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The Decoupling Effect in Italian Agricultural Waste: An Empirical Analysis

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Abstract: The environmental Kuznets curve has received widespread attention from scholars for its ability to vividly capture the dynamics between economic growth and waste generation. The so-called waste Kuznets curve (KWC) has been used in different fields (e.g., municipal waste, e-waste, construction waste, tourism waste, etc.); nonetheless, WKC studies into agricultural waste remain relatively scarce. Due to the impact of agriculture on socio-economic development and environmental protection, this study applied KWC to the Italian agricultural sector. The aim was to investigate whether a "decoupling effect" exists between agricultural production and waste generation and assess the effects of certain socio-economic variables. The analysis was based on a panel dataset, including geographical observations at a regional level and a time series of 14 years (2002–2015). Empirical results show that the delinking point has not yet been reached, but can be reached if specific policy instruments are applied. Our evidence suggests that public expenditure for environmental protection or the promotion of organic farming could help to achieve this goal. Future studies are recommended to further validate the waste Kuznets curve for agriculture using a wider set of economies and longer panel data.

Keywords: agricultural waste; GDP–waste decoupling; waste Kuznets curve (WKC); Italian agricultural sector

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1. Introduction

According to the most recent World Bank report, waste generation is estimated to grow from 2.24 billion tons in 2020 to 3.88 billion tons in 2050 [1] given the relation between economic growth and waste production. In the European Union (EU), between 2010 and 2020, waste generation decreased slightly, with the total annual waste generation per capita reducing from 5.0 to 4.8 tons/capita. A relatively small decrease (4.2%) was produced due to the slowing down of the global economy during the pandemic period [2]. In 2020, more than 2 billion tons of waste (4815 kg per capita) were produced in EU, and 4.4% of the total amount was classified as hazardous, which means that it represents an elevated risk to human health and the environment if not managed and disposed safely [3].

Prevention and recycling are the best practices to minimize waste generation and improve the efficient use of resources (Directive 2008/98/EC), while disposal is the last solution for managing waste [4]. According to this trajectory, the European Package for the Circular Economy underlines that the transition to a more circular economy also depends on the minimization of waste generation [5]. With the awareness that prevention is the best strategy to reduce the environmental and economic impact of waste, it is fundamental to forecast the effects of economic growth on the environment and assess its impact on ecosystems.

Since 1990, the relationship between gross domestic product (GDP) and environmental quality has been assessed by a set of empirical studies [6,7], and the functional form is described by an inverted U-shaped relationship between economic growth and different pollution indicators used as proxies of environmental quality. This functional form, called the environmental Kuznets curve (EKC) and taken from a study by Kuznets (1955) [8], predicts that pollution emissions increase and environmental quality declines in the early stages of economic growth, but that from a certain moment onward (the so-called turning point) the trend reverses so that the production of pollution no longer follows the trend of economic growth [6]. According to the EKC, given an increase in the per capita income, there is an initial increase in pollution due to resource usage, followed by its eventual decline due to an increase in consumers' willingness to pay for environmental quality [9] or improvement in clean technologies [10,11].

As highlighted by a recent literature review [7], the EKC is undoubtedly a starting-point tool to use when investigating evidence of a relationship between growth and effects on environmental changes. However, what needs to be better investigated are the variables that consider the effects linked to the following areas: an effective energy transition; consumer behavior changes due to rises in income; the consequences of an even faster technological progress dynamic; and the relocation of pollutant industries and the related climate financing systems. Adding these elements, whose in-depth analysis refers to the cited literature review, to the EKC should improve the description of the decoupling and coupling dynamics evident in the majority of the studied conducted.

The use of waste as a proxy of environmental degradation allows scholars to investigate the existence of a waste Kuznets curve (WKC), which predicts an inverted U-shaped dependence of waste production on economic development [12–20]. The concept that waste production decreases while economic growth increases is usually referred to as the "decoupling effect" [1,6,21]. Decoupling occurs when the growth rate of an environmental pressure is less than that of its economic driving force (e.g., GDP) over a given period [22]. An absolute decoupling of waste generation from GDP occurs when waste quantities are stable or decrease while GDP increases. We refer to a relative decoupling when waste quantities still increase but do so at a slower rate than economic growth (Figure 1).

