič, 2023), Indonesia (Riady et al., 2024), and Serbia (Popović et al., 2025) affirm that market control and visibility support adoption, but effects vary across contexts. Despite growing literature, most studies lack causal insight into how market engagement concretely drives green technology adoption in agritourism. Hence, this study tests:

*H1: A higher degree of market engagement by agritourism households positively influences the adoption of sustainable production practices*.

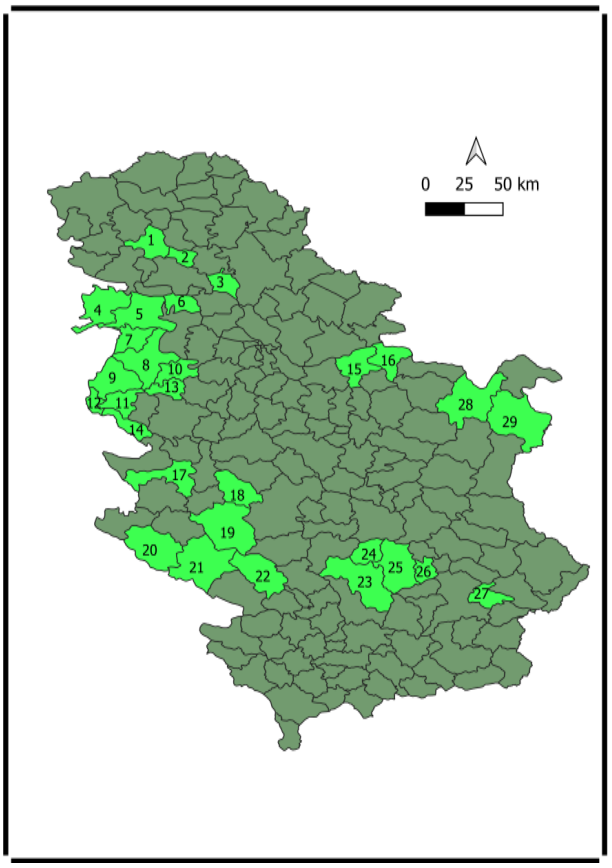
While institutional incentives matter, they fall short without producer awareness. Kiełbasa et al. (2018) and Petway et al. (2019) note barriers like poor nutrient practices, yet offer little on structural solutions. Ramborun et al. (2020) and Li et al. (2020) highlight ecological awareness but don't clarify whether it stems from learning or market forces. Muhamadi and Boz (2022) and Sulaj et al. (2022) link education to sustainability openness, ignoring wider socio-institutional factors. Baipai et al. (2023) and Cigale & Lampič (2023) stress the role of cognitive readiness but remain case-bound. Riady et al. (2024) show that direct sales aid green adoption only when market complexities are understood, without broader generalization. Others (Nistoreanu et al., 2024; Bednář et al., 2025; Kanazoe et al., 2025; Kule et al., 2025; Batas et al., 2025; Stankulova et al., 2024) confirm awareness as key but often treat it passively. Based on these insights, the second research hypothesis is formulated to test whether market engagement indirectly influences the adoption of sustainable technologies through the development of cognitive awareness among farm households:

*H2: The effect of market engagement on the adoption of sustainable production practices is partially mediated by the cognitive awareness of farm households regarding sustainable production.*

## Methodology

The research was conducted in Serbia on 148 registered agritourism households combining farming, tourism, and direct food sales. Data were collected from August 2024 to May 2025 across Vojvodina, Šumadija, Western, and Eastern Serbia, ensuring regional diversity. The sample included both households using digital sales channels (websites, social media, apps) and those relying on traditional on-site sales, enabling a direct comparison of their impact on sustainable production adoption.

**Figure 1**. Research area




Area of research (Municipalities where the research was conducted with the number of agrotourism farms):

Republic of Serbia
1. Vrbas (3)
2. Temerin (4)
3. Titel (4)
4. Šid (5)
5. Sremska Mitrovica (8)
6. Irig (5)
7. Bogatić (6)
8. Šabac (7)
9. Loznica (7)
10. Vladimirci (5)
11. Krupanj (5)
12. Mali Zvornik (3)
13. Koceljeva (3)
14. Ljubovija (5)
15. Požarevac (4)
16. Veliko Gradište (4)
17. Užice (6)
18. Lučani (4)
19. Ivanjica (7)
20. Prijepolje (6)
21. Sjenica (4)
22. Novi Pazar (4)
23. Kuršumlija (7)
24. Blace (5)
25. Prokuplje (6)
26. Žitoradja (3)
27. Vlasotince (6)
28. Majdanpek (6)
29. Negotin (2)

