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Economic Development and Pesticide Use in EU Agriculture: A Nonlinear Panel Data Autoregressive Distributed Lag Approach

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Abstract: Within the regime established by the Directive on Sustainable Use of Pesticides (SUDP); the present work explores the relationship between pesticides' agricultural use per hectare of cropland and the GDP per capita of the rural population for twenty-five EU countries to unveil the efficiency of the current EU strategy. With the econometric tool of panel nonlinear autoregressive distributed lag (NARDL) cointegration technique; we try to capture potential asymmetries in the agricultural use of pesticides concerning positive and negative variations in agricultural income. The findings validate the existence of a long-run relationship that supports an Environmental Kuznets Curve (EKC); i.e., an inverted U-shaped relationship between the variables; since increasing agricultural income is related to reductions in the use of pesticides after the turning point. Even though this result is not validated in the short run; our findings confirm the existence of a steady-state situation with asymmetric responses to pesticides. In terms of policy implications; more measures need to be taken; along with the education of farmers; aiming to enhance their consciousness towards environmental issues and; in consequence; for them to prefer environmentally friendly plant protection methods over chemical ones.

Keywords: environmental and ecological economics; agricultural policy; climate change; greenhouse; econometrics

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1. Introduction

Agriculture is one of the main sectors releasing major pollutants to the environment, mainly due to the extensive use of pesticides and fertilizers. The role of fertilizer inputs is highly significant for the productivity of the agricultural sector, while the role of pesticides may well ameliorate their extensive use. More specifically, their use contributes not only to hunger reduction but also to food security sustainability [1]. Long-term studies have unveiled that pesticides are responsible for 40 to 60% of crop yields in temperate climates, like those of most EU countries [2].

The environmental problems caused by the excessive use of pesticides are characterized by complexity, given that these harmful substances may pose a danger to the health of their users and consumers, along with water impairment, soil acidification, and air pollution, that may well lead to a regime of diminishing returns in yield improvement [2,3]. All of the above issues can be addressed with the mediation of novel technologies and the cooperation of specialists from different scientific fields [4].

In 2021, 355,175 tons of pesticides were sold in the EU, a moderate increase of 2.7% compared to the year 2020 (346,000 tons), with the vast majority being destined for the agricultural sector [5]. Accordingly, an effort on a global level to mitigate climate change through the limitation of greenhouse gas (GHG) emissions from all sectors was made with the Kyoto protocol as a starting point. Despite the prospects for this agreement, set to expire in the year 2012, to be fulfilled, the low effort made by most of the countries to address phenomena like severe increases in carbon emissions, along with the goal to keep temperature increases under the 2 °C mark, extended the timeframe of the Kyoto protocol [6,7].

Pesticide use globally is characterized by volatility within the period studied here. More specifically, the increasing rate in the period 1990–2007 was followed by a decreasing trend after the year 2007. However, in the period 2009–2014, an expansion in the pesticides market was notable, and was attributed to the increasing use in developing countries (with China being the leader, as shown in Figure 1). In the period 2014–2017, the recorded decline was related to the harvested stock in the year 2014 and the corresponding price reduction, while their recovery was evident in 2018 [8,9]. More specifically for the EU case, similar variations have been recorded. At the same time, the interactions between agricultural land use, rural ecosystems, and the environment necessitated the implementation of a reformed EU Common Agricultural Policy (CAP) for the purposes mentioned above. All the measures mentioned above set a target for economic profitability and the minimization of environmental impacts in the sector of agriculture, namely, eco-efficiency [10].

