
TOWARDS SUSTAINABLE GROWTH: ASSESSING THE NEXUS BETWEEN AGRICULTURAL OUTPUT AND CIRCULAR ECONOMY INDICATORS

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ABSTRACT

This paper examines the relationship between agricultural output and circular economy indicators in 36 European countries over the period 2015–2024. Using an unbalanced panel of 360 observations, a panel regression model with fixed effects was estimated following a series of diagnostic tests that confirmed the robustness and reliability of the estimates. Agriculture, forestry and fishing value added per worker was modelled as a function of five circular economy indicators, alongside GDP per capita, rural population share and agricultural employment. All estimated coefficients were significant at the 1% level. The recycling rate of municipal waste and the share of renewable energy positively affect agricultural value added, while the generation of municipal waste, raw material consumption, rural population and agricultural employment exert negative effects. The findings confirm that circular economy practices and agricultural productivity are complementary rather than conflicting areas, whose long-term synergy depends on coordinated economic policy support.

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Introduction

Agriculture remains one of the most resource-intensive sectors of the European economy, and its long-term productivity is inseparably connected to how efficiently natural resources, waste and energy are managed across the food and land-use value chain. Over the last decade, the European Union has placed the transition toward a circular economy at the centre of its environmental and economic agenda, seeking to decouple growth from resource depletion through targets related to recycling, waste reduction, renewable energy and material efficiency (Castillo-Díaz et al., 2024). Agriculture, forestry and fishing occupy a distinctive position within this transition: they are simultaneously significant generators of environmental pressure, through greenhouse gas emissions, raw material use and land-related waste, and potential beneficiaries of circularity, since practices such as composting, biomass valorisation, renewable-energy adoption and closed-loop nutrient cycles can lower input costs and raise resource productivity (Erdiaw-Kwasie et al., 2025; Giacomello et al., 2025).

Despite growing academic and policy interest in the circular economy, empirical evidence on how specific circular economy indicators relate to agricultural output remains fragmented, often confined to individual countries, a single circularity dimension, or comparatively short observation periods (Novaković D. et al., 2025; Novaković T. et al., 2025a). Most cross-country panel studies of the circular economy-growth nexus in the EU treat GDP or aggregate resource productivity as the outcome variable, while comparatively few isolate the agricultural sector, and fewer still extend the analysis beyond the EU-27 to EEA and EU candidate countries, whose agricultural structures, resource endowments and stages of circular economy adoption differ substantially from those of longstanding member states (Dimitrijević et al., 2025; Đokić et al., 2022b).

This gap is particularly relevant for Southeast Europe and the Western Balkans, where accession negotiations require gradual alignment with EU environmental and agricultural policy, and where the pace of this alignment has direct consequences for agricultural competitiveness and rural livelihoods (Đokić et al., 2022a). Understanding whether, and how, circular economy performance translates into higher agricultural value added is therefore relevant not only for academic reasons but also for policy design in both EU member states and candidate economies.

Against this background, the aim of this paper is to examine the relationship between agricultural output, measured as agriculture, forestry and fishing value added per worker, and a set of circular economy indicators (generation of municipal waste, recycling rate of municipal waste, greenhouse gas emissions from production activities, share of renewable energy and raw material consumption), while controlling for GDP per capita, rural population share and agricultural employment. The analysis covers 36 European countries – all 27 EU member states, three EEA countries and six EU candidate countries – over the 2015–2024 period, using panel regression methodology.

The remainder of the paper is organized as follows. The next section reviews the relevant literature on the circular economy-agriculture nexus. This is followed by a

description of the data and methodology used in the empirical analysis. The subsequent section presents and discusses the estimation results, after which the final section offers conclusions and policy implications.

Literature review

The relationship between circular economy practices and agricultural performance has attracted increasing scholarly attention as part of broader research into the circular economy transition in the European Union. At the policy level, the alignment between the EU Common Agricultural Policy and circular economy principles has been shown to encourage more efficient use of inputs and by-products, although the practical uptake of circular practices differs considerably across member states depending on farm structure, access to funding and institutional support (Castillo-Díaz et al., 2024). These structural differences help explain why studies that rely on aggregate, EU-wide circular economy indicators often need to be complemented with more detailed sector-level analysis, such as the one presented in this paper.

Regarding the waste and recycling dimension of the circular economy, prior research indicates that higher municipal waste generation is generally associated with adverse environmental outcomes, including soil, water and air pollution stemming from inadequate treatment or disposal, all of which undermine agricultural productivity (Giacomello et al., 2025). Conversely, higher recycling rates, particularly through the conversion of organic waste into compost and organic fertilizers, have been found to substitute for costly chemical inputs, restore soil health and reduce greenhouse gas emissions, thereby supporting agricultural employment and value added (Erdiaw-Kwasie et al., 2025).

