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# Circular economy and agricultural employment: a panel analysis of EU advanced and emerging economies

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## Abstract

Using data from 24 European advanced and emerging countries between 2000 and 2020, this paper examines the impacts of circular economy (CE) on agriculture employment (AE) and female employment patterns. Based on the availability of data, the study uses three CE indicators: generation of municipal waste (GMW) per capita, the recycling rate of municipal waste (RRMW), and patents related to recycling and secondary raw materials (PRSRM). To investigate the relationship between CE and AE, as well as CE and female AE, panel cointegration analysis and Granger causality tests are conducted. The results reveal that whereas RRMW, PRSRM and AE are in equilibrium in the long run, increasing waste lowers female attraction to the sector. The study therefore suggests that developing and expanding waste management initiatives and innovation are critical to the growth of agricultural employment and the closing of existing gender gaps. Despite concerns that rising recycling practices may negatively impact employment, our empirical results indicate that CE will create opportunities and increase employment levels. The evidence suggests that promoting CE in agriculture is economically, ecologically, and socially beneficial.

**Keywords** Circular economy · Agricultural employment · EU countries · Gender dynamics · Panel analysis

## Abbreviations

CEM	Circular economy model
CE	Circular economy
AE	Agriculture employment
ARDL	Autoregressive distributive lag model
EU	European Union
GMW	Generation of municipal waste
RRMW	Recycling rate of municipal waste
PRSRM	Patent related to recycling and secondary raw materials
ILO	International Labour Organization
ADF	Augmented Dickey–Fuller

Extended author information available on the last page of the article

## 1 Introduction

With rising global food demand and waste patterns, the world's agricultural production is expected to increase by 70 per cent by 2050 to meet consumption demand (Aznar-Sánchez et al., 2020; Velasco-Muñoz et al., 2021). While achieving this goal is necessary, implications on natural resources are inevitable (Toop et al., 2017). According to Santibanez-Gonzal et al. (2019), production systems are anticipated to utilise close to 140 billion tons of raw materials, minerals, and energy (e.g. fossil fuel) in the immediate future. Similarly, production systems have been anticipated to intensify resource use and waste generation, especially in the agricultural sector (Qadir et al., 2020; Rashid & Shahzad, 2021; Sato et al., 2013). In response to increasing resource scarcity, the circular economy (CE) concept has been promoted to transition to a more sustainable economic system (Flynn et al., 2019; Hobson & Lynch, 2016). It is important to note, however, that most CE-related approaches are primarily concerned with the environment and the economy, whereas social aspects, such as employment patterns, employment practices, and gender dynamics, have only been peripherally and sporadically incorporated (Moreau et al., 2017; Padilla-Rivera et al., 2020). Creating a sustainable alternative to the current economic system requires a more balanced integration of the social dimension. In order to fill this gap, this study thoroughly examined the impacts of CE on employment levels and gender dynamics in Europe's agriculture sector.

There are four fundamental reasons why CE and agriculture employment should be studied. The first difficulty is that CE social impacts cannot be measured with certainty, unlike those related to, for example, carbon emissions (Corvellec et al., 2022; De Pascale et al., 2021; Hailemariam & Erdiaw-Kwasie, 2023). While reviewing CE's measures, new indicators must be taken to balance the given rationalities. The second reason is due to the scale and scope of the CE transition challenge (Mhatre et al., 2021; Ranjbari et al., 2022; Van Langen et al., 2021). According to some scholars, CE transition and implementation are unattractive to many actors across sectors due to the lack of evidence on job opportunities (Ddiba et al., 2022; Hopkinson et al., 2020; Jabbour et al., 2019; Rainville, 2021). Thirdly, while evidence exists regarding the association between CE and employment, results remain mixed and inconclusive (Burger et al., 2019; Repp et al., 2021). The inconclusiveness of findings about how CE boosts employment suggests further studies (Garcia-Muina et al., 2021; Velasco-Munoz et al., 2021). Finally, the fourth reason emphasises how CE is not simply an outcome of sustainable development but is a driver of it (Barros et al., 2021; Danta et al., 2021; Khan et al., 2021). In addition to being a valuable part of social progress, CE contributes to reducing greenhouse gas emissions and minimising waste (Baah et al., 2023; Chojnacka et al., 2021; Hailemariam & Erdiaw-Kwasie, 2023; Sharma et al., 2021). Despite its importance, the social dimension of CE, especially its impacts on employment trends in the agricultural sector, has not received priority from the global community. The absence of such consideration among CE scholars constitutes a critical literature gap, according to Velasco-Munoz et al. (2021). This study fills the existing gap in the literature, mainly by analysing the impact of CE on agricultural employment for a panel of developed and emerging European economies. Moreover, this study is also novel in that it uses more advanced panel data techniques for making the required estimates since it covers twenty-four emerging economies from 2000 to 2020.

Europe and its agricultural domains were investigated due to the sectors' massive contribution to greenhouse gas emissions and the significant waste generated in the current production and consumption systems. Toop et al. (2017), in their study on developing an

agro-cycle based on CE principles, highlighted the wasteful nature of Europe's agricultural sector, which generates 700 million tonnes of agri-food waste each year. Specifically, this study investigates the effects of CE indicators, including production and consumption and waste recycling and innovation, on agriculture sector employment using panel data from 24 EU advanced and emerging countries between 2000 and 2020. In this study, while production and consumption indicators were measured with the generation of municipal waste (GMW) per capita, waste recycling and innovation were measured, respectively, with the recycling rate of municipal waste (RRMW) and patents related to recycling and secondary raw materials (PRSRM). In detail, the research questions are: Does CE affect agricultural employment? Second, if so, which CE indicators contribute the most? Finally, how does CE affect the employment of women in agriculture?

Our study makes three main contributions. First, this study systematically analyses how CE patents, such as innovations, waste recycling, and production and consumption, affect agricultural employment in EU advanced and emerging countries. In addition to a better understanding of how CE impacts agriculture employment in EU advanced and emerging countries, this study suggests new policy directions for promoting circular strategies that could contribute to increased employment in the sector. Furthermore, most existing studies used traditional production and consumption as a variable in their models and thus failed to account for the shifting trends of resource utilisation in the agriculture sector. As a result, new results are obtained regarding the disaggregated employment impacts of CE sub-indicators, such as waste recycling, innovation, production, and consumption. Third, previous studies have avoided considering the potentially heterogeneous and asymmetries in the effects of CE patents on agricultural employment in EU advanced and emerging countries, leading to biased and inconsistent results. We use panel quantile regression to explore heterogeneity and asymmetries in the relationship between CE patents (production and consumption, innovation, and waste recycling) and employment in the agricultural sector.

The remainder of this study is structured as follows. Section 2 presents the literature review. The next section discusses the data, empirical specification, and econometric method adopted to examine the CE-employment nexus in the agriculture sector. Section 4 presents the results from econometric panel data modelling. Finally, the discussion is presented in Sect. 5, while Sect. 6 concludes the study.

## 2 Literature review and hypothesis development

The purpose of this section is to present the theoretical relationship between CE and employment. Firstly, we present the theoretical links between CE and agricultural employment and gender dynamics, then summarise CE indicators and their employment relationship.