*Source*: Authors' calculations

Prior to the main survey, a pilot study was conducted to test the clarity, comprehensibility, and functionality of the questionnaire. The pilot sample included 20 agritourism households, structurally representative of the target population but not included in the final analysis. Based on pilot results, minor adjustments were made to improve the precision, terminology, and interpretability of measurement scales. The questionnaire design involved consultations with experts in rural development, agritourism, and sustainable agriculture, ensuring content validity and methodological consistency. These consultations helped identify ambiguous formulations and enhanced instrument reliability. The questionnaire was based on validated instruments related to digital sales, agritourism, and sustainable agriculture (Jha et al., 2020; Torres et al., 2020; Ammirato et al., 2020; Datta & Behera, 2022; Gajić et al., 2024; Zhang et al., 2025), adapted to the Serbian context (Petrović et al., 2021; Vuksanović et al., 2024). It covered household characteristics, market engagement, and sustainability perceptions, with emphasis on cognitive awareness of green production—measured through knowledge,

responsibility, and perceived benefits (Ramborun et al., 2020; Li et al., 2020; Muhamadi & Boz, 2022; Sulaj et al., 2022; Kanazoe et al., 2025)—using five-point Likert scales. An entropy-weighted composite index captured awareness multidimensionality (Cigale & Lampič, 2023; Baipai et al., 2023; Bednář et al., 2025; Kule et al., 2025). Among 148 valid responses (41.9% digital, 58.1% traditional), most were farm owners or managers. The average respondent was 49.7 years old, with secondary education, 12.3 years of agritourism experience, and 4.7 hectares of land. Net income averaged €5,200 per household member. Local product specialization (64%) and participation in sustainability training (47%) indicate moderate but improvable market orientation and formal knowledge (Table 1).

**Table 1**. Overview of basic descriptive statistics for agritourism household sample variables

| Variables | Variable definition | M (SD) |
|---|---|---|
| **Age of household head** | Chronological age in years | 49.7 (8.4) |
| **Education level** | 1 = primary or lower; 2 = secondary; 3 = higher education | 2.31 (0.68) |
| **Number of active family Members** | Total number of family members engaged in farm activities | 2.44 (0.93) |
| **Years in agritourism** | Number of years engaged in agritourism activities | 12.3 (5.9) |
| **Cultivated land area (ha)** | Total area of cultivated land (hectares) | 4.7 (3.2) |
| **Net income per household member** | Annual net income per household member (in thousand EUR) | 5.2 (2.1) |
| **Specialized production** | 1 = household produces specific local products; 0 = no | 0.64 (0.48) |
| **Partial off-farm employment** | 1 = household member has additional non-farm income; 0 = no | 0.22 (0.42) |
| **Participation in training** | 1 = participated in sustainable production training; 0 = no | 0.47 (0.50) |
| **Digital sales participation** | 1 = uses digital sales channels; 0 = traditional sales only | 0.42 (0.49) |
| **Number of sustainable practices adopted** | Total number of sustainable technologies adopted (0 to 5) | 2.36 (1.14) |

*Source*: author's research

The study followed strict ethical standards. Participants were fully informed about the research purpose, ensured anonymity, and participated voluntarily with the right to withdraw at any time. All data were used exclusively for research, with personal information kept confidential. Measures were taken to minimize moral hazard through transparent communication and the prevention of any undue influence during data collection.

## Model design and estimation strategy

### *Addressing selection bias using propensity score matching*

In this study, the adoption of digital sales channels by agritourism households is treated as a non-random decision influenced by education, income, production specialization, and market orientation. As these same factors may also affect the adoption of sustainable

practices, the risk of selection bias arises. To address this, the analysis applies the Propensity Score Matching (PSM) method, which compares households with similar characteristics but differing digital sales engagement (Angrist & Pischke, 2009). This quasi-experimental approach estimates how digital households would behave in the absence of digital sales. Propensity scores were calculated using a logit model based on relevant socio-economic and production variables. The probability of household participation in digital sales channels (i.e., the propensity score) was estimated using a logit model, specified as follows:

$$Pi = P(Di = 1 \mid Xi) = \frac{e\beta 0 + \beta 1Xi1 + \beta 2Xi2 + \cdots + \beta kXik}{1 + e\beta 0 + \beta 1Xi1 + \beta 2Xi2 + \cdots + \beta kXik}$$