The relationship between greenhouse gas emissions and agricultural performance is more ambiguous in the literature. Some studies report a dynamic, occasionally positive short-run association between emissions and agricultural productivity, explained by temporarily favourable effects on plant growth that are eventually outweighed by longer-term damage to the environmental systems on which agriculture depends (Mulusew & Hong, 2024). Similar interlinkages between energy-driven economic growth and environmental degradation have been documented for EU agriculture more broadly, confirming that the emissions-productivity relationship is strongly context- and time-dependent (Zafeiriou et al., 2023).

The role of renewable energy in agriculture has received growing attention, with evidence from both EU and non-EU country groups suggesting that a higher share of renewable energy reduces input costs, increases efficiency and strengthens the climate resilience of farms, ultimately boosting agricultural economic output (Soni & RL, 2024). Raw material consumption, on the other hand, shows conflicting effects depending on the channel through which it operates: rising raw material costs increase intermediate consumption and can reduce value added, whereas adequate access to essential agricultural raw materials can raise physical yields and, through that channel, increase economic value added (Ali et al., 2025).

Beyond circular economy indicators, macroeconomic and structural determinants remain central to explaining agricultural value added. As economies grow and diversify, labour tends to shift away from agriculture, while capital investment and technology adoption increase value added per remaining worker (George, 2020). A similar mechanism has been identified for rural population decline, where capital deepening and mechanization tend to raise agricultural productivity even as the rural labour force shrinks (Shen et al., 2023).

Several recent studies specifically address the intersection of circular economy indicators and agricultural or agri-food performance in Serbia and the broader Western Balkan region. Dynamic panel evidence for the Serbian agri-food sector confirms a statistically significant link between resource efficiency and circular economy indicators (Novaković D. et al., 2025), while stochastic frontier analyses of crop and dairy production in the European Union and Serbia show that eco-efficiency gains are closely tied to circular economy adoption at the farm level, including input reduction and waste valorisation (Novaković T. et al., 2025a; Novaković T. et al., 2025b). This is further supported by an efficiency-based assessment of circular economy performance across European countries and Serbia using Data Envelopment Analysis, which finds that Serbia lags behind the EU average in circular economy efficiency and highlights the need for targeted improvements in resource productivity and waste management (Radovanov et al., 2023a). These findings reinforce the relevance of extending the analysis of circular economy-agriculture linkages to candidate countries, whose agricultural sectors are undergoing parallel processes of modernization and EU alignment.

From a comparative regional perspective, studies contrasting the agricultural sectors of the European Union and the Western Balkans consistently find a productivity and competitiveness gap, driven by lower technical efficiency, weaker value-added generation and less intensive use of production factors in the Western Balkan countries (Đokić et al., 2022a; Đokić et al., 2022b). Similarly, evidence on the competitiveness of the Southeast European agricultural sector highlights that raising productivity through modern technology and greater processing of agricultural products, rather than relying on low input prices, is essential for closing this gap (Dimitrijević et al., 2025).

The policy dimension of this nexus is equally important. Analyses of the Common Agricultural Policy emphasize that agricultural labour productivity and greenhouse gas emissions represent central milestones in its evolution, requiring member states to balance productivity growth with climate objectives (Constantin et al., 2021). For the Western Balkans, the alignment of national agricultural policies with the CAP and the European Green Deal is considered essential for sustainable agricultural development and climate change mitigation (Županić et al., 2021), while the efficient and sustainable use of agricultural inputs has been identified as a precondition for reconciling productivity growth with environmental protection in both innovative economies and the Republic of Serbia (Dimitrijević et al., 2024). Recent evidence on competitiveness and cereal self-sufficiency in the Western Balkan countries

further shows that economic development and agricultural value added per worker positively influence comparative advantage, linking sectoral productivity to broader macroeconomic conditions (Kovljenić et al., 2024). At the same time, persistent competitiveness gaps between old and new EU member states point to the need for productive and sustainable agricultural systems across the enlarged Union (Jarosz-Angowska et al., 2022).

Methodologically, panel data models with fixed or random effects, selected on the basis of the Hausman specification test, are widely used in agricultural and financial economics to account for the grouped, cross-country and cross-time nature of the data and to improve the robustness of the estimated coefficients (Radovanov et al., 2023b; Sotiroski et al., 2023; Wooldridge, 1999). This methodological approach is also well established in the regional economic literature, as illustrated by a recent panel regression analysis of profitability determinants among wholesale companies in Serbia, which likewise relies on fixed- and random-effects estimation to capture firm-level heterogeneity over time (Dakić et al., 2025).