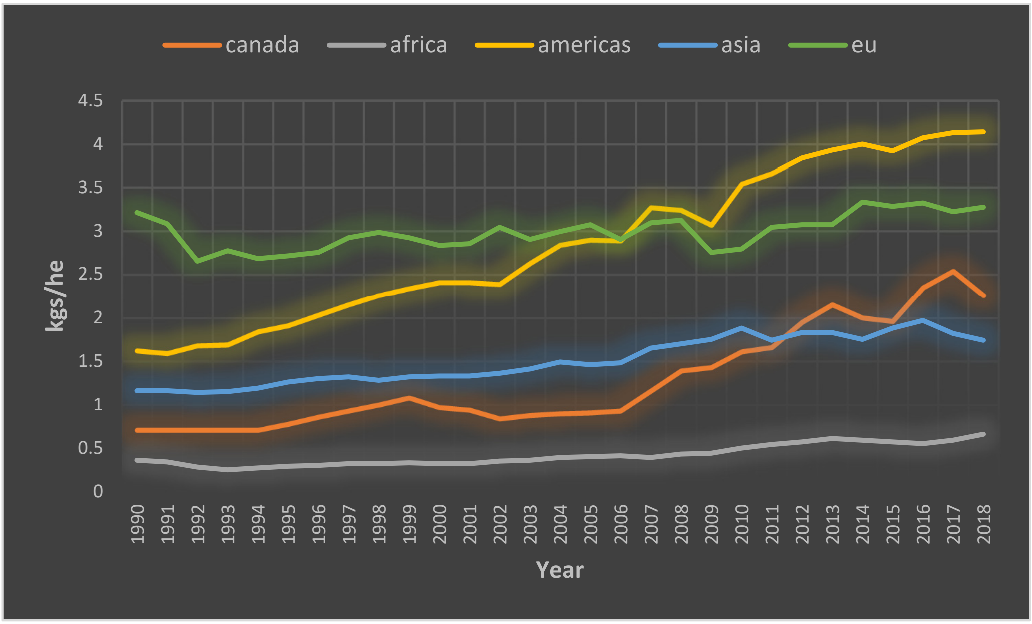

Figure 1. The evolution of pesticide use per hectare of cropland in different regions (1990–2018). Source: UN Food and Agricultural Organization (FAO) data and own elaboration.

Figure 1 illustrates the evolution of pesticide use per unit of cropland, measured in kilograms per hectare for the time period 1990-2018 in Africa, the EU, Canada, Asia, and the Americas.

The change in the intensity of pesticide use in the European Union, in particular for the two years 1990 and 2017, is also an element that describes the change in attitude towards pesticides in the EU. The following diagram illustrates the value of the difference in pesticide use per hectare of cropland for the years 1990 and 2017 in EU countries.

It is evident as illustrated in Figure 2 that in Central Europe there was a significant change in the pesticide use per hectare between 1990 and 2017. More specifically, a decrease was recorded in France, an increase in Spain and Portugal, and a slight increase in the Scandinavian countries. For the case of newly-entrant countries and with reference period 1992 or 1994 for Czechia Croatia and Slovakia respectively, a decrease is evident while

Malta is the country with the greatest decrease in the use of pesticides between the two years under review. The time period studied includes the effort made to mitigate climate change impacts through different environmental agreements.

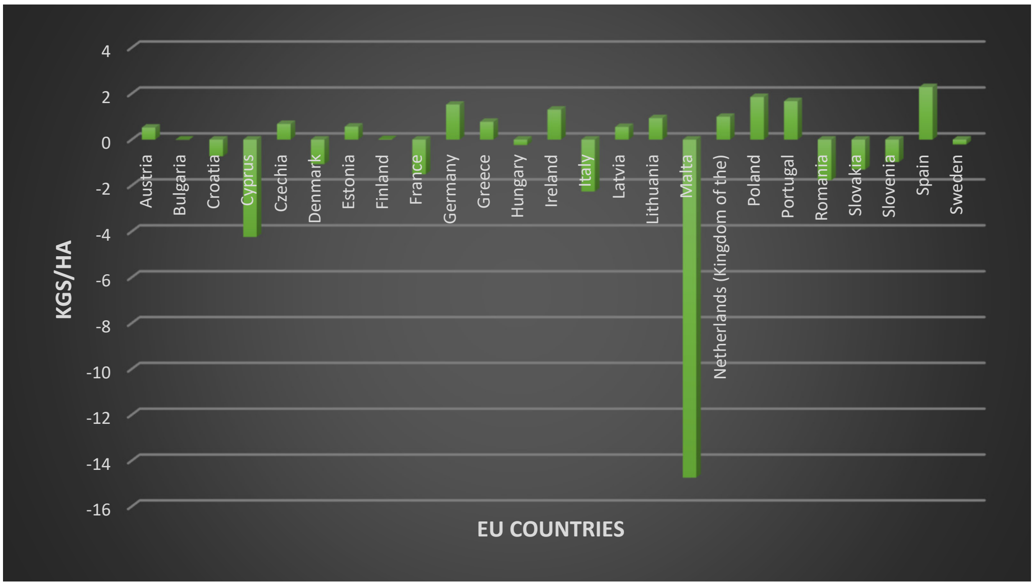

Figure 2. Change in Pesticide use per hectare of cropland for the countries of the European Union between the years 1990 and 2017. Source: UN Food and Agricultural Organization (FAO data and own elaboration).