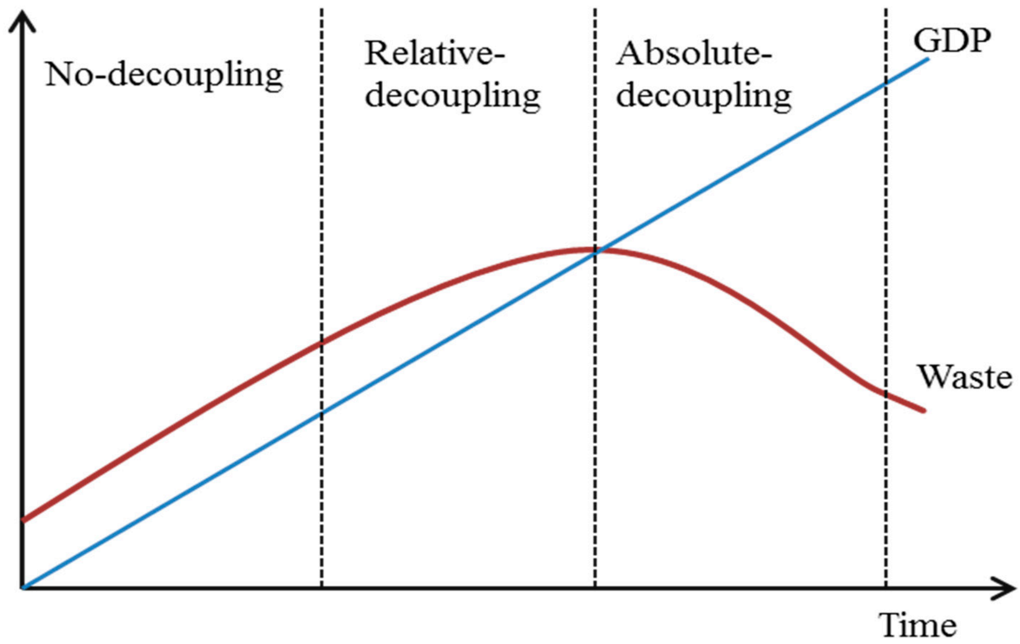

Figure 1. Decoupling effect in the waste sector. Source: elaboration from [23].

Some projections of future quantities of waste in the EU are indicative of the relative decoupling of waste generation from GDP and household consumption [24,25]; others, however, find no evidence for absolute or relative decoupling [17].

To accelerate the decoupling effect, reducing waste and preventing waste generation, the EU has laid down the Waste Framework Directive 2018/851, which amends Directive 2008/98/EC, and the zero-pollution action plan [26] to drive European countries to zero pollution across various fields (e.g., health impacts, air pollution, and nutrient losses).

The contribution of the EU agricultural sector to waste generation is diminishing every year, with a 66.7% reduction between 2004 and 2020 [27]. This positive trend also depends on the increasing relevance of the circular economy approach in agriculture, in which targets such as the reuse of wastewaters, reductions in plastic litter, and the reduction in and enhancement of agri-food waste are included as objectives of different programs and strategies [28]. Moreover, agricultural wastes are recognized as having a "hidden" economic value [29]. In fact, with their management through bioeconomic strategies, it is possible to prevent the underutilization of livestock excrement, valorize waste to generate value-added products, and create job opportunities [30].

Studies investigating the agricultural sector under the lens of the WKC are relatively scarce, with studies usually focusing on GHG emissions related to waste management [16,18,20]. The review conducted by Leal and Marques [7] asserts that the relationship between growth and environmental degradation is described by different variables and indicators, of which none are directly linked with the role of agricultural waste. In fact, the contribution of the agricultural sector is mainly described (i.e., 59 authors) by CO_2 emissions due to the production process. Scholars have mainly focused their attention on municipal waste [17,19], e-waste [15], and waste generated by the tourism [13] or construction sectors [14].

In such a context, given the scarce literature available related to the role of the agricultural sector in waste management, our contribution stands as a novel analysis of Italian agricultural waste production using the WKC model and provides relative considerations about the decoupling point. In Italy, agriculture is an important sector contributing to the national economy in terms of job creation and income generation, especially in rural areas. Driven by "Made in Italy", Italian agriculture contributed almost one-fifth to the added value of the EU's agricultural system [31] and 2.1% to the Italian added value [32] in 2022. However, important imbalances exist between different geographical areas; despite half the farms being in the south, the agriculture in northern Italy accounts for more than 50% of national agricultural value. Italian regions have differences due to the characteristics of farms (type, size, products, etc.) as a result of cultural identity associated with certain agricultural products, and climate conditions vary due to differences in the orographic characteristics of each region. This also reflects the environmental implications and amount of waste generated in agricultural production.