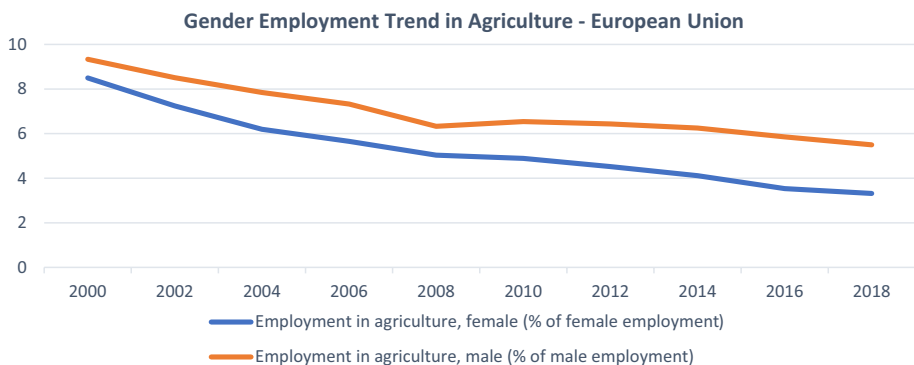
Historically, although the CE field has seen significant progress (see Erdiaw-Kwasie et al., 2023a, 2023b; Winans et al., 2017), research shows that indicators to capture CE contributions at different levels are in their infancy (Figge et al., 2018; Marra et al., 2022; Rincón-Moreno et al., 2021). In the 2015 CE action plan (European Commission, 2018), the EU aimed to measure four areas related to the different phases of CE: (a) Production and consumption, (b) Waste management, (c) Secondary raw materials and (d) Competitiveness and innovation. Based on existing official statistics from Eurostat and supplemented by other official sources, the EC published 10 indicators, some breaking down

further into sub-indicators. According to Cayzer et al. (2017), using circularity indicators to track CE performance is important to ensure that stakeholders at various levels are motivated to implement this new model. A useful set of indicators for assessing circularity performance is vital for enhancing and measuring the feasibility of CE models (Erdiaw-Kwasie, 2023, Niero & Kalbar, 2019; Smol et al., 2017; Tenakwah & Tenakwah, 2023). Evidence shows that progress cannot be tracked meaningfully without tested indicators (Bocken et al., 2018; Rincón-Moreno et al., 2021). By integrating and measuring circular performance at all levels, actors can set goals, peer review, measure, and benchmark their performance (Erdiaw-Kwasie et al., 2023b; Kern et al., 2020; Niero & Hauschild, 2017). Studies on the empirics of CE practices are critical and pressing under current circumstances, as measuring performance on CE practices is difficult to comprehend.

Past studies have thus shown inconclusive results, with some indicating an increase in employment statistics (Horbach et al., 2015) and others showing a decreasing trend (El Wali et al., 2021; Repp et al., 2021). Some studies have established a link between gender dynamism, age distribution and CE (Coghlan et al., 2021; Laoire, 2002; Prügl, 2011; Whittock, 2018). Given the male-dominated state of the agriculture sector and the contested gender debates surrounding CE, studies have called for more evidence on how CE impacts female employment, particularly in agriculture. Figure 1 shows male and female agricultural employment trends in the EU from 2000 to 2019 (Eurostat, 2021). The gender gap among farmers is very wide in Europe, notably in the Netherlands, where only one in every twenty farmers (5.2%) was female in 2016. Female farmers were also underrepresented in Malta (6.0% of total farmers), Denmark (7.7%), and Germany (9.6%). Latvia and Lithuania had a nearly equal gender distribution (each had 44.9% female farmers) (Eurostat, 2021).

## 2.1 CE indicators and employment

The following section examines the extent to which three selected CE sub-indicators are related to agriculture employment (AE) and gender dynamics in the sector. The selection of the three sub-indicators is based on the availability of data. First, we focus on the production and consumption sub-indicator GMW per capita to understand how it impacts agriculture employment. The second section establishes the link between the waste management sub-indicator RRMW and employment. The third section examines how the competitiveness and innovation sub-indicator PRSRM affects employment. The overall section



**Fig. 1** Gender employment trend in EU agriculture sector

is summarised in Table 1, which presents adopted CE thematic areas and their associated sub-indicators and employment nexuses. Reviewed literature revealed mixed findings regarding the relationship between CE indicators, employment patterns and gender dynamics. Drawing from the literature review, hypotheses are developed to illustrate the relationship between each sub-indicator and AE and female AE, as shown in Fig. 2.

### 2.1.1 CE production and consumption and employment

Unlike traditional systems, where waste is collected at the end of the cycle, hybrid production and consumption systems in CE emphasise waste minimisation at each cycle stage due to a focus on GMW per capita (Chioatto & Sospiro, 2022; Mhatre et al., 2021). According to Santibanez Gonzal et al. (2019), production and consumption in a CE take a proactive stance in constructing self-sustaining closed-loop systems that facilitate the 4Rs of CE, namely reducing, reusing, recycling, and recovering. In a decade systematic literature review (2010–2020), Mhatre et al. (2021) noted that production and consumption in CEs have been adopted in agriculture, forestry, and fisheries to substantially eliminate waste and reintroduce organic nutrients into the production-consumption cycle. The Ellen MacArthur Foundation (2013) emphasised the need for all enterprises and operational business models to have strategic business units specifically responsible for reconciling production and consumption systems with waste management and sustainable environmental and development goals.

In their CE and agri-food sector assessment, Esposito et al. (2020) emphasised that hybrid systems of production and consumption in a CE enable agricultural sector employment opportunities. Jun and Xiang (2011), while describing how a CE promotes sustainable agriculture growth, indicated that a CE generates employment through the introduction of practices which previously did not exist, such as waste sorting, recycling of by-products, and use of secondary raw materials for mulching and fertilisers. Korhonen et al. (2018), who emphasise CE's social side, hypothesise that hybrid CE production and consumption systems eventually result in job creation and employment. Despite the above indication of the positive impact of production and consumption in CE, Velenturf and Purnell (2021) argue that CE has a bad side that the literature seems to ignore. Highlighting that CE production and consumption systems require sophisticated technology for resource recovery and recycling, as well as considerable investments to get the system running, making manual workers (often women) redundant, forcing some SMEs out of business due to the inability to meet CE demands. Supporting this finding, recent studies found that a shift from traditional production and consumption system to hybrid systems led to a decline in female employment due to disparities between skills and job demands (Fernandez-Stark & Gereffi, 2019; Valverde et al., 2022). As a result of these arguments, the study hypothesises that:

**H1a** GMW negatively influence AE

**H1b** GMW negatively influence female AE

### 2.1.2 Waste management and employment

Dealing with solid waste presents both challenges and opportunities. Lack of effective recycling systems, infrastructure, and unregulated disposal of waste leads to unhealthy and polluting environments (Sharma et al., 2021). Using non-scientific landfill