Taken together, the reviewed literature confirms that individual circular economy indicators can exert markedly different, and at times opposing, effects on agricultural output, and that these relationships are shaped by country-specific structural and institutional conditions. However, comprehensive panel evidence that jointly considers multiple circular economy dimensions, alongside macroeconomic and structural controls, across the full spectrum of EU, EEA and EU candidate countries remains scarce. This paper aims to address this gap by providing an integrated empirical assessment of the circular economy-agriculture nexus across 36 European countries over the 2015–2024 period.

Data and methodology

Given the specificity of the topic, the availability of data sources as well as the possibilities of comparability of European countries, the creation of an adequate data sample implies an important step in the quantitative analysis procedure. In this regard, the comparison of EU, EEA and candidate countries through panel analysis is ideal because it enables the monitoring of economic and social indicators over time and space. This method precisely maps the path of convergence, helping researchers to assess the effects of gradual integrations and assess the “step-by-step” enlargement policies before full membership. For this reason, the sample consists of all 27 member states of the European Union, 3 member states of the European Economic Area (Iceland, Norway and Switzerland) and 6 EU candidate countries (Albania, Bosnia and Herzegovina, Montenegro, North Macedonia, Serbia and Turkey) in the period from 2015 to 2024. Overall there are 360 panel data in the sample. The annual values of the indicators collected in the sample are directed towards the analysis of the effects of the state and development of agriculture, as well as circular economy and sustainable development. Therefore, the following indicators were used:

Agricultural indicators

AVA - Agriculture, forestry, and fishing, value added per worker (constant 2015 US\$) (World Bank Open Data)

RP - Rural population (%) (World Bank Open Data)

EMP - Employment in agriculture (%) (World Bank Open Data)

Macroeconomic indicator

GDP - GDP per capita (World Bank Open Data)

Circular economy indicators

GMW- Generation of municipal waste per capita (Eurostat)

RR - Recycling rate of municipal waste (Eurostat)

GGE - Greenhouse gases emissions from production activities (Eurostat)

SRE - Share of renewable energy (Eurostat)

RMC - Raw material consumption (Eurostat)

In order to conduct an adequate analysis based on the collected data, panel data models (Fixed or Random Effects) are used instead of Pooled ordinary least squares because Pooled OLS ignores the grouped nature of the data. By treating all observations independently, Pooled OLS risks severe omitted variable bias and incorrect standard errors if unobserved individual traits correlate with your variables. Also, the model wants to enhance the robustness of the estimated values (Wooldridge, 1999). The initial functional structure of the studied model is presented as follows:

$$AVA_{it} = \alpha + \beta_1 GMW_{it} + \beta_2 RR_{it} + \beta_3 GGE_{it} + \beta_4 SRE_{it} + \beta_5 RMC_{it} + \beta_6 GDP_{it} + \beta_7 RP_{it} + \beta_8 EMP_{it} + \varepsilon_{it}$$

AVA is dependent variable, i is a symbol that represents the cross-section data (i -th country), t represents the time (yearly data), α is an intercept coefficient, β_j indicates a regression coefficient for each of the independent variable and ε represents the error term of the model.

In order to properly implement the panel regression model methodology, it is necessary to test the existence of fixed or random effects in this model. Such model position refers to the application of a specification test based on the differences between the fixed effects and random effects estimators, known as the Hausman test. If the null hypothesis is true, the fixed effect estimator is not efficient under the random effect specification because it counts only on the within variation in the data series (Radovanov et al, 2023b).

Results and discussion

Before presenting the results of the econometric analysis, the results of the descriptive statistics are presented in order to overview the main characteristics of the included variables (Table 1).