The probability that a household adopts digital sales channels (Pi) was estimated using a logit model, where Xi_includes socio-demographic, economic, and production characteristics, and β represents model coefficients. The procedure involved three stages. First, households were classified into treatment (digital sales users) and control groups. Covariates included age, education, income, farm size, agritourism experience, specialization, and prior training. Second, households were matched using various PSM algorithms (nearest neighbor, radius, caliper, kernel) to ensure comparability. Finally, the Average Treatment Effect on the Treated (ATT) was calculated to measure the difference in the number of sustainable practices adopted, defined as ATT=*E(Y1− Y0□D=1)* where Y1 is the observed outcome with digital sales and Y0 the counterfactual without it (Hayes, 2018).

*Causal pathways: the mediation analysis framework*

To clarify how digital sales influence the adoption of sustainable practices, the study applies mediation analysis, aiming to uncover not just whether an effect exists, but how it operates. Guided by the Theory of Planned Behavior (Ajzen, 1991), the model assumes that digital participation affects green production both directly and indirectly, by shaping farmers' knowledge, attitudes, and perceptions. The cognitive awareness index reflects key TPB components: behavioral attitudes and perceived control. Engagement in digital platforms increases exposure to sustainability-oriented market demands, encouraging producers to learn about ecological techniques and standards. This acquired awareness is posited as the mediating factor linking market integration to adoption decisions. The mediation was tested via a two-step model: first estimating the effect of digital sales on the awareness index, and then analyzing the index's influence on the adoption of sustainable technologies (Zou et al., 2021). Formally, the basic regression specification of the mediation model was defined as follows:

$$M_i=\alpha+\beta D_i+\gamma Xi+\varepsilon_i$$

In the mediation model, the mediating variable $M_i$ represents the level of sustainable production awareness for household *i*, $D_i$ indicates digital sales participation, $X_i$ includes control variables, and $\varepsilon_i$ is the error term. A significant β\betaβ coefficient confirms the mediation effect. Constructing the awareness index posed a challenge in

weighting its components objectively. To address this, the entropy weighting method was used, assigning weights based on response variability. The results showed that perceived personal responsibility had the highest weight, followed by technical knowledge, awareness of resource depletion, and understanding of pollution effects, together forming a multidimensional profile of ecological cognition (Table 2).

**Table 2.** Weighted results of sustainable practices knowledge dimensions (entropy weighting method)

| Dimension of Sustainable Practices Knowledge | Indicator Description | Assessment scale | Weight |
|---|---|---|---|
| **Technical Knowledge** | Familiarity with specific sustainable technologies applicable on the farm (e.g., composting, solar panels, biological pest control, irrigation optimization) | Uninformed (1) – Fully informed (5) | 0.378 |
| **Awareness of Economic Benefits of Sustainable Production** | Understanding long-term economic benefits and cost reductions through green technology adoption | Strongly disagree (1) – Strongly agree (5) | 0.264 |
| **Perception of Personal Responsibility** | Degree of personal responsibility for preserving natural resources and food quality on the farm | Strongly disagree (1) – Strongly agree (5) | 0.198 |
| **Awareness of Pollution Risk and Ecological Consequences** | Understanding potential negative impacts of chemical use on soil, water, biodiversity, and health | Strongly disagree (1) – Strongly agree (5) | 0.113 |
| **Residual Variations** | Other non-systematized components | – | 0.047 |

*Source*: author's research

The results presented in Table 3 indicate significant differences between households using digital sales channels and those relying solely on traditional sales models. The average number of sustainable practices adopted is significantly higher among digitally active households (M = 2.63) compared to those without digital sales (M = 1.91), confirming the positive association between digital presence and ecological engagement (t = 0.72; ***p < 0.01). Regarding individual technologies, particularly large differences were observed in drip irrigation (0.58 vs. 0.33), biological pest control (0.39 vs. 0.17), and mulching with crop residue return (0.65 vs. 0.38), with all differences being statistically significant at p < 0.01. In contrast, differences in the use of organic fertilizers and waste recycling were not statistically significant, suggesting that these practices may be more influenced by local policies and technical capacities than by market engagement alone. The largest difference between the groups was found in the sustainable practices knowledge index, where digitally active households demonstrated substantially higher levels of awareness (M = 0.622) compared to traditional producers (M = 0.431), further confirming the cognitive gap in perception and understanding of sustainable production (t = 0.19; ***p < 0.01).