Due to these differences and in order to broaden the capacity of our model to describe the agricultural waste production curve, we included and tested the effects of some socio-economic variables which, in our opinion, influence agricultural waste at a production level, aiming to suggest strategies and policies for reducing and preventing waste production. To accomplish these goals, our research questions aimed at the following statements: (i) there is evidence of a WKC for the waste produced by the Italian agricultural sector; (ii) the decoupling point has been reached; (iii) there are socio-demographic variables that can influence production, but also prevent agricultural waste; and (iv) actions can be implemented in order to direct waste management and prevention policies to achieve the European target [26] and national objectives [33,34] of zero waste production.

The paper is structured as follows: Materials and Methods (econometric model and data) are presented in Section 2; Section 3 presents the results of the decoupling effect on agricultural waste production (Section 3.1) and the effects of socio-economic variables affecting agricultural waste production (Section 3.2); policy suggestions are discussed in Section 4, while final remarks and suggestions for future research are provided in Section 5.

2. Materials and Methods

2.1. The Econometric Model of the Agricultural WKC

The performance of the Italian agricultural waste production function and the relevance of the socio-economic variables considered are tested by employing an econometric method using Stata 16.1, a statistical software package.

To model the agricultural waste production function according to the statement of circular economy, we should assume that each industry minimizes its waste production to achieve a hypothetical point of zero waste [35]. However, given actual technological frontiers, industries cannot avoid waste when they vary in relation to the production level. Waste production, in fact, can be defined, based on the Sjöström and Östblom model [36], as a function of an initial production decision. For this reason, waste could be considered a collateral output of a production function.

In our analysis, the production of agricultural waste was assumed to follow the Cobb–Douglas production function:

$$Y = AK^{a} L^{b} \tag{1}$$

where $Y = Q_a \times W_a$, with W_a = agricultural waste and Q_a = agricultural product.

Equation (1) can be estimated using a multi-regression analysis and panel data because the observations have both a spatial dimension and a time-series dimension. The panel data methodology has several advantages over cross-sectional or time-series data analysis [13,37] and, for Italy in particular, it is important to consider the geographical differences among regions given their different environmental and economic differences [38].

The amount of agricultural waste produced by different Italian regions is, indeed, extremely varied, and garbage is managed at a local level according to the country's national legislation. Furthermore, the municipality is responsible for the disposal of trash, resulting in different regional waste management strategies. Equation (1) can be written as follows:

$$Y = X\beta + \varepsilon \tag{2}$$

where Y represents the output vector, X is the vector of the independent variables influencing the waste production (later explained in more detail), and β is the vector of the coefficients, while ε represents the error term vector.

Therefore, Equation (2) can be written as

$$y_{it} = \beta_1 X_{it1} + \beta_2 X_{it2} + \cdots + \beta_k X_{itk} + \varepsilon_{it} \tag{3}$$

where subscript $i = 1,\ldots,N$, represents the Italian regions and subscript $t = 1,\ldots,T$ represents the time period. Considering the possible presence of unobservable variables fixed in time (sensitivity to environmental protection and cultural aspects), we defined a fixed-effect regression model, and the error term was assumed to be: $\varepsilon_{it} = \alpha i + u_{it}$, with α_i = individual effect, a time constant (unobserved factors), and u_{it} = time-varying error (independent and identically distributed across i and t).

The estimation of the parameters requires a logarithm transformation of the Cobb–Douglas production function, so that Equation (3) can be written as

$$\ln(Y_{it}) = \alpha \ln(X_{it}) + \beta \ln(C_{it}) + v_i + \varepsilon_{it} \tag{4}$$

where $v_i = \ln(\alpha_i)$. The coefficients α and β reflect the output elasticity of the inputs (i.e., the % change in waste because of a 1% change in one of the other variables, ceteris paribus). Fixed effects are often used in panel data analysis [39,40]. In order to remove the fixed-effect terms, the estimation of Equation (4) uses a within-estimator and the autocorrelation ρ is estimated using the Arellano–Bond estimator [41].

We introduced eight socio-economic variables related to the agricultural sector to measure their impact on regional waste agricultural production, such as (i) the physical and economic dimensions; (ii) productivity; (iii) the cost of waste (related to the regulation policy); and (iv) the response of consumer sensitivity to environmental degradation, which represents socio-economic drivers related to waste generation [6,42].