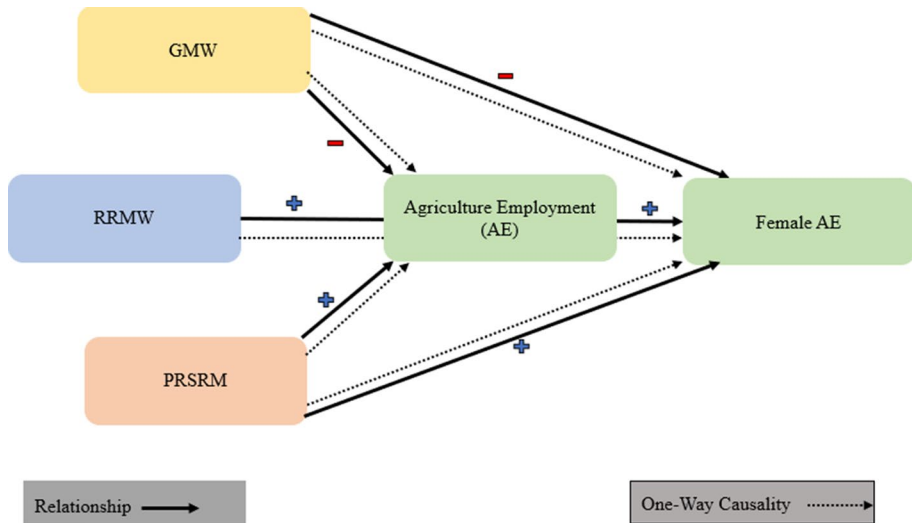
**Table 1** Linking CE thematic areas and sub-indicators to employment

CE thematic area	Sub-indicator	Sub-indicator description	CE thematic area-sub-indicator nexus	Paper type/References	Implications for CE-Employment nexus	
Production and consumption	Generation of municipal waste per capita	This is the amount of municipal waste generated (households, businesses, offices, and public institutions) and then collected by or on behalf of municipal authorities	Composting biodegradable municipal waste increases soil fertility and production levels	Empirical Empirical Empirical Empirical	Lebersorger and Beigl (2011) Le et al. (2018) Pomberger et al. (2021)	1. Lower generation of municipal waste is observed in areas with a higher proportion of people employed in agriculture 2. Increased utilisation of municipal waste generation through the application of CE principles (e.g. composting) significantly affects agricultural production and employment 3. The application of sophisticated approaches to waste management has a positive impact on employment creation and sustainability
Waste management	Recycling rate of municipal waste	The recycling rate is the share of recycled municipal waste in the total municipal waste generated	Higher recycling rate reduces waste that ends up in the landfill	Review empirical	Ezeah et al. (2013) Nedelea et al., (2018)	1. Recycling municipal waste provides employment and sustains the livelihood of impoverished and vulnerable social groups such as refugees 2. The municipal waste recycling rate increases the employment rate in a CE

**Table 1** (continued)

CE thematic area	Sub-indicator	Sub-indicator description	CE thematic area-sub-indicator nexus	Paper type/References	Implications for CE-Employment nexus
Competitiveness and innovation	Patents related to recycling and secondary raw materials	This is the number of patents related to recycling and secondary raw materials	Patents are a strategic tool used to enhance competitiveness and innovation	Empirical Buerger et al. (2012) Veltis et al. (2022)	1. Patent and job creation are positively and significantly related in the medical and optical sector, including electronics and electronics, while not significant in the transport and equipment sector





**Fig. 2** A conceptual model based on the review of the literature

techniques and unsanitary waste dumps pollute the air and contaminate groundwater. The proper management of waste can not only help make cities clean and green and improve living standards, but also provide breathable air, clean water, and land, and improve health and education (Kaza et al., 2018). Solid waste management techniques such as recovery and recycling are frequently considered more efficient than landfilling or combustion without heat recovery (Kaza et al., 2018; Morsetto, 2020). Investing in recycling, reuse, remanufacturing, maintenance, refurbishing, and repair services minimise waste and creates jobs for vulnerable groups, including women (Abunyewah et al., 2023; Gulati et al., 2020). Contrary, data from 86 countries from the ILO reveal that recycling creates more male jobs than females in a circular phosphorus model, thereby widening employment inequality between gender (ILOSTAT, 2020).

A study by Kaza et al. (2018) estimates that global waste generated will rise from 2 billion tons annually to 3.4 billion tons by the year 2050. The number of jobs required to recycle, reuse, and recover every 1,000 metric tons of waste is 3–20 versus 0.1 for landfilling and incineration (Goldstein et al., 2011; Stahel, 2016). The International Labour Organization (ILO, 2018) estimates that 45 million new jobs could be created in the waste management sector by 2030 if the world shifts to more recycling, reuse, and repair. Furthermore, Eurostat estimates that the waste management sector contributed 0.44% to total employment across the EU during the past decade (EC, 2018). By diversifying 60% of the waste, the zero-waste program in Canada created 1000 jobs in the garbage collection and processing industry and 2,000 in the used goods collection industry (Nizar et al., 2018). However, some studies have also shown that although capital-intensive waste management approaches handle large volumes of waste, it negatively impacts employment (Halkos & Petrou, 2016; Horbach et al., 2015). Drawing from the above discussion, the study proposes the following hypotheses:

**H2a** RRMW positively influence AE

**H2b** RRMW positively influence female AE**2.1.3 CE innovation and employment**

Moraga et al. (2019) explain that one of the main advantages of a CE is innovation, primarily visible in the gross value added to products and services. Kołodziejczak (2020) also emphasizes a comparative correlation between employment and gross value added from CE innovation across 17 EU countries and 11 other non-EU countries. While the study concluded that gross value-added boosted employment in the agricultural sectors of the 17 EU countries by 13.1%, the 11 European countries only saw a 4% increase in employment. Elsewhere, Harizanova et al. (2021), using ARDL models in Bulgaria, stipulated that although innovation-driven gross value-added influenced employment in the agriculture sector, such employment mostly required highly educated individuals (often men) to make significant impacts. In the EU context, Robaina et al. (2020) also highlighted those transitions driven by CE innovation could open avenues for jobs for both sexes due to production expansion and high consumption. Elsewhere, Boon and Anuga (2020) also noted that CE has the potential to not only engage the youth in agriculture to meet food demands but also present avenues to balance agricultural gender employment in the region.

Ellen MacArthur Foundation (2013) and Horbach and Rammer (2020) assert that CE innovation is claimed to have more employment, value-added and effective use of secondary raw material. Huygens and Saveyn (2018) specified in the agricultural context that innovation in CE has resulted in the employment of personnel who drives recycling, waste sorting and the use of selected phosphorous fertilisers derived from secondary raw material. Similarly, Cai et al. (2018) also stressed that CE innovation reduced the use of synthetic fertilisers in rice production systems through secondary raw materials such as organic fertilisers. In spite of all the benefits, there were issues with high employee turnover, as shown by Katz-Gerro and Lopez Sintas (2019). Considering the mixed results coupled with the limited number and scope of studies on CE innovation and employment in the agricultural sector, there is a need for further probing into the nexus between CE innovation and agricultural sector employment.

**H3a** PRSRM positively influence AE**H3a** PRSRM positively influence AE**H3b** PRSRM positively influence female AE**3 Methodology**

The study used annual time series data from 2000 to 2020 for twenty-four EU advanced and emerging countries to examine the relationship between CE and AE. These countries and periods of the study were selected based on data availability and reliability. Agricultural employment is the dependent variable, whereas CE variables such as production and consumption, waste recycling and innovation are the primary independent variables. Furthermore, whereas the production and consumption variable are proxied by GMW per capita, waste recycling and innovation are proxied by RRMW and PRSRW, respectively.