**Table 3**. Descriptive statistics of key variables and group differences

| Variable | Total sample (n=148) | Digitally active (n=62) | Non-digital sales (n=86) | Difference (t-test) |
|---|---|---|---|---|
| **Adoption of Sustainable Practices (0–5)** | 2.21 (1.08) | 2.63 (0.91) | 1.91 (0.99) | 0.72*** |
| **Use of Organic Fertilizer (0/1)** | 0.51 (0.50) | 0.55 (0.50) | 0.48 (0.50) | 0.07 |
| **Drip Irrigation (0/1)** | 0.43 (0.50) | 0.58 (0.50) | 0.33 (0.47) | 0.25*** |
| **Biological Pest Control (0/1)** | 0.26 (0.44) | 0.39 (0.49) | 0.17 (0.38) | 0.22*** |
| **Mulching and Crop Residue Return (0/1)** | 0.49 (0.50) | 0.65 (0.48) | 0.38 (0.49) | 0.27*** |
| **Waste Recycling (0/1)** | 0.46 (0.50) | 0.50 (0.50) | 0.44 (0.50) | 0.06 |
| **Sustainable Practices Knowledge Index** | 0.519 (0.22) | 0.622 (0.19) | 0.431 (0.17) | 0.19*** |

*Source*: author's research

## Analysis and results

The analysis employed a comprehensive set of statistical and econometric methods to test the hypotheses and examine the relationship between market engagement and the adoption of sustainable practices among Serbian agritourism households. Data processing was conducted using STATA 17 and SPSS 27. Descriptive statistics were first used to profile the sample and assess variability in key socio-economic variables. To address selection bias stemming from non-random adoption of digital sales, Propensity Score Matching (PSM) was applied (Rosenbaum & Rubin, 1983), with matching performed via nearest neighbor, radius, caliper, and kernel algorithms. Covariate balance was assessed using pseudo $R^2$, chi-square, standardized biases, and B/R indicators. To validate causality, an instrumental variable (2SLS) approach was used, leveraging the average digital engagement within villages (Caliendo & Kopeinig). Mediation analysis tested indirect effects via cognitive awareness, with a composite index constructed through entropy weighting (Wager & Athey, 2018). Robustness was confirmed using Double Machine Learning (Chernozhukov et al., 2018), applying LASSO and Random Forest to capture nonlinearities and complex interactions.

*Logit model estimation results for the decision to participate in digital sales*

The logit model revealed that higher education, greater income, and specialized local production significantly increase the likelihood of digital sales adoption, reflecting the role of financial and cognitive assets. More active household members also support adoption, while older household heads and larger landholdings reduce it, pointing to generational and structural barriers. Non-significant factors included agritourism experience and land quality. These patterns confirm that digital adoption is influenced by diverse household characteristics, justifying the use of PSM for unbiased comparison of sustainability outcomes (Table 4).

**Table 4.** Logit model results for estimating the probability of participation in digital sales

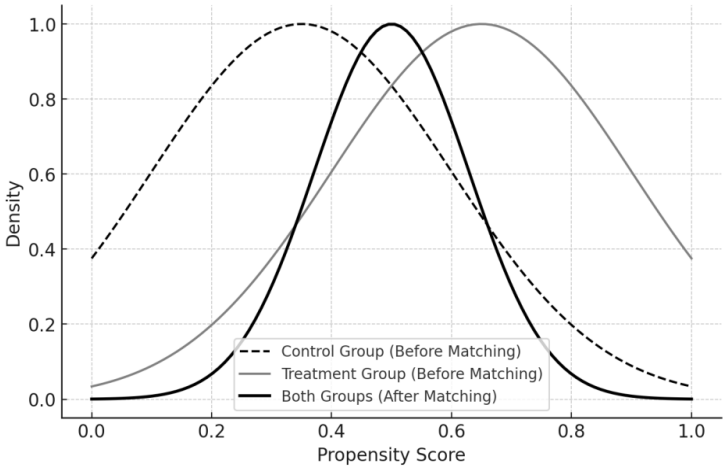
| Variable | Coefficient | Z-value | Standard Error |
|---|---|---|---|
| **Age** | -0.063*** | -3.02 | 0.021 |
| **Education Level** | 0.872*** | 3.79 | 0.230 |
| **Number of Active Family Members** | 0.354* | 1.82 | 0.195 |
| **Years in Agritourism** | -0.011 | -0.57 | 0.020 |
| **Land Area** | -0.006* | -1.69 | 0.004 |
| **Net Income per Household Member** | 0.298*** | 3.61 | 0.082 |
| **Specialized Production** | 1.093*** | 3.42 | 0.320 |
| **Partial Off-Farm Employment** | -0.076 | -0.19 | 0.394 |
| **Participation in Training** | 0.617*** | 3.00 | 0.206 |
| **Constant** | -0.985 | -0.65 | 1.517 |
| **Log-likelihood** | -147.295 | | |
| **LR chi2(10)** | 128.73 | | |
| **Pseudo $R^2$** | 0.303 | | |
| **Number of Observations** | 148 | | |

*Source*: author's research

Notes: * and *** indicate significance at the 10% and 1% levels, respectively.