First, we introduced the regional GDP as an economic driver. Then, we considered (i) the agricultural surface, the number of animals kept and the annual work units (ULA) as proxies for the dimensions of the agricultural system; (ii) the production and the added value as proxies for the efficiency of the agricultural system; (iii) the public expenditure for environmental protection as proxy for social investment in waste management; and finally, (iv) the number of organic activities as a proxy for the interest in a higher environmental quality. Equation (3) can be written as

$$\text{Agricultural\_waste}_{it} = \beta_0(\text{surface}_{it}) + \beta_1(\text{production}_{it}) + \beta_2(\text{regional\_GDP}_{it}) + \beta_3(\text{added\_value}_{it}) + \beta_4(\text{public\_expenditure\_for\_environmental\_protection}_{it}) + \beta_5(\text{ULA}_{it}) + \beta_6(\text{n\_organic\_activities}_{it}) + \beta_7(\text{n\_animalsbreed}_{it}) + \alpha_i + u_{it} \quad (5)$$

where $i = 1\ldots20$, $t = 2002\ldots2015$ and α_i, represents the regional fixed effects. All dependent variables are expressed in natural logarithms to ensure a positive domain. The null hypothesis used to test the significance of the effect of the variables on agricultural waste is

$$H_0\colon \beta_0 = \beta_1 = \cdots = \beta_K = 0 \quad (6)$$

The coefficients indicate how much Y (waste) changes over time on average per country when X increases by one unit.

We built a panel dataset comprising the measurement of agricultural waste and GDP produced by each region and observed over a 14-year period (2002–2015).

Based on the above, we tested the functional form of the regression between waste and GDP to provide preliminary evidence of the waste generation/economic driver relationship. There is no agreed consensus among researchers on how to specify the WKC functional relationship. In fact, some authors use a second-order polynomial, while others have estimated third- and even fourth-order polynomials, comparing different specifications for a relative robustness [12,43].

We tested linear, quadratic, and cubic regressions [17] to analyze the relationship between GDP and waste production. A cubic regression implies that environmental degradation will tend towards plus or minus infinity as income increases; a quadratic regression implies that environmental degradation may eventually tend toward zero. Finally, use of the GDP factor only, without quadratic and cubic terms expressing the linearity of the relation between GDP and waste, would cause the WKC analysis to collapse to basic decoupling analysis, and the decoupling effect would be measured via the GDP coefficient.

The hypotheses on delinking are thus tested by estimating a reduced form regression model:

$$W_{it} = \beta_{0i} + \beta_{1i}(\text{GDP}) + \beta_{2i}(\text{GDP})^2 + \beta_{3i}(\text{GDP})^3 + e_{it} \quad (7)$$

The null hypothesis testing the significance of the effect of GDP on agricultural waste is

$$H_0\colon \beta_0 = \beta_1 = \beta_2 = \beta_{3f} = 0 \quad (8)$$

According to the ISPRA (Institute for Environmental Protection and Research) methodology, the decoupling indicator is defined as the percentage variation of the agricultural waste for GDP unit ($\frac{\Delta \text{Wa}}{\Delta \text{GDP}}$), measured according to the following equation:

$$\frac{\Delta \text{Wa}}{\Delta \text{GDP}} = \frac{(\text{Wan} + 1/\text{GDPn} + 1) - (\text{Wan}/\text{GDPn})}{(Wan/GDPn)} \quad (9)$$

where $\frac{Wa_{n+1}}{GDP_{n+1}}$ represents the ratio between waste and the GDP of the following year, and $\frac{Wa_n}{GDP_n}$ is the ratio between waste and the GDP of the previous year.

According to Equation (9), $\frac{\Delta \text{Wa}}{\Delta \text{GDP}} = 0$ if $\frac{Wa_{n+1}}{GDP_{n+1}} = \frac{Wa_n}{GDP_n}$ indicates no time variation; $\frac{\Delta \text{Wa}}{\Delta \text{GDP}} > 0$ $\frac{Wa_{n+1}}{GDP_{n+1}} > \frac{Wa_n}{GDP_n}$ means that the waste produced for a GDP unit increases with time; and $\frac{\Delta \text{Wa}}{\Delta \text{GDP}} < 0$ if $\frac{Wa_{n+1}}{GDP_{n+1}} < \frac{Wa_n}{GDP_n}$ means that the waste produced for a GDP unit decreases with time (decoupling).

In Italy, the national program for waste production, i.e., the Waste Framework Directive, establishes targets for waste reduction in relation to the GDP. The program set the following targets to be achieved by 2020: hazardous industrial waste were required to be reduced by 10% per GDP unit, while this was 5% for non-hazardous waste [33]. To observe whether Italy is close to reaching the waste reduction target (−5% for non-hazardous waste, as stated by the national program for waste production), the decoupling indicator is measured by fixing the starting point (n) in 2010 and observing its variation during the following years (i.e., 2011; 2012 to 2015).