All the data used in this study were collected from the Eurostat Database except for the AE data set, gleaned from the World Development Indicators. AE is expressed as a percentage of total employment. In contrast, GMW is represented in kilograms per capita. Furthermore, the PRSRW indicates the total number of patents issued. Finally, the RRMW is expressed as a percentage of total recycled waste. The ARIMA model was used to forecast data for PRSRW from 2017 to 2020. At the same time, the ARDL model is used to examine the short and long-run relationship between the variables.

#### 4 Auto-regressive lag distributive model

The ARDL model has many advantages over the traditional method of testing co-integration. Firstly, this method can be applied when variables are a mixture of  $I(0)$  and  $I(1)$ . The ARDL can simultaneously estimate the short-run and long-run relationship among variables using the ARDL bounds test procedure. Furthermore, the ARDL model takes care of the endogeneity issue by adding lags to the variables in the model. The ARDL model is written as

$$AE_t = C_0 + \beta_1(GMW) + \beta_2(PRSRM)_t + \beta_3(RRMW) + \varepsilon_t \quad (1)$$

where AE, GMW, PRSRM, and RRMW are variables of the study representing Agricultural Employment, Generation of Municipal Waste, Patents Related to Recycling and Secondary Raw Materials and Recycling Rate of Municipal Waste, respectively, whereas  $\varepsilon_t$  represents the white noise term. The ARIMA model forecasts data for PRSRM from 2017 to 2020. As a result, the data for PRSRM for ARDL analysis are future expected values. The bound test can be used by converting Eq. (1) into a bound testing equation by including both short-run and long-run dynamics. The bound testing approach to co-integration permits us to carry out F-test on the selected ARDL bound testing equation with appropriate lag lengths. We enforced a mandate of a maximum of 3 lags on the level of variables, and then the optimal lag length was chosen based on Akaike information criterion. The existence of co-integration is confirmed by the standard F test (Pesaran et al., 2001), which has come up with two sets of critical values (i.e. lower and upper) for the bound test. The lower and upper critical values encompass the assumptions of all variables, being  $I(0)$  and  $I(1)$ , respectively. This provides a bound restriction encompassing all possible classifications of the variables. If the generated F-statistics from the bound testing equation lie above the upper bound, the null hypothesis of no co-integration is rejected. If it lies below the lower bound, the test fails to reject the null hypothesis. However, the result is inconclusive if the value of F statistics lies between the lower and upper bound. Once the long-run relationship is confirmed, we can capture the short-run dynamics by converting Eq. (1) into an error correction specification (ECM) as follows:

$$\Delta AE_t = \theta_1 + \sum_{i=1}^n \beta \Delta GMW_{t-1} + \theta_2 \sum_{i=1}^n \beta \Delta FPRS_{t-2} + \sum_{i=1}^n \beta \Delta RMW_{t-2} + \delta EC_{t-1} + \varepsilon_t \quad (2)$$

where  $\delta$  captures the speed of adjustment,  $EC_{t-1}$  represents disequilibrium, and  $\Delta$  denotes the first difference. The error correction coefficient indicates the speed of re-adjustment to the long-run equilibrium after short-run shocks lead to disequilibrium. In this process, the causality is portrayed by the negative and statistically significant value of the error correction term coefficient  $\delta$ .

Model diagnostic checking is essential because some key ARDL assumptions, such as serially independent and normally distributed errors, are violated. So, the Breusch-Pagan-Godfrey Serial Correlation Lagrange Multiplier test is used to check serial independence, and the Jarque-Bera test is used to test normality. While the autoregressive conditional heteroskedasticity (ARCH) test is used to check for heteroskedasticity in the model, the Ramsey RESET test is applied to check whether there is any misspecification in the model.

## 5 Results

### 5.1 Diagnostic test results

The diagnostic statistics for all individual ARDL models are presented in Table 2. The Ramsey RESET test results indicate that the models do not suffer misspecification problems. The LM tests reveal no serial correlation at a 5% significance level, and JB test

**Table 2** Diagnostic tests

Country	Jarque-Bera normality test	Breusch-Pagan-Godfrey test	RESET test	Lagrange multiplier test
Germany	1.64(0.43)	0.74(0.11)	0.40(1.05)	0.47(0.53)
France	0.80(0.66)	0.78(0.13)	0.80(0.33)	0.46(0.53)
Spain	2.41(0.29)	0.53(0.39)	0.25(1.54)	0.59(0.28)
Austria	0.17	0.57(0.37)	0.26(1.50)	0.36(0.82)
UK	2.26(0.30)	0.94(0.33)	0.28(0.83)	0.12(2.20)
Belgium	0.19(0.90)	0.66(0.18)	0.25(1.53)	0.67(0.17)
Greece	6.33(0.39)	0.69(0.22)	0.70(0.47)	0.45(0.62)
Poland	1.53(0.47)	0.57(0.32)	2.13(0.14)	0.51(0.43)
Ireland	0.22(0.89)	0.18(1.77)	0.13(2.30)	0.55(0.34)
Denmark	0.21(0.89)	1.53(0.21)	0.19(1.84)	0.39(0.72)
Portugal	0.78(0.67)	0.54(0.46)	0.64(0.60)	0.51(0.43)
Finland	0.46	0.06(3.47)	0.61(0.62)	0.14(2.14)
Czech Republic	1.92(0.38)	0.13(2.24)	0.98(0.06)	0.16(1.88)
Romania	2.30(0.35)	0.97(0.00)	0.36(1.20)	0.36(0.82)
Estonia	0.69(0.70)	0.62(0.24)	0.29(1.39)	0.57(0.31)
Italy	0.99(0.60)	0.25	0.8(0.33)	0.94(0.06)
Luxembourg	28.47(6.6)	0.88(0.06)	0.17(1.93)	0.49(0.45)
Malta	0.64(0.72)	0.65(0.20)	0.73(0.44)	0.69(0.14)
Netherlands	0.66(0.71)	0.63(0.25)	0.07(3.37)	0.76(0.09)
Croatia	6.73(0.34)	0.61(0.25)	0.70(0.47)	0.40(0.69)
Sweden	0.73(0.61)	0.72(0.35)	0.07(3.42)	0.76(0.09)
Slovenia	0.29(0.80)	0.68(0.21)	0.28(1.63)	0.77(0.10)

1. The values above the parenthesis are p-values. 2. The value in parenthesis is F-statistics. 3. RESET is a Ramsey model specification test to check model stability. 4. LM is the Lagrange Multiplier test for serial correlation. 5. Jarque-Bera is for the normality test. 6. Breusch Pagan is for the Heteroskedasticity test

results show that all residuals are normally distributed. Further, the ARCH test shows no heteroscedasticity problem in our models.

## 5.2 Stationarity test

A fundamental assumption of the classical linear regression model is that all variables are stationary, which means they have a common trend or mean. Violation of this assumption results in erroneous regression. To avoid such an erroneous result, a unit root test was performed on all variables to determine whether they were stationary or not. As a result, the augmented Dickey–Fuller (ADF) tests were used to see if the series has a unit root. A detailed description of the analysis for each variable is provided below. If the ADF test fails to reject the null hypothesis, the series has a unit root and is thus not stationary; however, if the tests reject the null hypothesis, the series has no unit root and is stationary. Table 3 presents the results.