To verify the reliability of the matching process, a common support test was performed to examine the overlap in propensity scores between treatment and control groups. Before matching, density curves showed clear separation, digital sales households had higher propensity scores, while non-users clustered at lower values, indicating initial imbalance. After matching, the distributions converged significantly, with both groups falling within a shared support region. This improved overlap confirms that the matching procedure effectively corrected structural differences, validating the use of PSM and enabling unbiased estimation of digital sales effects on sustainability adoption (Figure 2).

**Figure 2**. Propensity score distribution before and after matching.




*Source*: Authors' calculations

*Covariate balance test between treatment and control groups*

To confirm that observed differences stem from digital sales participation and not from structural disparities, covariate balance was assessed before and after matching. Multiple algorithms were used, nearest neighbor (1:2, 1:4), radius, caliper, and kernel matching, with standard diagnostics applied: pseudo $R^2$, LR $chi^2$, mean/median bias, and B/R indicators. Before matching, the pseudo $R^2$ was 0.278, LR $chi^2$ = 125.11, mean bias 49.4%, and median bias 47.1%, showing substantial imbalance. After nearest neighbor matching (1:2), pseudo $R^2$ fell to 0.018, mean bias to 7.3%, and median bias to 5.9%. Across all algorithms, mean bias ranged from 3.3% to 6.1%, while B and R indicators remained within acceptable limits. These results confirm the success of the PSM procedure in minimizing selection bias and ensuring valid estimation of digital sales effects on sustainable production (Table 5).

**Table 5**. Covariate balance test results after different PSM matching methods

| Matching method | Pseudo $R^2$ | LR $chi^2$ | Mean bias (%) | Median bias (%) | B-value | R-value |
|---|---|---|---|---|---|---|
| **Before matching** | 0.278 | 125.11 | 49.4 | 47.1 | 132.6* | 1.22 |
| **Nearest neighbor (1:2)** | 0.018 | 4.58 | 7.3 | 5.9 | 30.4* | 1.46 |
| **Nearest neighbor (1:4)** | 0.007 | 1.72 | 5.0 | 4.6 | 18.5 | 1.41 |
| **Radius matching** | 0.009 | 1.89 | 3.9 | 2.1 | 19.8 | 1.50 |
| **Caliper matching** | 0.010 | 2.42 | 6.1 | 5.4 | 22.7 | 1.33 |
| **Kernel matching** | 0.007 | 1.76 | 3.3 | 2.5 | 18.6 | 1.38 |

*Source*: author's research

Notes: * indicates significance at the 10% level.

*Estimation of average treatment effects (ATT) and heterogeneity analysis*

Using various PSM algorithms (nearest neighbor 1:2 and 1:4, radius, caliper, kernel), the analysis confirmed a stable, significant effect of digital sales participation on sustainable technology adoption. Households using digital channels adopted on average 2.84 sustainable technologies, compared to 1.92 among non-users, a statistically significant difference of 0.92 across all models. These results support the hypothesis that digital engagement enhances sustainable practices. In Serbia, digital sales connect farms with ecologically conscious consumers, creating pressure to meet green standards. They also improve access to educational content, advisory platforms, and peer support, fostering a "see–learn–apply" mechanism for technology diffusion. Digitally active households respond more effectively to market incentives for eco-labeled, local products and often gain price premiums that offset the costs of adopting sustainable practices. Additionally, digitalization reduces transaction costs and improves access to inputs, further easing the transition toward environmentally responsible production (Table 6).