Table 1. Descriptive statistics and stationarity test

Variable	Mean	Median	Standard deviation	ADF test	Skewness	Kurtosis	Jarque-Bera test
AVA	33063.747	25554.446	26218.265	11.626	1.554	2.702	146.244
GMW	512.011	489.000	132.932	17.586	0.543	-0.250	176.180
RR	33.941	36.000	18.256	10.001	-0.240	-0.890	230.457
GGE	7785.045	7476.494	3051.798	20.337	1.280	1.529	130.780
SRE	27.579	22.879	16.412	18.056	1.490	2.102	145.326
RMC	19.405	17.533	7.871	15.212	1.367	1.667	138.749
GDP	32413.970	22397.764	25427.055	10.112	1.243	0.938	156.406
RP	27.636	29.708	12.965	14.060	-0.161	-1.040	246.397
EMP	6.600	3.950	7.088	22.511	2.450	6.764	572.546

Source: Authors' estimations

Table 1 presents descriptive statistics of given variables in case of 36 selected European countries during the 2015-2024 period. The values from Table 1 are applied to estimate agricultural output, selected circular economy indicators as well as macroeconomic indicators overall. Before proceeding with the panel regression estimation, it is necessary to examine the dynamic characteristics of the variables that will be used in the model. In this regard, non-stationary variables can produce spurious relationships and biased coefficient estimates (Novaković et al, 2025). Consequently, Augmented Dickey-Fuller test (ADF test) is applied to determine whether the series were stationary over the observed period. The results of the ADF test indicate the existence of stationarity at the level of the mentioned variable time series, which means that the null hypothesis is rejected according to the ADF test. It is important to notice that in this situation it is not necessary to transform the original variables because their mean and variance remain stable over time, indicating that the variables return to equilibrium after short-term fluctuations. In addition to the aforementioned, Table 1 also contains the test results of the normal distribution of the included variables. The results indicate that the individual variables are not normally distributed, which should not be a concern because through the application of the panel ordinary least squares methodology, they become resistant to deviations, especially in the case of the application of the fixed effects models.

Table 2. Correlation matrix

	AVA	GMW	RR	GGE	SRE	RMC	GDP	RP	EMP
AVA	1								
GMW	-0.4794	1							
RR	0.4367	0.4368	1						
GGE	0.4182	0.3726	0.0403	1					
SRE	0.4670	0.1191	-0.0450	0.2604	1				
RMC	-0.3840	0.2138	-0.0157	0.5157	0.6784	1			
GDP	0.6274	0.7224	0.5741	0.4078	0.1521	0.3531	1		
RP	-0.6835	-0.5475	-0.3406	-0.3009	-0.1112	-0.1238	-0.5824	1	
EMP	-0.5137	-0.5086	-0.5973	-0.0845	0.0511	-0.0523	-0.5119	0.4484	1

Source: Authors' estimations

Table 2 contains the results of comparing the relationships between the included variables. Therefore, the presented correlation matrix is included to transparently summarize variable relationships, check for multicollinearity among predictors (independent variables), and validate that your data meets the assumptions required for further modeling process. Since there are no strong correlations between independent variables, the results indicate that there is no significant concern regarding multicollinearity.

Table 3. Estimation results of the panel regression model

Variable	Coefficient	t-Statistic	VIF test
C	43491.9500	8.2118***	-
GMW	-36.7482	-4.6089***	2.3674
RR	145.0638	2.7195***	5.6014
GGE	1.6717	5.8030***	0.9804
SRE	753.5714	12.7152***	1.0566
RMC	-469.3270	-3.2306***	3.8821
GDP	0.2400	4.8139***	4.1008
RP	-817.3400	-11.6823***	5.0772
EMP	-972.2642	-7.2892***	6.1177
R-squared	0.7597		
F-statistic	138.6828***		
Hausman test	22.8116***		
Breusch-Pagan-Godfrey F test	1.7492		
Durbin-Watson statistic	1.7709		

Source: Authors' estimations

Note: *** indicates significance at the level of 1%

The results shown in Table 3 are the outcome of the modeling process by inserting one variable at a time. The final model represents the best possible choice, and therefore the best representation of the impact on agricultural output at the macroeconomic level. The consistency of the presented model with the available data is best determined by the high value of the coefficient of determination (R-squared), which in this case is at the level of almost 76%. In addition, a high F-statistic value indicates a statistically significant joint effect of all estimated parameters in the model at the significance level of 1%. Based on the prior remarks associated to the outcomes from the correlation matrix, the variance inflation (VIF) test was implemented and the results approve that there is no statistically significant multicollinearity between the independent variables (VIF test values below 10). These results indicate the stability of the estimated coefficients so that the relationships between the introduced variables remain statistically reliable without any negative effects of multicollinearity. Further verification of the robustness of the model specification was accomplished by using the Hausman test. The χ^2 test result points to the rejection of the null hypothesis and states that in this case it is necessary to use the model specification with fixed effects. To additionally improve model fit, the Breusch-Pagan-Godfrey test was conducted in order to detect potential heteroscedasticity of the model residuals. Only models that fulfilled the null hypothesis that there is homoscedasticity among the residuals of the estimated model can be considered as appropriate ones. The result indicates that in the selected model there are no problems with residuals caused by the occurrence of independent variables. Finally, Durbin-Watson statistic is implemented to detect serial correlation in the residuals of the regression model. By using the generally accepted rule of thumb, the results in the range of 1.5 to 2.5 are generally considered normal with a little to no autocorrelation.