## 5.3 Long-run relationship

Following the conclusion that the variables under study are integrated into the combination of order zero and order one, the bounds test for cointegration was performed to establish a long-run relationship between the variables. Our test results are shown in Table 3.

The bounds test results show the computed F-statistic value of all the countries. Furthermore, the results reveal that France, the UK, Austria, Denmark, Portugal, the Czech Republic, Estonia, Croatia, and the Netherlands had their computed F-statistic being greater than the upper bound value of 4.35. Hence the null hypothesis of no cointegration was not rejected. This implies that these countries have a long-run relationship between Agricultural Employment and CE.

Table 4 only includes countries where the CE indicators have a long-term relationship with agricultural employment. Therefore, it shows the long-term relationship between the variables of these countries. Countries such as Germany, Estonia, the UK, Croatia, and the Czech Republic have a statistically significant and positive relationship between RRMW and agricultural employment in the long run. The results of Germany, the UK and Estonia indicate that a percentage increase in the RRMW, all other things being equal, leads to an increase in agricultural employment by 0.1% in Germany, 0.081% in the UK and 0.05% in Estonia. Also, PRSRM at a 1% significance has a positive effect on agricultural employment in Estonia and the Czech Republic, indicating that a percentage increase in PRSRM effects a 0.02% increase in agricultural employment in the Czech Republic and Estonia. This shows that, all other things being equal, an increase in CE innovation leads to agricultural employment in these countries. Also, results in Table 3 indicate that the GMW negatively impacts agricultural employment in all the countries except the Czech Republic, Estonia, and Denmark in the long run. However, at a 5% significance level, GMW negatively affects agricultural employment in the UK, indicating that a percentage increase in GMW leads to a decrease in agricultural employment by 0.55% in the long run.

## 5.4 Estimation of ARDL error correction model (Short-Run Estimation)

After obtaining the long-term relationship according to the co-integration model, the ECM model was estimated to test the short-term relationship between the independent and

**Table 3** ARDL bounds test for cointegration (agricultural employment and CE indicators)

Country	Computed F statistic	Lower bound I(0)	Upper bound I(1)	Remarks
Germany	1.4	3.23	4.35	No cointegration
France	5.15*	3.23	4.35	Cointegration
Spain	3.21	3.23	4.35	No cointegration
UK	4.48*	3.23	4.35	Cointegration
Austria	6.25*	3.23	4.35	Cointegration
Belgium	2.60	3.23	4.35	No cointegration
Malta	0.56	3.23	4.35	No cointegration
Poland	4.80	3.23	4.35	No cointegration
Ireland	1.69	3.23	4.35	No cointegration
Denmark	14.5*	3.23	4.35	Cointegration
Portugal	4.37*	3.23	4.35	No cointegration
Finland	2.09	3.23	4.35	No cointegration
Czech Republic	4.76*	3.23	4.35	Cointegration
Romania	1.63	3.23	4.35	No cointegration
Hungary	1.91	3.23	4.35	No cointegration
Luxembourg	2.98	3.23	4.35	No cointegration
Croatia	14.78*	3.23	4.35	Cointegration
Sweden	3.20	3.23	4.35	No cointegration
Italy	2.80	3.23	4.35	No cointegration
Slovenia	2.01	3.23	4.35	No cointegration
Netherlands	4.45*	3.23	4.35	No cointegration
Estonia	4.69*	3.23	4.35	Cointegration

**Table 4** Long run estimates (Agricultural Employment and CE Indicators)

Country	Variable	Coefficients	Standard error	T-Ratio	P value
Germany	GMW	-0.013	0.002	-0.52	0.628
	RRMW	0.100	0.060	2.52	0.470*
	PRSRM	0.020	0.029	0.99	0.366
Austria	GMW	-0.011	0.001	-1.34	0.237
	RRMW	-0.186	0.140	-1.32	0.245
	PRSRM	-0.068	0.049	-1.37	0.229
Estonia	GMW	0.001	0.001	1.72	0.149
	RRMW	0.012	0.019	2.36	0.050*
	PRSRM	0.020	0.003	5.73	0.002*
Denmark	GMW	0.005	0.001	0.05	0.673
	RRMW	0.012	0.013	0.91	0.405
	PRSRM	-0.032	0.016	-1.92	0.113
UK	GMW	-0.550	0.005	2.75	0.045*
	RRMW	0.081	0.083	2.82	0.046*
	PRSRM	0.002	0.009	0.23	0.113
Croatia	GMW	-0.008	0.002	-5.26	0.003*
	RRMW	0.021	0.226	3.21	0.030*
	PRSRM	0.130	0.322	0.43	0.687
Czech Republic	GMW	0.001	0.007	1.71	0.149
	RRMW	0.012	0.620	0.62	0.56
	PRSRM	0.020	0.003	5.73	0.002*

\*\* and \* denotes significance at 1 and 5% level, respectively

dependent variables. The coefficient of the variables shows the short-run impact. Table 5 summarises the estimated short-run ARDL model;

Table 5 indicates the short-run implications of the variables. At a 5% significance level, GMW is found to have a negative and significant relationship to AE in the UK, Austria, Finland, Denmark, Hungary, Ireland, Croatia, and Slovenia. This indicates that an increase in the GMW drives down AE in these economies. However, GMW is found to have a negative but insignificant impact on agricultural employment in Malta, Belgium, Luxembourg, Estonia, Germany, Spain, and Portugal. In contrast, at 5% significance, GMW has a positive and significant relationship with AE in Romania. This shows that an increase in waste generated by production and consumption, all other things being equal, negatively affects AE. In the UK, Austria and Croatia, our results indicate that all other things being equal, a percentage increase in the GMW leads to a decrease in agricultural employment in these countries by 0.05, 0.02 and 0.11%, respectively. However, RRMW influences agricultural employment positively and is statistically significant in France, Germany, the UK, Hungary, Croatia, Estonia, Malta, Luxembourg, and the Netherlands, indicating an increase in the RRMW has a significant effect on agricultural employment. The results show that a percentage increase in RRMW causes an increase in AE by 0.41% in Germany, 0.44% in Estonia and 0.22% in France in the short run (Table 6). Also, PRSRM has got a positive and statistically significant impact on Spain, Austria, Croatia, Finland, the Czech Republic, and Malta. At the same time, the results in France, Ireland, Netherlands, Luxembourg,