To this extent, Equation (9) becomes

$$\frac{\Delta Wa}{GDP} = \frac{(Wa2010 + 1/GDP2010 + 1) - (Wa2010/GDP2010)}{(Wa2010/GDP2010)} \tag{10}$$

2.2. Data

The dataset used for the empirical analysis includes nine variables: (i) the amount of agricultural waste produced; (ii) the number of animals kept; (iii) the area of agricultural activities; (iv) production of agricultural activities; (v) unit of labor; (vi) added value of production; (vii) regional GDP; (viii) regional expenditure for environmental protection; and (ix) the number of organic agricultural operators.

The dataset used is a balanced panel of Italian local authorities observed over a 14-year period (2002–2015). For the analysis, we used the data collected in the annual report on special waste published by ISPRA [44], while we referred to the National Institute of Statistics (ISTAT) datasets for information related to national, regional, and sectoral GDP [45].

The animals kept, regional production (million EUR), added value (million EUR), and the ULA of the agricultural industry production are recorded by the National Institute of Agricultural Statistics [46], while the total regional agricultural area (hectares), regional GDP (EUR), and regional expenditure for environmental protection (EUR) are recorded by ISTAT [45].

Finally, the number of organic agricultural activities at a regional level is reported by the National Information System on Organic Agriculture [47].

Waste data, referring to non-hazardous agricultural waste production, are recorded by ISPRA [44]. For each region, the amount of non-hazardous agricultural waste produced (tons) was used and labelled with the European Classification Code CER 02, which includes all wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, and food preparation and processing. Information relating to the period of 2006–2008 and 2011 was not available in the form needed (tons of waste codified CER 02 per region); hence, the data used for the analysis were interpolated, using other years, for this period. Starting from the total non-hazardous waste produced by each region, the annual variation was calculated and then, hypothesizing the same variation, the amount of agricultural waste was derived (CER 02).

3. Results

This section presents the results of the analysis relating to: (i) the time trend analysis of Italian agricultural waste in relation to the sectoral GDP; (ii) the regression functional form to observe how it fits the waste Kuznets curve; and (iii) the decoupling of agricultural waste related to the GDP trend and the effects of the other socio-economic variables (in the period of 2002–2015).

3.1. Decoupling Effect in Agricultural Waste Production

Several studies have proven the existence of EKC in solid waste [48–50], showing that, at a certain point, it is possible to achieve a reduction in waste production in a growing economy.

According to our data, non-hazardous agricultural waste decreased from 2002 to 2008, and then increased from 2008 until 2013, followed by a rapid reduction up until now. On the other hand, the sectoral GDP increased almost constantly over the same years. Starting from 2013, the analysis of the time trend seems to show a certain delinking from the GDP of the agricultural waste produced (Figure 2), and this trend is confirmed by other similar European sectoral studies [34].

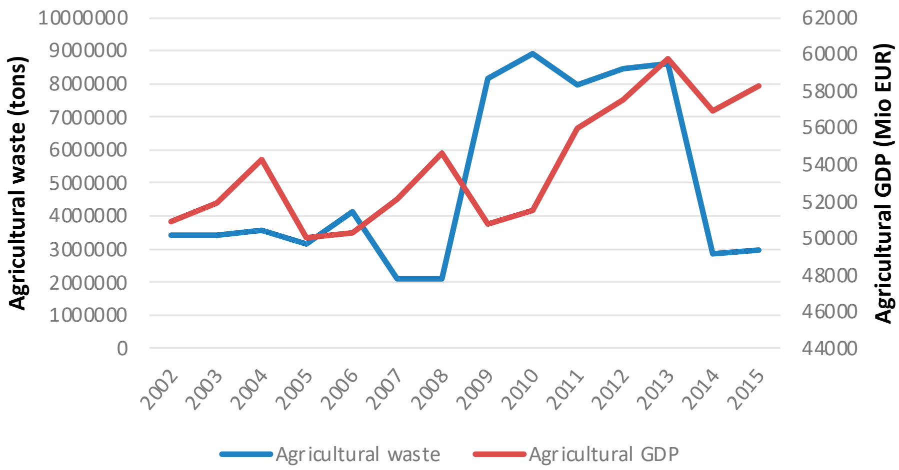

Figure 2. Trend of agricultural waste and national GDP (%) (2010–2015). Source: our elaboration on [44,45] datasets.

However, the decoupling effect should not be measured by observing the time trend in absolute terms, but through specific decoupling indicators with an environmental pressure variable for the numerator and an economic variable as the denominator [8].

Looking at the annual variation trend (Figure 3), we noticed that the waste/GDP ratio is almost constantly equal to zero, indicating no variation in time, with the unique exception of the 2008–2009 period. Here, there is a positive value, indicating a high difference between the trend of the two variables.