The Kyoto protocol and other global or regional environmental agreements, although not always binding, have set objectives, such as the elimination of the risks of environmental degradation related to the use of pesticides, and the enhancement of agro-ecosystems sustainability. The achievement of those objectives will be based on agri-environmental measures and related policies that are adopted. The most significant policy measures that refer to pesticides involve input from suppliers, farmers, the food industry, and consumers. For each one of the groups mentioned above, the target is different. Namely, for suppliers, it is new technologies; for the farmers in sustainable farming, it is new inputs; for the food industry, it is new processes and labels; and for consumers, it is a shift in demand and preference [11,12]. For the case of farmers, the CAP involves measures designed to reduce the risks of environmental degradation and improve the sustainability of agro-ecosystems. More specifically, the measures taken promote the sustainable use of pesticides with the decoupling of direct payments for production, by introducing and expanding green payments, as well as imposing the loss of payments in case farmers do not comply with the requirements of EU legislation on the environment, climate change, the good agricultural condition of the land, animal and plant health standards, and animal welfare [13].

The EU measures, along with the market expansion of biocidal products and a set of EU requirements on plant protection products applied to the market, have contributed greatly to the limitation of chemical pesticides. Thus, the farm advisory system, established by Regulation (EU) No. 1306/2013, is a requirement for the implementation of an effective agri-environmental policy. This system involves the farmers' notification of the conditions under cross-compliance, green direct payments, issues related to the water- framework directive, and the sustainable use of pesticides directive [14].

One key element of the policy regarding pesticides is the Integrated Pest Management (IPM) plan, which involves adopting practices aimed at reducing dependency on pesticides. Among the instruments activated by the current CAP to support IPM are crop rotation and requirements for a minimum share of agricultural area to be under non-productive features. Within this scheme, the member states should implement eco-schemes to promote, among other things, an alternative to environmentally friendly pesticide substances. The IPM has led to a limited reduction in the use of pesticides since it is still responsible for health risks and impacts on the environment [13–15]. The limited effectiveness of the IMP in the EU is attributed to impediments in the widespread implementation of the related policies, including difficulties in finding research funds and limited expertise, knowledge transfer at all levels, and networking, along with global-level issues such as climate change and the development of pesticide resistance [16,17].

In global terms, the European Union is enacting a stringent system for authorizing and controlling the use of pesticides [7]. The legal framework is complicated and includes, among others, Directive 2009/128/EC2 on the sustainable use of pesticides (SUDP), Regulation (EC) No. 1107/20093, Regulation (EC) No. 396/20054, Regulation (EU) 2017/6255, and Regulation (EC) No. 1185/20096 [17]. The aforementioned regulations proved to be too weak; therefore, initiatives were introduced through the Farm-to-Fork Strategy. The particular initiatives aim to tackle climate change impacts, protect natural resources, and enhance biodiversity. More specifically within this strategy, the first and foremost target is related to a 50% reduction in the use and risk of chemical pesticides and the use of more hazardous pesticides by 2030. Furthermore, a second measure involves an enforcement framework to ensure that all farmers practice Integrated Pest Management, 'IPM', and use chemical pesticides only when nothing else can be used. Two more measures have been suggested; namely, a prohibition on the use of all chemical pesticides in ecologically sensitive areas and within 3 m of them, and finally support to farmers for 5 years to cover the costs of the new requirements for farmers for the particular time period [18].

Nevertheless, despite the temporary fluctuations in pesticide use, from the currently available data concerning either the sale or the agricultural use of pesticides per hectare of cropland, its stable growth is evident over the long term for most EU countries. In addition, the member states' implementation of integrated pest management practices has generally been weak and has had a limited impact on reducing the health and environmental risks generated by pesticide use [17].

Within this framework, the present work investigates whether the increasing use of pesticides goes hand in hand with increasing agricultural income or, instead, there is a turning point after which higher incomes imply a decrease in pesticide use. Hence, the validity of the Environmental Kuznets Curve (EKC) is tested with the econometric methodology of nonlinear cointegration for panel data. A nonlinear Autoregressive Distributed Lag model (NARDL hereafter) for twenty-five EU countries was estimated with data from 1990 to 2018 [19]. As a proxy for environmental degradation, the agricultural use of pesticides per hectare of cropland was selected. As main income variable we used the agricultural value-added for all the EU countries, except for Belgium and Luxemburg. The model employed is bivariate, since we want to focus on the interlinkages of those two variables, ceteris paribus. What is more, the data employed were extended until 2018, since afterwards no data for the European Union as an entity are provided as BREXIT changed the total EU profile and therefore our conclusions would be of limited significance.