**Table 5** Estimated short-run ARDL Coefficients (Agricultural Employment and CE Indicators)

Country	Variable	Coefficients	Standard error	T-Ratio	P value
Spain	GMW	-0.022	0.039	-0.58	0.580
	RRMW	0.013	0.015	0.88	0.419
	PRSRM	0.116	0.046	2.52	0.048*
Germany	GMW	0.001	0.011	0.09	0.931
	RRMW	0.410	0.026	2.58	0.040*
	PRSRM	0.009	0.125	0.78	0.471
Austria	GMW	-0.022	0.009	-2.43	0.050*
	RRMW	-0.030	0.045	1.47	0.200
	PRSRM	0.510	0.140	3.58	0.016*
Estonia	GMW	-0.005	0.003	-0.13	0.899
	RRMW	0.440	0.180	2.36	0.048*
	PRSRM	0.470	0.230	2.08	0.092
Ireland	GMW	-0.017	0.003	-0.44	0.680
	RRMW	-0.024	0.096	-0.25	0.813
	PRSRM	0.041	0.360	0.11	0.915
Denmark	GMW	-0.0001	0.163	-2.62	0.050*
	RRMW	0.0002	0.001	0.02	0.98
	PRSRM	0.001	0.020	0	0.998
Malta	GMW	-0.007	0.002	-0.03	0.970
	RRMW	0.037	1.890	2.48	0.050*
	PRSRM	1.700	0.830	2.51	0.048*
Netherlands	GMW	0.005	0.008	0.61	0.569
	RRMW	0.520	0.233	2.52	0.049*
	PRSRM	0.170	0.101	1.70	0.150
UK	GMW	-0.050	0.005	2.75	0.045*
	RRMW	0.081	0.083	2.82	0.046*
	PRSRM	0.002	0.009	0.23	0.113
France	GMW	0.005	0.004	1.20	0.290
	RRMW	0.220	0.086	2.58	0.040*
	PRSRM	0.002	0.014	2.02	0.113
Belgium	GMW	-0.008	0.008	-0.96	0.381
	RRMW	-0.087	0.035	0.82	-0.998
	PRSRM	-0.677	0.269	-1.37	0.160
Poland	GMW	0.004	0.007	0.50	0.636
	RRMW	0.020	0.039	0.52	0.627
	PRSRM	0.045	0.370	1.21	0.280
Finland	GMW	-0.002	0.002	-2.63	0.049*
	RRMW	-0.050	0.017	-3.02	0.026
	PRSRM	0.244	0.100	2.43	0.047*
Czech Republic	GMW	0.003	0.001	2.54	0.049
	RRMW	0.779	0.158	4.91	0.004*
	PRSRM	0.451	0.146	3.09	0.027*



**Table 5** (continued)

Country	Variable	Coefficients	Standard error	T-Ratio	<i>P</i> value
Luxembourg	GMW	-0.045	0.343	-0.13	-0.901
	RRMW	0.168	0.120	2.61	0.047*
	PRSRM	0.095	0.450	0.21	0.842
Portugal	GMW	-0.003	0.009	-0.30	0.775
	RRMW	-0.010	0.009	1.11	0.309
	PRSRM	1.720	0.899	1.92	0.113
Hungary	GMW	-0.010	0.007	-0.21	0.840
	RRMW	0.080	0.086	2.78	0.039*
	PRSRM	0.300	0.930	0.32	0.750
Croatia	GMW	-0.117	0.0032	-3.65	0.015*
	RRMW	0.083	0.250	2.95	0.040*
	PRSRM	2.12	0.463	4.58	0.006*
Sweden	GMW	0.001	0.020	0.40	0.704
	RRMW	-0.002	0.016	-0.16	0.875
	PRSRM	0.004	0.077	0.06	0.955
Italy	GMW	0.131	0.008	1.58	0.174
	RRMW	0.035	0.040	0.84	0.439
	FPRS	0.032	0.024	1.32	0.243
Romania	GMW	0.038	0.0245	2.28	0.050*
	RRMW	0.330	0.240	0.16	0.882
	PRSRM	0.177	0.590	0.30	0.776
Slovenia	GMW	-0.006	0.009	2.54	0.045*
	RRMW	-0.013	0.060	0.22	0.836
	PRSRM	-1.800	1.800	0.10	0.923

\*\* and \* denotes significant at 1 and 5% level, respectively

Italy, Romania, Denmark, and Germany indicate a positive but insignificant impact on agricultural employment. This result shows that innovation in CE increases agricultural employment.

## 5.5 CE and agriculture labour force employment

An ECM model is estimated to test the short-term relationship between the CE indicators and female agricultural employment. The coefficient of the variables shows the short-run impact. Table 7 shows the estimated short-run autoregressive distributed lag coefficients of our model.

## 5.6 Long-run relationship between female agricultural employment and CE indicators

A cointegration bounds test was performed to test the long-run relationship between female AE and CE indicators. Our test results are shown in Table 8.

**Table 6** Estimated short run ARDL coefficients (Short-Run Relationship between CE and Female Agricultural Employment)

Country	Variable	Coefficients	Standard error	T-Ratio	<i>P</i> value
Spain	GMW	0.002	0.004	0.64	0.540
	RRMW	-0.060	0.011	-0.51	0.630
	PRSRM	0.850	0.044	1.90	0.115
Germany	GMW	-0.013	0.002	-0.52	0.628
	RRMW	0.100	0.060	2.52	0.047*
	PRSRM	0.020	0.029	0.99	0.366
Austria	GMW	-0.025	0.001	-2.16	0.083
	RRMW	-0.250	0.600	-0.90	0.400
	PRSRM	-0.650	0.170	-3.78	0.013*
Estonia	GMW	0.008	0.004	0.20	0.848
	RRMW	-0.009	0.020	-0.46	0.663
	PRSRM	-0.460	0.350	-1.28	0.255
Ireland	GMW	-0.011	0.001	-2.96	0.039*
	RRMW	-0.058	0.020	-1.99	0.118
	PRSRM	0.250	0.170	1.42	0.220
Denmark	GMW	-0.0001	0.163	-2.62	0.05*
	RRMW	0.0002	0.001	0.02	0.980
	PRSRM	0.001	0.020	0.00	0.998
Malta	GMW	0.001	0.001	0.14	0.895
	RRMW	0.005	0.010	0.57	0.592
	PRSRM	-0.6	0.290	-0.24	0.822
Netherlands	GMW	0.005	0.084	0.61	0.569
	RRMW	0.300	0.210	2.41	0.061
	PRSRM	-0.720	0.114	-0.60	0.556
France	GMW	-0.006	0.006	-1.10	0.323
	RRMW	-0.650	0.700	-0.93	0.0.39
	PRSRM	0.720	0.057	1.27	0.260
UK	GMW	-0.017	0.005	-0.35	0.074
	RRMW	-0.019	0.082	-0.23	0.827
	PRSRM	0.004	0.012	0.34	0.750
Belgium	GMW	-0.013	0.009	-0.15	0.887
	RRMW	-0.006	0.049	0.14	-0.898
	PRSRM	-0.509	0.260	-1.90	0.116
Poland	GMW	0.002	0.700	0.50	0.636
	RRMW	-0.031	0.035	-0.88	0.421
	PRSRM	0.023	0.330	0.71	0.508
Finland	GMW	-0.002	0.002	-0.68	0.524
	RRMW	-0.009	0.018	-0.52	0.626
	PRSRM	0.190	0.130	1.43	0.683
Czech Republic	GMW	0.0028	0.002	1.37	0.228
	RRMW	0.330	0.331	1.20	0.284
	PRSRM	0.530	0.063	0.07	0.857