**Table 6**. Estimated average treatment effects (ATT) of digital sales on the adoption of sustainable production practices

| Matching method | Treatment group mean (digital sales) | Control group mean (traditional sales) | ATT | T-value |
|---|---|---|---|---|
| **Nearest neighbor (1:2)** | 2.84 | 1.93 | 0.91*** | 4.15 |
| **Nearest neighbor (1:4)** | 2.84 | 1.92 | 0.92*** | 4.32 |
| **Radius matching** | 2.84 | 1.89 | 0.95*** | 4.58 |
| **Caliper matching** | 2.84 | 1.90 | 0.94*** | 4.42 |
| **Kernel matching** | 2.84 | 1.91 | 0.93*** | 4.48 |

*Source*: author's research

. Notes: *** indicates significance at the 1% level.

*Differential analysis of effects by types of green technologies*

Additional analysis explored how digital sales affect the adoption of specific sustainable technologies. The strongest effect was observed for drip irrigation, with a 23.4% higher adoption probability among digital households. Biological pest control also showed a significant 12.7% increase, reflecting alignment with consumer demand for transparency and minimal input use. Mulching and crop residue return showed marginal effects (significant at the 10% level), while no significant differences were found for organic fertilizer use or systematic waste recycling. These results suggest that such practices remain more dependent on institutional incentives than on market-driven digital engagement (Table 7).

**Table 7.** Estimated ATT effects of digital sales by types of green technologies (nearest neighbor 1:4)

| Technology | Treatment group | Control group | ATT | Significance level |
|---|---|---|---|---|
| **Organic Fertilizer** | 0.53 | 0.48 | 0.05 | ns |
| **Drip Irrigation** | 0.64 | 0.40 | 0.24*** | 1% |
| **Biological Pest Control** | 0.38 | 0.25 | 0.13*** | 1% |
| **Mulching** | 0.59 | 0.47 | 0.12* | 10% |
| **Waste Recycling** | 0.50 | 0.47 | 0.03 | ns |

*Source*: author's research

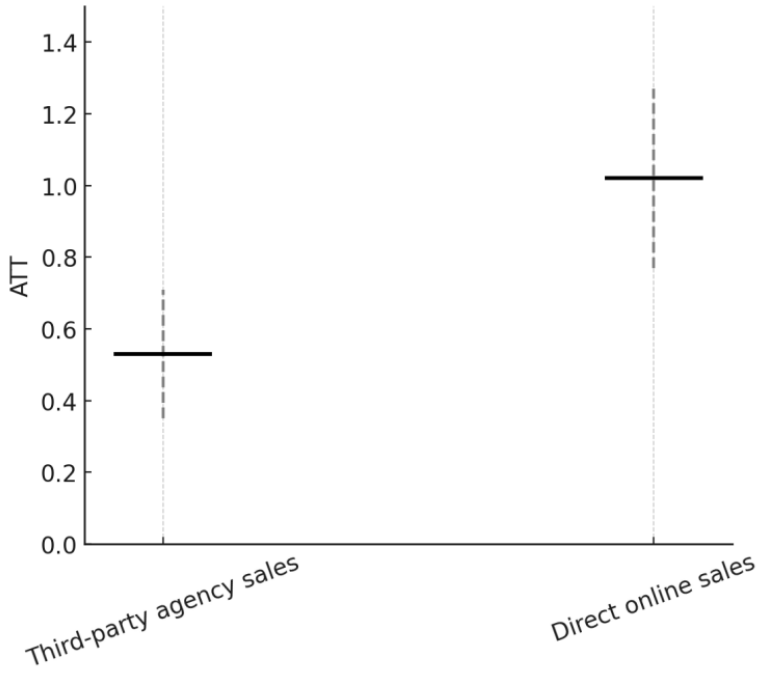
Notes: ns – not significant; * and *** indicate significance at 10% and 1% levels, respectively.

*Heterogeneity of effects by type of digital sales model*

The analysis confirmed that while both direct and third-party digital sales models enhance green technology adoption, direct sales yield stronger effects. Households using direct channels adopted 1.02 additional technologies, compared to 0.53 for those using intermediaries, a statistically significant difference of 0.49. The greater impact of direct sales likely stems from enhanced control over marketing, pricing, and consumer interaction, which reinforces sustainability incentives. In contrast, third-party platforms may dilute these signals. Thus, the structure of e-commerce channels shapes not only

economic but also environmental outcomes for agritourism households.