The novelty of the present work stands on the methodology of the NARDL employed on panel data for the sector of agriculture and the index used as a proxy for environmental degradation, i.e., the agricultural use of pesticides per hectare of cropland. Despite the fact that, if available, extensive agricultural use should be used as a proxy for environmental degradation, the variable employed is still suitable to address the question, since we examine the responses of the agricultural users of pesticides to the changes in agricultural income. The results derived in this paper can provide policymakers with insights concerning the relationship between environmental degradation and agricultural income and the efficiency of the measures in the IPM, and some suggestions for improving agricultural productivity with the use of environmentally friendly pesticides to achieve eco-efficiency in European agriculture.

2. Literature Review

Since the beginning of the 21st century, the sustainable economic growth–environmental degradation relationship has been thoroughly studied, as synopsized in the EKC framework [20]. The validity of the EKC hypothesis has been tested by many researchers using data from different countries and several methodologies, and a wide array of variables measuring environmental degradation. The variables most frequently used are carbon dioxide (CO_2) emissions, sulfur dioxide (SO_2) emissions, nitrous oxide (N_2O) emissions, methane (CH_4) emissions, and water pollution [21]. Respectively, the economic indicators used to explain the level of environmental degradation are energy consumption, gross domestic product, trade openness, industrial output, urbanization, financial development, population density, and foreign direct investment (FDI). However, the results from the extant literature are generally conflicting, and no clear consensus can be derived. Within the last decade, agriculture-induced environmental degradation has attracted scientific interest [22–30].

Panel data cointegration, generalized moments as well as fixed-effects panel data methodologies and time series cointegration, have mainly been employed with agricultural income to reflect economic performance, and several different indices to measure the environmental degradation [22]. Carbon emissions have been extensively used as a proxy for environmental degradation with divergent results [22–25]. In terms of geography, the results also contradict each other for different regions in the existing literature, i.e., for the case of Asian and different EU countries, no validation of the EKC has been recorded, as opposed to the studies that concern countries located in the southern Sahara [22–25]. It is also worth mentioning that in the modern literature, the inverted U pattern of the EKC might be substituted by an N or an inverted N-pattern relationship for the variables studied [22–31].

The number of studies focusing on agrochemical consumption as an index of environmental degradation in the EKC framework is limited [2]. Despite the different sources of environmental degradation within the agricultural sector mentioned above, the extended use of pesticides entails significant risks for humans and the environment in general unless they are used with caution; in that case, numerous advantages have been reported. In particular, according to [31], the use of pesticides increases yield, saves labor, and reduces fertilizer use since it increases productivity. Increasing pesticide use around the world since the 1960s has enabled farmers to boost production without having many losses from pests [32]. On the other hand, the excessive use of pesticides has had several negative consequences related to their harmful effects on the environment, the genetic structure of living organisms, and the reduction of biodiversity [33–35]. The costs related to the use of pesticides may be either direct or indirect, being perceived by society and not by the farmers who are making pesticide choices. Damages to ecosystems, ecosystem biodiversity, and human health are extremely high, as pesticide use is associated annually with thousands of deaths due to poisoning, either by direct contact with the chemicals or indirectly from contact with contaminated objects [36–39]. In addition, the monitoring costs for contaminated ecosystems, food, water, and the impact on non-target organisms are a few of the indirect costs [39]. Ruttan [40] commented that "the problem of pest and pathogen control will represent a more serious constraint on sustainable growth in agricultural production at a global level than either land or water constraints".

Despite the aforementioned impacts on the agro-ecosystem and the environment, the excessive use of pesticides does not provide optimal economic returns to society [41].

The role of pesticides in agricultural production has also been the subject of extended study, particularly pesticide use with crop profitability interlinkages [42] or identification and quantification of the determinants of pesticide use [32,41]. As for the EKC literature related to the use of pesticides, it is scarce. Longo and York [43] examined the existence of an EKC between agricultural exports (as a percentage of GDP) and both fertilizer- and pesticide-use intensity. They found no evidence of an EKC for fertilizer consumption while, on the other hand, there was evidence to suggest the possible existence of a pesticide EKC.

The authors offered as a possible explanation the fact that developed countries have been mobilized against pesticides due to their harmful effects. In contrast, the use of fertilizers has remained stable. The authors also agreed with Jorgenson and Brett [44], that there was a possibility that developed countries would outsource environmentally destructive production practices to less-developed countries.