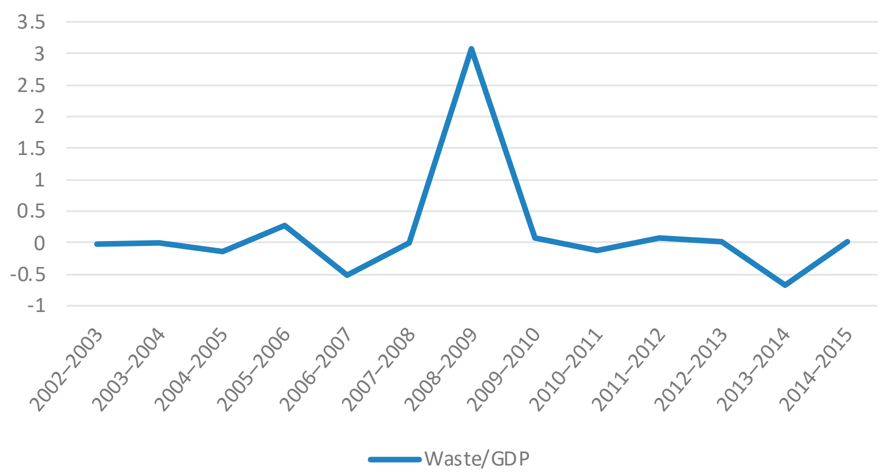

Figure 3. Annual variation of the waste/GDP ratio in Italy (2002–2015). Source: our elaboration on [44,45] datasets.

Between 2008 and 2009, the Italian GDP decreased in real terms by about 5% from its average value recorded in 2008 [45] due to the financial crisis. However, at the same time, the financial contraction did not affect the agricultural waste generated. This can be explained by the fact that the Italian agro-food system was less exposed than other productive sectors to the financial crisis [51].

A certain delinking between economic growth and waste production can be observed, but the level is not enough to reach the target. Since 2013, the waste/GDP ratio has become negative, but less than 1% negative. Additionally, measuring the decoupling indicator over a longer period (2002–2015) shows that the trend is no better (Figure 4).

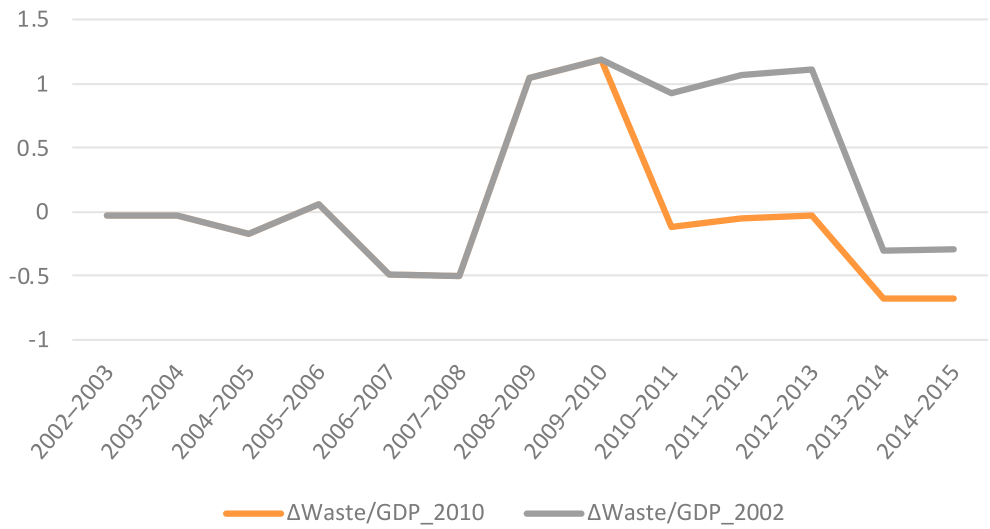

Figure 4. Trend of the time variation of waste per unit of GDP. Source: our elaboration on [44,45] datasets.

These results, as well as those of similar studies [17,52], show that the waste generation decoupling process is extremely weak. Moreover, Wang and Lv [53] describe alternated decoupling and coupling states for the relationship between grain production and agricultural CO_2 emissions. The decoupling phase is favored by environmental policies that are not enough effective in the long run to support a stable U-shaped relationship. Long-term incentives, such as an ecological compensation policy, could perhaps drive carbon emission reduction.

For this reason, an empirical analysis is needed to better investigate the effect of GDP variation on waste production [17]. Our results (Table 1) show no significant coefficient for either the cubic or quadratic form, implying that the waste production does not follow a U-shaped form (waste tends to zero WKC) or an N-shaped form (waste tends to plus or minus infinity as the GDP increases). The functional form that better fits our data, with an F-statistic of 321.616 *** (df = 1; 259), is linear form (1).