**Table 6** (continued)

Country	Variable	Coefficients	Standard error	T-Ratio	<i>P</i> value
Luxembourg	GMW	-0.002	0.011	-1.68	0.900
	RRMW	0.167	0.760	2.18	0.081
	PRSRM	-0.110	0.190	-0.59	0.581
Portugal	GMW	0.081	0.140	1.28	0.258
	RMW	0.074	0.170	0.43	0.684
	FPRS	1.740	1.200	1.35	0.023
Hungary	GMW	-0.002	0.009	-0.29	0.783
	RRMW	0.025	0.610	2.40	0.048*
	PRSRM	0.524	0.090	0.57	0.593
Croatia	GMW	-0.197	0.034	-0.57	0.590
	RRMW	0.260	0.340	0.08	0.942
	PRSRM	5.020	10.880	0.46	0.663
Sweden	GMW	-0.003	0.040	0.80	0.462
	RRMW	0.007	0.019	0.04	0.970
	PRSRM	0.030	0.050	0.69	0.523
Italy	GMW	-0.001	0.003	-0.44	0.680
	RRMW	-0.020	0.090	-0.25	0.810
	PRSRM	0.040	0.340	0.11	0.950
Romania	GMW	0.033	0.031	1.06	0.338
	RRMW	0.540	0.310	1.70	0.149
	PRSRM	0.036	0.650	0.05	0.980
Slovenia	GMW	-0.004	0.010	-0.47	0.661
	RRMW	-0.032	0.07	-0.04	0.960
	PRSRM	-1.800	1.80	0.10	0.923

\*\* and \* denotes significant at 1 and 5% level, respectively

The bounds test results show that the computed F-statistic value of all the countries, except Austria, Estonia, and Poland, is lesser than the 5% critical values of both the lower bound value of 3.23 and the upper bound value of 4.35; hence the null hypothesis of no cointegration was accepted. This implies that a long-run relationship exists between female AE and CE indicators of only Austria, Estonia, and Poland.

Table 8 only shows countries where the CE indicators have a long-term relationship with female agricultural employment. It shows the long-term relationship that exists between the variables of these countries. From the results presented, only Austria, Estonia, and Poland exhibit a long-term relationship between the variables. There is a positive relationship between the RRMW and female agricultural employment in the long run in Estonia, whereas the results of Poland and Austria indicate a negative relationship, suggesting that an increase in the RRMW leads to a decrease in female agricultural employment in the long run. The results of Estonia suggest that a percentage increase in RRMW, all other things being equal, leads to an increase in agricultural employment by 0.1% in the long run at 5% significance. The GMW negatively affects female agricultural employment in all three countries. This indicates that the production of goods

**Table 7** ARDL bounds test for Cointegration (Female Agricultural Employment and CE Indicators)

Country	Computed F statistic	Lower bound I(0)	Upper bound I(1)	Remarks
Germany	1.17	3.23	4.35	No cointegration
France	2.38	3.23	4.35	No cointegration
Spain	1.45	3.23	4.35	No cointegration
UK	1.27	3.23	4.35	No cointegration
Austria	<b>6.89*</b>	3.23	4.35	Cointegration
Belgium	<b>4.10</b>	3.23	4.35	No cointegration
Malta	1.04	3.23	4.35	No cointegration
Poland	8.7*	3.23	4.35	Cointegration
Ireland	0.41	3.23	4.35	No cointegration
Denmark	0.92	3.23	4.35	No Cointegration
Portugal	2.40	3.23	4.35	No Cointegration
Finland	2.19	3.23	4.35	No Cointegration
Czech Republic	<b>1.73</b>	3.23	4.35	No Cointegration
Romania	1.41	3.23	4.35	No Cointegration
Hungary	4.14	3.23	4.35	No Cointegration
Luxembourg	2.98	3.23	4.35	No Cointegration
Croatia	<b>2.70</b>	3.23	4.35	No Cointegration
Sweden	2.30	3.23	4.35	No Cointegration
Italy	0.41	3.23	4.35	No Cointegration
Slovenia	2.80	3.23	4.35	No Cointegration
Netherlands	4.20	3.23	4.35	No Cointegration
Estonia	7.53*	3.23	4.35	Cointegration

**Table 8** Long run estimates (Female Agricultural Employment and CE Indicators)

Country	Variable	Coefficients	Standard error	T-Ratio	P value
Austria	GMW	-0.013	0.110	-1.19	0.286
	RMW	-0.200	1.220	-1.22	0.278
	FPRS	-0.886	0.060	-1.47	0.202
Estonia	GMW	-0.0133	0.002	-0.52	0.628
	RMW	0.100	0.060	2.52	0.470*
	FPRS	0.020	0.029	0.99	0.366
Poland	GMW	-0.002	0.055	-0.44	0.670
	RMW	-0.005	0.023	-0.22	0.830
	FPRS	0.004	0.044	1.01	0.357

\*\* and \* denotes significance at 1 and 5% level, respectively

and services, which leads to waste generation, does not encourage female employment in the agriculture sector. Austria, Estonia, and Poland exhibit a long-term relationship between the variables, so PRSRM positively affects agricultural employment in Estonia and Poland, indicating innovation and competitiveness due to the CE practices promoting female agricultural employment in the long run.

## 6 Discussion and implication

### 6.1 Discussion of study findings

CE production and consumption, waste recycling and innovation are significant employment drivers in many sampled countries. Therefore, this study's estimates associated with the CE indicators are important in the ARDL bounds test for cointegration. Several seminal and recent studies support these findings (see, for instance, Burger et al., 2019; Horbach & Rammer, 2020; Horbach et al., 2015; Kinnaman & Fullerton, 1999; Liu et al., 2020; Schröder et al., 2019).

In both the short- and long-run models, GMW was significant and negatively related to AE in the UK, Austria, Finland, Denmark, Hungary, Ireland, Croatia, and Slovenia, indicating a rise in GMW reduces agricultural employment. A negative impact of GMW on agricultural employment was found in Malta, Belgium, Luxembourg, Estonia, Germany, Spain, and Portugal, but the effect was not significant. This indicates that all other things being equal, an increase in waste from traditional production and consumption systems limits employment opportunities in the studied sector. This suggests that sectors that generate the most waste have a harder time generating new jobs due to high production costs and haulage fees for discarding their waste. Thus, while structural policies on resource use in agriculture may impact sectors' growth, investing in hybrid CE production and consumption systems will minimise the amount of waste generated, accelerating employment growth in the sector.

In contrast, RRMW and PRSRM positively impacted AE across sampled countries. In France, Germany, the UK, Hungary, Croatia, Estonia, Malta, Luxembourg, and the Netherlands, the RRMW is statistically significant and a positive determinant of agricultural employment, indicating that waste recycling affects agricultural employment in other countries. For example, Spain, Austria, Croatia, Finland, the Czech Republic, Malta, and the Netherlands have all seen positive and statistically significant impacts of RRMW and PRSRM on employment. In contrast, France, Ireland, Netherlands, Luxembourg, Italy, Romania, Denmark, and Germany have seen positive but insignificant impacts of RRMW and PRSRM on employment. According to the study, PRSRM has a positive relationship with employment in the agriculture sector in most countries, affirming that introducing CE innovations can increase employment in the agriculture sector (See Sharma et al., 2019; Yoshikawa et al., 2021). The positive impact of RRMW and PRSRM on Europe's agriculture sector growth shows that CE policies might enable countries to specialise in technological innovations that offer their agriculture sector a dynamic comparative advantage in terms of potential productivity growth and diverse job opportunities.