Managi [45] analyzed the environmental risks resulting from pesticide use in US agriculture using panel data for 48 states from 1970 to 1997. The study tested the increasing returns to pollution abatement in the EKC framework. Four environmental-degradation indexes were used: the risk to human health from exposure to pesticide runoff, the risk to human health from exposure to pesticide leaching, the risk to fish life from exposure to pesticide runoff, and the risk to fish life from exposure to pesticide leaching. In addition, the paper combined the four indexes to construct an index of total environmental degradation from pesticides. The results show the importance of including an environmental productivity variable in the EKC framework. His estimates for US agriculture reaffirm the hypothesis of increasing returns to abatement.

Using an unbalanced panel data analysis, Ghimire and Woodward [46] studied how pesticide over- or under-use varies for countries with different per capita GDP and FDI stock. They found an N-shaped relationship between pesticide under- or over-use, agronomic residual, and per capita GDP. On the other hand, their results support an inverted U-shaped relationship between FDI stock and the agronomic residual. In addition, they found that the highest levels of FDI correlate with reductions in pesticide use, consistent with Borensztein et al. [47], who found that FDI stock can positively impact a nation's economic education level and environmental awareness.

Hedlund [12] examined the relationship between pesticide use and economic development from 1990 to 2014, employing pesticide data from the Food and Agriculture Organization of the United Nations (FAO) and economic and agricultural data from the World Bank. Within the bounds of this study, the existence of the EKC is not proven, but rather that there is a positive relationship between the variables. What is more, Pincheira et al. [21], based on data using planetary boundaries (incl. global chemical fertilizer consumption), and with the assistance of OLS and a fixed-effect model, along with the system generalized method of moment (GMM), validated the classic EKC for climate change and ocean acidification panels. However, when biochemical cycles, ozone depletion, freshwater use, land change, and biodiversity-loss boundaries were used as proxies for environmental degradation the EKC hypothesis was not supported in econometric studies.

Extending the current literature on the EKC and pesticide use, the present work applies the NARDL model to panel data. The method enables the distinction between short- and long-run effects and the verification of the asymmetric behavior of the variables. This methodology has been recently applied mainly in energy studies, e.g., [48–51], which have demonstrated its ability to produce robust results. Moreover, Kisswani [51] used NARDL in panel data and time-series data for five ASEAN economies from 1971 to 2013 to examine the long- and short-run nexus between GDP–energy consumption.

The NARDL model was also used by [52] to examine the asymmetric causality among renewable energy, carbon emissions, and real GDP in Saudi Arabia from 1990 to 2014. According to their results, an asymmetry exists in the long run between renewable energy, carbon emissions, and real GDP. Using the same methodology, Munir and Riaz [53] used annual panel data from three South Asian countries from 1985 to 2017 to evaluate the nonlinear effect of energy consumption on carbon emissions. They examined the long-run and short-run relationships and found that a nonlinear relationship exists between electricity consumption and carbon emissions, as well as between coal consumption and carbon emissions in South Asian countries in the long run. On the other hand, nonlinearities and asymmetric responses have been confirmed in oil consumption-carbon emissions, electricity consumption-carbon emissions, and coal consumption-carbon emissions relationships in Bangladesh and Pakistan.

Finally, Marques et al. [54] examined the relationship between the energy efficiency of the industrial sector and economic growth for eleven EU countries from 1997 to 2015. They used a NARDL model, which allowed for short- and long-run relationships to be analyzed for the variables' ascending and descending movements. Their findings indicate that investment initiatives contribute in a positive way to energy efficiency along with GHG emissions reduction.

In this study, we use an alternative indicator for environmental degradation; namely, the use of pesticides that have become one of the most important inputs in crop agriculture. The use of pesticides entails impacts on crop profitability along with environmental degradation.

3. Materials and Methods

3.1. Data

This paper uses pesticides' agricultural use per hectare of the cultivated area as a proxy for environmental degradation and the value-added in agriculture per capita as a proxy for agricultural income (i.e., its evolution is an indicator of economic growth). Both variables are derived from the FAOSTAT database [18]. The data sample involves twenty-five member countries of the EU; the panel data are unbalanced, with environmental degradation being the dependent variable and the agricultural income the independent variable.

This study employs the annual panel data of twenty-five EU countries (Belgium and Luxemburg are excluded) with a reference period from 1990 to 2018 (1992–2018 for the new-entrant ex-communist countries). Panel data provide more valuable information compared to time-series or cross-sectional data, given that the latter are affected by heterogeneity and cross-section-specific impacts leading to less-reliable and -robust results. What is more, the panel data incorporate more information, more variability, and more efficiency compared to pure time-series data or cross-sectional data. More specifically, panel data can detect and measure statistical effects that pure time-series or cross-sectional data cannot, and when using panel data the results become free from the severe impacts arising from collinearity [55–59].