Following linear specification test delinking, the effect of this can be observed via the GDP coefficient. In our analysis, the regional GDP was positively related to agricultural waste. A unitary increase in the GDP rate leads to an increase of 92% of agricultural waste produced (Table 1). These results confirm previous results, showing that countries with a higher GDP produce a higher level of industrial waste [54]. However, the R^2 of the regression was relatively low (0.554) and the presence of other omitted variables affecting waste production was very likely.

Table 1. Different model specifications for testing the functional form of GDP and waste.

Dependent Variable: Waste			
Regression	**(1) Linear**	**(2) Quadratic**	**(3) Cubic**
GDP	0.922 *** (0.051)	0.933 *** (0.066)	0.955 ***
GDP2	-	-1.860×10^{-12} (0.000)	-1.139×10^{-11} (0.000)
GDP3	-	-	2.862×10^{-17} (0.000)
Balanced Panel	280	279	279
R-Squared	0.554	0.554	0.554
Adj. R-Squared	0.519	0.517	0.515
F-statistic	321.616 *** (df = 1; 259)	159.347 *** (df = 2; 257)	105.897 *** (df = 3; 256)

Note: *** $p < 0.01$.

3.2. Socio-Economic Variables Affecting Agricultural Waste Production

To improve the decoupling effect, we needed to understand other factors influencing waste production in the agricultural sector.

The inclusion of socio-economic variables in our model (Table 2) significantly reduces the GDP coefficient (0.22), which remains positive, showing that waste production increases according to economic growth, but to a lower rate.

Table 2. Fixed-effect regression model.

Coefficient	**Estimate**	**Std. Error**	**t-Value**	**Pr(>|t|)**	
GDP	0.219034	0.100516	2.1791	0.0302435 *	
Production	2.447242	0.319285	7.6648	3.795×10^{-13} ***	
Added Value	−1.624414	0.324903	−4.9997	1.071×10^{-6} ***	
Expenditure for environmental protection	−0.605167	0.134242	−4.5080	9.997×10^{-6} ***	
ULA	0.748993	0.200615	3.7335	0.0002331 ***	
Organic production	−0.310188	0.081744	−3.7946	0.0001849 ***	
Arellano–Bond Estimated Coefficient	**Estimate**	**Std. Error**	***t*-value**	**Pr(>|*t*|)**	
GDP	0.219034	0.089251	2.4541	0.014794 *	
Production	2.447242	0.266424	9.1855	$<2.2 \times 10^{-16}$ ***	
Added value	−1.624414	0.262606	−6.1857	2.458×10^{-9} ***	
Expenditure for environmental protection	−0.605167	0.118421	−5.1103	6.328×10^{-7} ***	
ULA	0.748993	0.269485	2.7794	0.005854 **	
Organic production	−0.310188	0.101226	−3.0643	0.002417 **	
Residuals	Min −0.663987	1Q −0.198666	Median −0.025688	3Q 0.183119	Max 0.823934
Balanced Panel	*n* = 20		T = 14	N = 280	
Total Sum of Square			94.891		
Residual Sum of Squares			24.388		
R-Squared			0.74299		
Adj. R-Squared			0.71769		
F-statistic			122.38 on 6 and 254 DF		
p-value			*p*-value: $<2.22 \times 10^{-16}$		

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

A unitary increase in the GDP rate will lead to an increase of 21% in the waste production rate. This analysis shows that, in each region, GDP growth leads to an increase in waste production, even if it is less than proportional. This result, in line with other studies on waste production [48,55], explains that the amount of waste generated grows slower than income and suggests the occurrence of a relative decoupling effect.

Considering the added value of the production, the decoupling effect is even stronger in the regions in which the agricultural system has a good rate of economic development [50]. The results of the multivariate regression also show that the relation between the agricultural system production and the amount of waste is one of about three times over (estimated coefficient + 2.5), underlining the inefficiency of a production system that leads to great quantities of resources being wasted.

Considering the dimensions of farms, our results show that the only significant coefficient (positive) is the ULA. This means that a farm with more labor units produces more waste. On the contrary, the other variables chosen as proxies of the dimension of the agricultural sector (number of animals kept and area) are not significant, meaning that the amount of waste produced by the agricultural sector does not depend on the hectares used for production or the number of animals kept, but only on productivity.

Like other negative environmental externalities, agricultural waste generation is strongly influenced by regulatory instruments. The econometric model describes a negative relationship between the waste produced and public expenditure for environmental protection used as a proxy of the investment in waste management. In fact, ceteris paribus, an increase in social expenditure leads to a waste reduction of about 60%.