All previous tests allow a certain degree of confidence in the results of the regression model, and therefore its reliability in application. First of all, it should be emphasized that all the estimated coefficients in this regression panel model are statistically significant with a significance level of 1%. Generation of municipal waste per capita has a negative effect on the value of agricultural output per worker. High municipal waste generation often means increased landfilling. Improper waste management and the burning of municipal or industrial waste can lead to soil and water contamination and air pollution, which suppresses agricultural yields and degrades the underlying agricultural value added (Giacomello et al. 2025). On the other hand, recycling rate of municipal waste has positive impact on agriculture, forestry, and fishing, value added per worker. By transforming organic municipal waste into compost and organic fertilizers, regions can substitute costly chemical inputs, restore soil health, and lower greenhouse gas emissions, ultimately driving economic growth in the agricultural sector (Erdiaw-Kwasie et al. 2025). Against all expectations, greenhouse gases emissions from production activities have a positive relationship with agriculture, forestry, and fishing, value added per worker. This statement can be justified to some extent with the fact that increased emissions temporarily stimulate some plant growth, but these emissions damage the environmental systems that agriculture relies on, acting

as a negative feedback loop (Mulusew and Hong. 2024). This study shows that an increased share of renewable energy generally positively impacts agricultural value added. By transitioning to clean energy sources, farms reduce input costs, increase efficiency, and gain climate resilience, which subsequently boosts the economic output of the agricultural sector (Soni and RL. 2024). Raw material consumption demonstrates significant negative impact on agriculture value added. In the scientific literature, there are conflicting views on the connection between these indicators. Apparently, everything depends on how this influence takes place. When the cost of raw materials increases, it raises the intermediate consumption, which directly reduces the overall value added to the agricultural output. From another perspective, adequate consumption of essential agricultural raw materials increases physical yields. This boosts overall production, which mainly leads to an increase in economic value added (Ali et al. 2025). As confirmed in most scientific studies, GDP growth significantly affects agriculture value added per worker. As a nation's GDP and non-agricultural economy grow, they pull labor out of farming. This reduction in agricultural employment, combined with increased capital investment and better technology, directly drives up value added per remaining agricultural worker (George, 2020). In accordance with the previous facts, the coefficient explaining the relationship between agricultural employment and agricultural value added per worker presents a significant negative value. Finally, rural population shows a negative association with agricultural value added per worker. This finding are consistent with the fact that s rural populations shrink and non-farm sectors increase, agricultural productivity often increases through capital deepening (better machinery) and fewer workers dividing the same output (Shen et al. 2023).

Conclusions

This study investigated the relationship between circular economy indicators and agricultural output per worker in case of 36 European countries, among which all 27 EU countries, 3 EEA member countries and 6 candidate countries were analyzed over the period of 2015–2024. The empirical analysis leads to several major conclusion remarks.

Stating numerous circular economy indicators and establishing their statistically significant connection with agricultural outputs indicates the necessity of understanding environmentally responsible production and improving resource efficiency in order to achieve long-term economic goals. In this regard, the inclusion of individual indicators of the circular economy enables an adequate insight into the state, but also the possibilities for further development, first of all of the circular economy, and then, consequently, the efficiency of agricultural production.

The obtained results confirm that the circular economy and agricultural production are complementary areas rather than pursuing the same defined goal. Nevertheless, synergy is possible if time, sector characteristics, but also financial and institutional support are harmonized. Acceptance and implementation of circular economy practices can have a short-term effect on the reduction of output through the growth of investment costs.

However, this approach is introduced due to superior long-term performance and better competitiveness in the market.

The results of this analysis allow decision-makers to gain insight into possible changes in approach when creating economic policy and implementing the circular economy in all spheres of socially responsible work. In order to adequately connect this, policy makers should define certain targeted instruments, through green financial programs, innovation initiatives and knowledge exchange, all with the aim of accepting a circular and resource-efficient economy in agriculture.

Future research should target the microeconomic level through the analysis of profitability and efficiency of agricultural enterprises in the implementation of circular economy principles. Furthermore, the application of more advanced econometric methods can enable a better understanding of the heterogeneity between the entities within the sample, and thus a better understanding of the relationship between the circular economy indicators and agricultural value added.

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Conflict of interests

The authors declare no conflict of interest.

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