The selection of the dependent variable was based on the Dimitrescou and Hurlin [60] Granger-causality panel data test that is designed for heterogeneous panels and is based on the individual Wald statistics of the Granger non-causality averaged across the cross-section units. The graphs provided in Figures 3 and 4 depict the evolution over time of the variables employed in the model for each country. Figure 1 shows that pesticide use has followed a heterogeneous development in the countries analyzed. For some, pesticides use has increased steadily over time (Czech Republic, Estonia, Hungary, Ireland, and Poland), whereas for others, pesticide use first increased and then decreased (e.g., Croatia, Cyprus, Germany, Latvia, and Portugal), and for the rest, there are no clear patterns.

Figure 4 indicates that the per capita net value-added in agriculture (i.e., divided by the rural population) exhibits an increasing trend for specific countries (e.g., the Czech Republic, Estonia, Ireland, Poland, and Spain), and a decrease for others (e.g., Croatia, Estonia, France, the Netherlands, and Spain). For the remaining countries, the evolution over time presents ups and downs, but remains at similar levels both at the beginning and at the end of the period (e.g., Austria, Bulgaria, Germany, and Portugal).

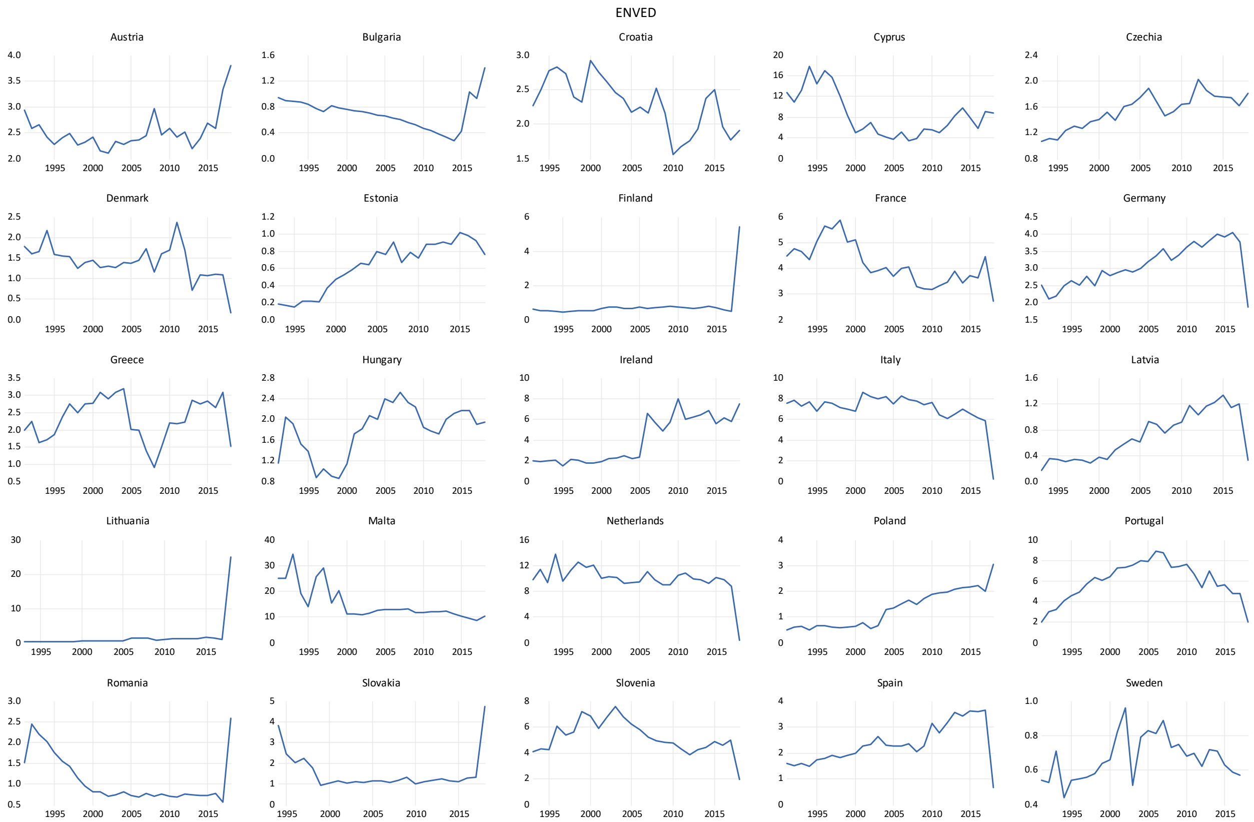

Figure 3. Pesticides agricultural use in kgs per ha of cropland as a proxy for environmental degradation in 25 EU countries. Source: FAOSTAT and own elaboration.