**Figure 3**. Comparative ATT estimates and confidence intervals across e-commerce participation modes.




*Source*: Authors' calculations

*Endogeneity and robustness test*

To address possible endogeneity, where prior adoption of green technologies may influence entry into digital sales or vice versa, a two-stage least squares (2SLS) method was applied. As an instrument, the average digital sales participation rate among other village households (excluding the observed one) was used. This variable meets both relevance (via social influence) and exogeneity (no direct effect on green adoption) criteria. The first-stage regression confirmed the instrument's strength ($F = 42.18$), avoiding weak instrument concerns. In the second stage, digital sales remained a significant and positive predictor of sustainable technology adoption, even after controlling for potential bidirectional causality. These results confirm the robustness of the original findings and further validate the causal interpretation of the digital–sustainability relationship (Table 8).

**Table 8**. Endogeneity test results (2SLS analysis)

| Stage | Variable | Coefficient | Standard Error |
|---|---|---|---|
| **First Stage** | Instrumental Variable (Village Average) | 0.671*** | (0.152) |
| | Constant | 5.104*** | (0.298) |
| | Control Variables | included | – |
| | Instrument F-statistic | 42.18 | – |
| **Second Stage** | Digital Sales | 1.489*** | (0.077) |
| | Adjusted $R^2$ | 0.0691 | |
| | Number of Observations | 148 | |

*Source*: author's research. Notes: *** indicates significance at the 1% level.

As an additional robustness test, the binary variable for digital sales was replaced with a continuous measure, the share of household income generated through e-commerce. Results confirm that a higher degree of digital sales engagement significantly increases the adoption of sustainable technologies, even when controlling for household characteristics. Farms that rely more heavily on e-commerce income are also more likely to adopt complex green innovations, indicating a stronger orientation toward long-term ecological competitiveness (Table 9).

**Table 9.** Robustness – substitution of the independent variable

| Variables | Model 1 (without controls) | Model 2 (with controls) |
|---|---|---|
| **E-commerce engagement level** | 3.042*** (0.531) | 1.312** (0.623) |
| **Constant** | 1.488*** (0.062) | 1.012* (0.589) |
| **Adjusted $R^2$** | 0.094 | 0.176 |
| **Number of observations** | 148 | 148 |

*Source*: author's research

Notes: *, *, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

To reinforce causal inference, a Double Machine Learning (DML) approach was used, combining Lasso regression and Random Forest algorithms via K-fold cross-fitting (K = 3, 5, 8). This method reduces bias from model assumptions and enhances estimate stability. Across all specifications, results consistently confirmed a significant positive effect of digital sales on the adoption of sustainable technologies, with Random Forest models indicating slightly stronger effects due to their ability to account for household heterogeneity (Table 10).

**Table 10**. DML test results

| Model | K-fold=3 | K-fold=5 | K-fold=8 |
|---|---|---|---|
| **Lasso** | 0.582*** (0.131) | 0.439*** (0.127) | 0.418*** (0.124) |
| **Random forest** | 0.788*** (0.126) | 0.691*** (0.118) | 0.642*** (0.113) |

*Source*: author's research

Notes: *** $p<0.01$

*Mediation effect of sustainable production cognition*

Grounded in the Theory of Planned Behavior, farmers' perceptions and knowledge of sustainable practices mediate the relationship between e-commerce participation and the adoption of green technologies. Households with higher ecological awareness are more inclined to accept the costs and risks of implementing sustainable innovations. Mediation analysis confirms that digital sales positively influence cognitive awareness, which subsequently increases the adoption rate of green technologies (Table 11).

**Table 11**. Mediation effects (sustainable production cognition)

| Variable | Coefficient | SE |
|---|---|---|
| **Digital sales → cognition** | 0.158*** | 0.027 |
| **Constant** | 0.321** | 0.117 |
| **Control variables** | included | |
| **Number of observations** | 148 | |

*Source*: author's research

Notes: ** indicates $p<0.05$; *** indicates $p<0.01$.

## Discussion

The results confirm that market integration, particularly through digital sales, significantly promotes the adoption of sustainable practices among Serbian agritourism households, supporting the first hypothesis. Farms using digital channels adopt more green technologies than those relying on traditional sales, consistent with Pehin Dato Musa and Chin (2022), who emphasized the sustainability benefits of shorter supply chains. This aligns with Cavalleri et al. (2022) and Baipai et al. (2023), who noted that stronger market competencies and income generation from digital engagement foster reinvestment in ecological technologies. However, the effects are not uniform across all practices. Technologies closely tied to food safety and transparency, such as drip irrigation, biological pest control, and residue treatment, showed the strongest association with digital market participation. This is in line with Wang et al. (2025), who highlighted the role of consumer-driven standards in shaping adoption patterns. In contrast, practices like organic fertilization and waste recycling showed no significant association, reinforcing Petrović et al. (2021), who pointed to producers' reliance on regulatory support due to limited financial capacity. The second hypothesis, regarding the mediating role of cognitive awareness, was also confirmed. Mediation analysis showed that participation in digital markets enhances farmers' knowledge and attitudes, which indirectly drive sustainable adoption. This supports Kule et al. (2025) and aligns with Muhamadi and Boz (2022), Sulaj et al. (2022), and Cigale and Lampič (2023), who emphasized that internalized ecological values and perceived long-term benefits increase adoption readiness. Moreover, households engaged in direct online sales demonstrated a greater intensity of green technology use than those using intermediaries. This reflects the findings of Riady et al. (2024) and Cigale and Lampič (2023), who noted that direct market feedback fosters adaptive learning and ecological innovation. The present study