There is statistical significance between the sexes. Most EU countries except Spain, Estonia, Poland, Sweden, and the Czech Republic show a short-term and long-term negative relationship between GMW and female employment in agriculture, which supports the study's hypothesis. Based on this negative relationship, it appears that waste generated by the production and consumption of goods makes the agriculture sector less attractive to females in most European countries in both the short and long term. The results in Hungary show that, in the short run, an increase in the RRMW leads to an increase in female agricultural employment of 0.025% at a 5% significance level. According to the Estonian data, an increase in RRMW leads to higher female employment in the agriculture sector by 0.1% over the long run at a 5% significance level. Many countries also reported positive effects of PRSRM on women's employment in agriculture, although they were not

significant in the short term. This suggests that Europe's agricultural sector could hopefully close the gender gap by increasing female employment through innovative CE practices.

Agricultural supply chain mismanagement causes 20–60% of waste and significantly impacts employment opportunities (Dulebenets et al., 2016). Study results imply that current conventional supply chain systems must be replaced with circular ones to achieve sustainable production and growth, reducing production costs, increasing employment and reducing waste. A CE-based agricultural strategy requires enhancing decision-making support and implementing sustainable, reverse, and closed-loop supply chains. In addition, organisations must develop data-driven management systems to make sense of data volumes and gain a competitive advantage. Considering the complexity of circular-driven technology and models, relationships with technology providers are strongly recommended. Developing a relationship like this can provide technology adopters with the ability to overcome technological skills challenges, which limit their ability to interpret and analyze collected data. Therefore, it is imperative that technology providers not only ensure continuous technical assistance but also get to know the specifics of the processes characterised by the adopters in great depth. Such initiatives can improve production processes in the agriculture sector and make existing supply chains more agile, resilient, and responsive to CE principles in the long run compared to traditional supply chains.

## 6.2 Implications of the study

Historically, previous studies have urged extending the scope of circular agriculture beyond its traditional economic and environmental challenges and solutions. Our findings represent an initial response to this call. Further, we have added an employment perspective to the discussion of circular agriculture models in the literature (e.g. Yazdani et al., 2019; Yue et al., 2022). With a specific focus on what actions should be incorporated into the value chain of circular agriculture, including job creation, we contribute to the extant literature on how circular agriculture can be translated into practice from a social perspective. In the light of this, we shed light on the circular disruption debate by explaining how the transition to a circular approach driven by employment is not simple, given that the CE indicators adopted in agriculture are interconnected in a complex way and impacted by geographical contexts.

The study offers three policy implications. Firstly, countries would benefit from implementing recycling initiatives and using secondary raw materials as part of their CE strategies. In the agricultural sector, governments can standardise clean production requirements to promote recycling and the use of *secondary* raw materials in a more targeted and innovative manner. This approach is to develop circular agriculture where minimal external inputs are used, nutrients are closed loops, soils are regenerated, materials are reused, and the environmental impacts are minimised. CE innovations lead to cleaner job creation across sectors, as affirmed by the study findings. Governments must enact policies to encourage industry adoption of CE innovations, which can generate sector-wide innovations that are environmentally friendly and create green jobs. The application of circular agriculture on a large scale in Europe can also significantly reduce resource requirements and the sector's ecological footprint.

Second, governments creating circular policies geared towards particular industries to address waste issues benefit more from such interventions. In this manner, governments can improve regulatory efficiency by targeting waste generated from production and consumption. The results of our study indicate that waste production and consumption

negatively impact job creation within the agriculture sector, which suggests a need to promote resource efficiency through a policy mix encompassing the full product life cycle. Within the agriculture sector, policy instruments, regulations, information-based and voluntary approaches, environmental labelling, and public financial support can internalise environmental costs and provide incentives for resource efficiency across the supply chain.

Finally, the study examines the role of a CE in generating jobs in the agriculture sector of EU countries and proves that the production and consumption of waste and municipal waste recycling rates can impede female employment. It was found that, in most EU countries, the production and consumption of goods that result in waste discourage women from working in the agricultural sector. Furthermore, due to outdated technology, more production consumes large amounts of energy and generates large amounts of waste. Therefore, policymakers must consider the diverse patents driving CE policies to build gender-sensitive circular futures across sectors. As a result, the study concludes that EU countries can foster inclusive growth and development by placing gendered and targeted employment strategies at the centre of CE policies.

## 7 Conclusion

This study examines the hypothesis that a CE increases agricultural employment in EU countries. During the research, three CE patents were examined: GMW (production and consumption), RRMW (recycling), and PRSRM (innovation). Unlike previous discourse, this study focuses on these unique patents and examines a more representative sample of EU countries. Production and consumption of municipal waste have negative effects. By this logic, European agricultural employment is encouraged by adopting recycling initiatives and the recycling of secondary raw materials rather than the generation of waste from production and consumption. These results support the purpose of the EU 2020 CE action plan, which is to create sustainable growth and jobs across the EU.

The findings of our study contribute to the growing literature on CE and job creation. Much attention has been paid to documenting CE's drivers and recommending an alternative approach for its measurement. The CE has, however, not been well studied in terms of its influence on employment. Furthermore, most existing evidence is based on cross-sectional data, making it impossible to control individual fixed effects, particularly time-invariant variables that can dramatically impact employment. With panel data, we can control for individual fixed effects and examine the effect of a CE on agricultural employment directly and subjectively.

The nuances of the relationship between CE and employment can be explored more in-depth in future research by, for instance, studying the channels through which CE patents operate. As such, future studies could examine potential mediators between circular economies and employment in agriculture and other industries. It would also be beneficial to investigate further the contextual issues pertaining to attitudes towards circular jobs, skills and training required, smart technology, and global equity in terms of the shift in employment trends in future studies.

In this study, a new research area is opened by suggesting that current efforts to circularise the agricultural sector might not be adequate to create jobs and increase gender opportunities in the sector. Despite the increasing commitment of agriculture businesses to promote circular practices, they lack appropriate indicators for measuring their progress and evaluating their impact on employment. By reporting these indicators, businesses can

progress information flows and move away from less sustainable forms of waste disposal towards more environmentally friendly options such as prevention, reuse, and recycling. It will take the collaboration of many stakeholders, including companies, entrepreneurs, governments, NGOs, and academic institutions, to scale up innovative partnerships and practices for advancing a circular agriculture sector. As a final step, governments can promote inclusive and sustainable growth across sectors by integrating gender-specific and targeted employment strategies into CE policies.

## 7.1 Limitation of the study

Some limitations are present in this study. First, only the recycling rate and the use of secondary materials are analysed as CE indicators. The literature review section of this paper discusses several potential channels, but data availability and reliability make empirical examination impossible. For instance, the recycling rate and secondary material use are not the only indicators that impact employment levels. Trade in recyclable raw materials, private investments, and circular material use, among others, can also significantly impact employment. The availability of appropriate data may prompt future studies to consider these potential CE indicators. Second, disaggregated waste data was not available. Our study used the aggregated data set for each area of the CE. Thus, future studies should explore how disaggregated data sets, once available, can impact the findings shared in our study. Third, although the study findings may apply to all companies, future researchers should add some sector-specific indicators to describe and measure the CE-employment relationship accurately. Moreover, pilot studies need to be conducted to determine the feasibility of proposed CE indicators in various sectors and refine them further. Finally, assessing CE's social dimensions, such as employment, can be more complex, and data are often not readily available, which limited the timeframe used in this study.

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**Data Availability** The data sets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

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