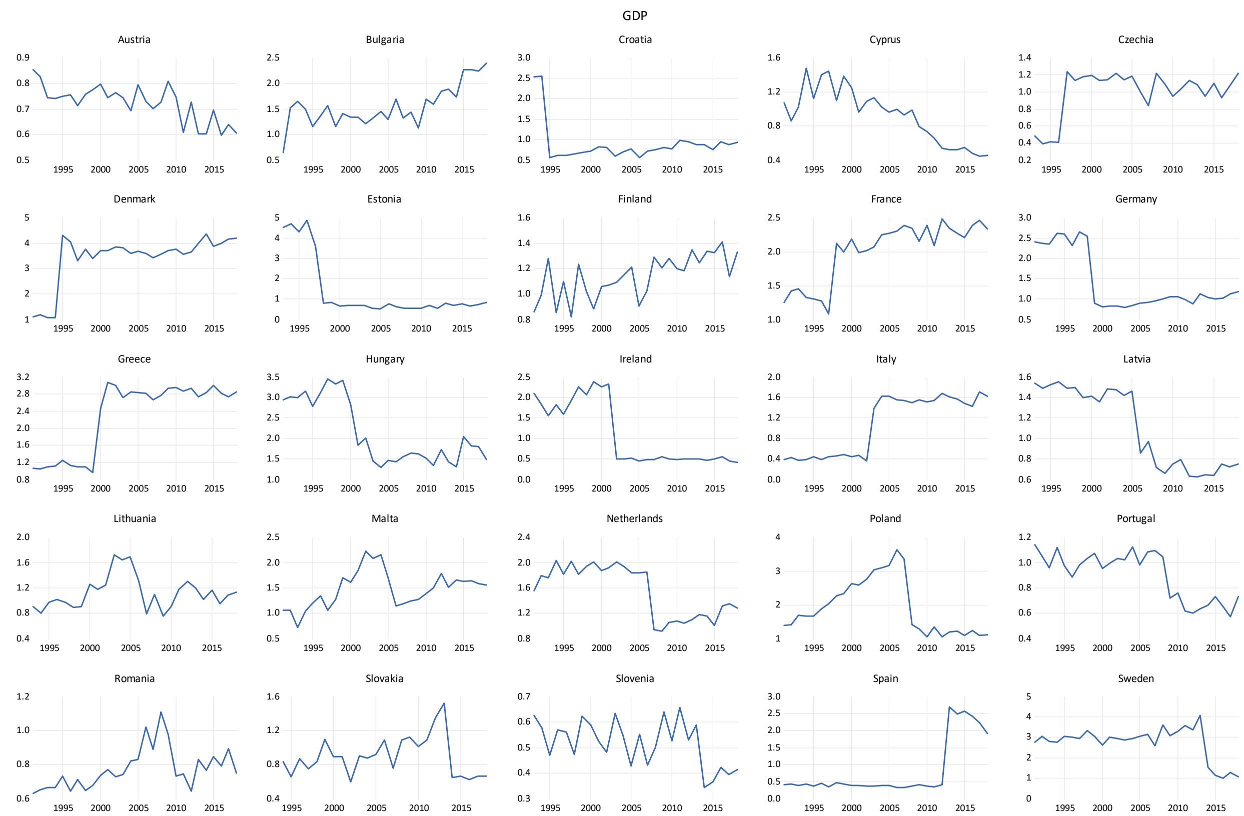

Figure 4. Net value-added per capita in agriculture as a proxy for agricultural income. Source: FAOSTAT and own elaboration.

3.2. Methodology

The present study uses two different methodologies; namely, the PMG-ARDL panel data and the panel NARDL that involves a combination of two techniques, namely the NARDL introduced by Shin et al. [58] and the panel ARDL methodology of Pesaran et al. [59]. With the assistance of these, we estimate the panel NARDL model to achieve this study's objectives. The advantages of employing the panel NARDL methodology compared to the NARDL and panel ARDL are provided below. First of all, the particular model captures the nonlinear asymmetric effects. Secondly, it measures the heterogeneity effects and, thirdly, the mixed order of the integration of variables may be employed. Although the panel data methodology is valid in all the other aspects, it may not capture adequately the evolution of the time series studied when our data, in terms of time, are limited. However, given that the isolated time series includes over twenty-five observations, our results are reliable.