thus empirically affirms that sustainable agritourism transformation relies not only on market access but also on the cognitive readiness of producers, an insight consistent with Shen et al. (2020), Zhang et al. (2025), and Nistoreanu et al. (2024). Together, market incentives and cognitive capacities emerge as mutually reinforcing conditions for sustainable agritourism development.

However, not all practices demonstrated equally strong effects, which requires further reflection. The limited effects of certain sustainable practices can be explained by a combination of structural, behavioral, and institutional barriers. Many agritourism households operate with restricted financial resources, which constrains their ability to invest in environmentally friendly technologies or advanced digital tools. In addition, knowledge gaps and limited access to specialized advisory services reduce the effectiveness of training and capacity-building programs. From the demand side, consumer preferences in Serbia still show a strong orientation toward traditional products, which lowers the immediate market incentives for innovation. Finally, policy support is often fragmented and short-term, leading to inconsistencies in implementation and difficulties in scaling up successful practices. These factors jointly explain why some initiatives demonstrate weaker impacts, despite their potential to contribute to sustainability.

## Conclusions

This study offered empirically grounded insights into how market integration, particularly through digital channels, influences the adoption of sustainable practices among agritourism households in Serbia. Findings confirmed that digital engagement not only improves market visibility and access to financial and educational resources but also strengthens cognitive awareness of sustainability, which in turn drives green technology adoption. These results support the research hypotheses and highlight the interplay of economic and psychological mechanisms in fostering sustainable transitions in rural contexts.

Theoretically, this study enriches understanding of sustainability transitions in transitional economies by demonstrating that digital market engagement acts as both an economic and cognitive driver. It builds on behavioral economic theory by showing how market exposure shapes producer awareness. The stronger effects of direct digital sales versus intermediary platforms add nuance to debates on e-commerce and rural sustainability. Moreover, the multifunctional nature of Serbian agritourism households, as production, tourism, and consumption units, suggests the need for more integrative models of rural development. Importantly, a stronger emphasis on the tourism dimension and a tighter link between empirical results and policy implications would further enhance the explanatory and practical value of the study.

Practically, the findings point to clear policy directions. Capacity-building programs in digital marketing and e-commerce logistics are essential. Supporting local platforms that enable direct producer–consumer interaction can reduce reliance on intermediaries and boost returns for sustainable products. Advisory services should integrate agronomic and

digital skills, while incentives should promote environmentally friendly technologies aligned with market demand. These measures can enhance competitiveness, income diversification, and resilience among rural producers.

From a political perspective, the study highlights the importance of integrating agritourism into broader strategies for rural development and food security. Policymakers should ensure that sustainable agritourism is embedded in national agricultural and tourism policies, supported by regulatory frameworks that encourage innovation, transparency, and equitable market access. Strengthening cross-sectoral governance, particularly cooperation between ministries of agriculture, tourism, and environment, can provide institutional backing for local initiatives. Furthermore, aligning these measures with EU accession processes and international sustainability commitments would not only reinforce Serbia's strategic positioning but also create transferable lessons for other emerging economies.

However, several limitations must be acknowledged. The focus on registered agritourism farms may limit broader applicability. Although Propensity Score Matching mitigated selection bias, unobserved factors such as entrepreneurial capacity remain potential sources of endogeneity. The reliance on self-reported data to measure awareness may introduce social desirability bias. Future studies should adopt objective measures and expand analytical models to include psychological, institutional, and sociocultural variables. Regional disparities in Serbia also warrant attention, as do cross-country comparisons in the Western Balkans. Finally, longitudinal research is needed to track how emerging technologies, such as blockchain and digital export models, continue to shape sustainability adoption in agritourism.

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## Conflict of interests

The authors declare no conflict of interest.

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