Finally, considering organic production, our analysis shows that the coefficient is negative, demonstrating that organic farms produce less waste. The lower levels of fertilizer and other chemical products used can explain the lower amount of waste produced. Even though there is no specification about waste in organic farming regulation, organic producers may reduce their waste to achieve higher sensitivity for environmental protection.

4. Discussion

The environmental Kuznets curve (EKC) describes the damage that unsustainable economic development can cause to the environment, and highlights the necessity to delink economic driving factors, such as GDP, from environmental protection.

A recent contribution related to the study of decoupling effect dynamics in an agricultural contest analyzed the effects of the Chinese economic green development, indicating that a win-win result, described by a U-shaped EKC, can generate a better agricultural income thanks to the investments in agricultural green total factor productivity [56].

The absolute decoupling condition is difficult to achieve because it occurs when the pressure on environmental variables is stable or decreasing, but while economic forces are growing. Different studies show that absolute decoupling is not that common given the differences in economies, industrial sectors, environmental indicators, and regulations.

According to other studies conducted in European countries [33], our analysis confirms that the decoupling effect is not absolute. In fact, a relative decoupling effect of waste generation has been estimated (ascending part of an inverted U-shaped EKC), but no evidence of absolute decoupling has been observed (descending side of an inverted U-shaped EKC), and accomplishing the reduction target, −5% by 2020, set by the national waste prevention program is far from reach.

To reinforce the goal of waste reduction, the regulatory system is fundamental to controlling waste intensities linked to companies, and policy instruments should be oriented toward waste-preventing tools such as raw material taxes. Targeting waste prevention at the source through more effective waste management instruments can be a good strategy for reducing waste generation, accelerating the decoupling effect [50] and finally reaching more efficient ecosystem management.

As supported by the literature [6,7], we observed that the decoupling effect is stronger, and the turning point can be reached faster, upon adopting new technologies that increase the efficiency of the agricultural production system and have a positive effect on environmental quality. Moreover, we argue that a higher expenditure for environmental protection and the promotion of a transition toward organic production can be a successful strategy to reduce waste produced by companies. Furthermore, organic products have higher added value on the market [57] and the demand for organic products is increasing worldwide. For these reasons, promoting a transition toward organic production instead of conventional production can lead to an increase in agricultural GDP, at the same time reducing the amount of waste produced.

Much still needs to be improved in terms of waste prevention because the regulatory framework is still a step behind the needs of society. In fact, the new European Waste Prevention Program is under revision and waiting to be published in 2023 (expected duration 2023–2030). It will be based on an approach of integrated programming to fund a program to create coherence/blending among various funds related to waste management, waste prevention, circular economy, and green economy (including regional funds).

This study presents some limitations that could be addressed in future analyses regarding other European countries to compare the performance of different agricultural systems. The time series could be wider, with the inclusion of data up until 2022 to analyze the pandemic effect on the WKC; furthermore, it is also recommended to expand the explanatory power to include additional variables (e.g., regulatory changes) and sensitivity analysis.

5. Conclusions

This study delves into the waste Kuznets curve (WKC) and its application to the agricultural sector in Italy by exploring the relationship between economic growth, as represented by gross domestic product (GDP) and agricultural waste generation. The analysis considers the period from 2002 to 2015 and employs a panel data econometric model, incorporating socio-economic variables to better understand the factors influencing waste production.

The findings suggest a relative decoupling effect in the agricultural sector, indicating that waste generation increases with economic growth, but at a slower rate than the former. The study emphasizes the importance of considering GDP and various socio-economic variables in understanding waste production dynamics. Factors such as the size of agricultural operations, productivity, public expenditure on environmental protection, and the prevalence of organic farming are significant contributors to waste generation.

While the study acknowledges a certain degree of decoupling between economic growth and waste production, it highlights that absolute decoupling, where waste quantities stabilize or decrease while GDP increases, remains elusive. The observed trends indicate a need for more effective waste management policies and a shift towards sustainable practices, such as organic farming, to achieve the European target of zero waste production. This research underscores the role of regulatory instruments in influencing waste intensities and suggests policy instruments like raw material taxes as potential strategies for waste prevention.

Despite shedding light on the dynamics of waste production in the Italian agricultural sector, the study acknowledges certain limitations. Recommendations for future research include expanding the analysis to encompass a more comprehensive time range, incorporating additional variables, and conducting comparative studies across different European countries. Overall, the study contributes valuable insights into the complexities of waste generation and the challenges associated with achieving a sustainable and circular economy in the agricultural domain.

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