Prior to the presentation of the methodology steps, we identified the causality direction among the variables employed with the assistance of the Dimitrescou–Hurlin methodology (2012) [60]. Having validated that the causality runs from agricultural income to environmental degradation and not vice versa, we documented the selection of environmental degradation as the dependent variable.

The methodology employed in the present work was completed in four steps: (i) panel unit root tests, (ii) decomposition of stationary variables in positive and negative variations, (iii) estimation of the ARDL and NARDL models based on the pooled mean group, and (iv) diagnostic tests of the estimated model. The first step involved the implementation of panel-data unit root tests. Specifically, the tests involved the one suggested by [61] Levin, Lin, and Chu (LLC), and the one introduced by Im, Pesaran, and Shin [62] (IPS). Both tests were applicable given that the number of countries was less than twenty-five and the variables were normally distributed with finite heterogeneous variance and zero mean [63].

Regarding the second stage, the techniques suitable for estimating the non-stationary dynamic panel are the pooled mean group (PMG), and the panel ARDL model. This methodology was introduced by Pesaran and Shin and Pesaran et al. [64,65]. The PMG methodology provides plausible results for the estimation of the short- and long-run relationship among the variables.

The general form of the PMG model or panel ARDL is specified as follows:

$$Enved_{it} = \sum_{j=1}^{k} \mu_{ij} Enved_{i,t-j} + \sum_{j=0}^{\lambda} \theta_{ij}{}' GDP_{i,t-j} + \beta_1 GDP_{it-j}{}^2 + \pi_i + \varepsilon_{it} \quad (1)$$

$Enved_{it}$ denotes the dependent variable (kgs of pesticides per hectare of cropland as a proxy for environmental degradation); GDP_{it} is a vector of the explanatory variable, that is, the net value-added per capita of the rural population as a proxy for agricultural income per capital; π_i represents the fixed effects; μ_{ij} represents the coefficient of the lagged dependent variable; $\theta_{ij}{}'$ is the coefficient vector of the independent variable; and ε_{it} denotes the error term.

Equation (1) can be re-written in the form of the vector error correction model as follows:

$$\Delta Enved_{it} = \theta_i ECT_{it} \sum_{j=1}^{k-1} \mu^*{}_{ij} \Delta Enved + \sum_{j=0}^{\lambda-1} \theta_{ij}{}^{*\prime} \Delta GDP_{i,t-j} + \beta_1 \Delta GDP_{it-j}{}^2 + \pi_i + \varepsilon_{it} \quad (2)$$

where

$$ECT_{it} = \varphi_i Enved_{i,t-j} - \beta_i' GDP_{i,t} - \gamma_\iota \Delta GDP_{i,t}{}^2$$

The coefficient of the error correction term (asymmetric error correction mechanism in the NARDL model) is the parameter that provides the speed of adjustment to the long-run equilibrium, while the negative sign is indicative of convergence in the short run.

Given that the objective was to examine the existence of nonlinearities in the relationship between environmental degradation and agricultural income evolution in a panel form, the methodology employed was the one introduced by Shin et al. (2014) [61], denoted as NARDL, which is based on the linear ARDL model suggested by Pesaran et al. and Pesaran and Shin [64,65]. The NARDL methodology came after the method indicated by Granger and Yoon [66] and Schorderet [67]. The main feature of this particular methodology is the decomposition of a stationary variable into positive and negative variations. The decomposition of the variables mentioned above involves the independent variable, while the square form of the variable for agricultural income per capita and the mathematical form are represented as follows:

$$GDP^{+} = \sum_{j=1}^{t} \Delta GDP_j^{+} = \sum_{j=1}^{t} max\left(\Delta GDP_j, 0\right) \quad (3)$$

$$GDP^{-} = \sum_{j=1}^{t} \Delta GDP_j^{-} = \sum_{j=1}^{t} max\left(\Delta GDP_j, 0\right) \quad (4)$$

Regarding the long-run association, the mathematical form is provided in the following equations:

$$Enved_t = \beta^{+} GDP_t^{+} + \beta^{-} GDP_t^{-} + \mu_t \quad (5)$$

where

$$GDP = GDP_0 + GDP_t^{+} + GDP_t^{-} \quad (6)$$

The coefficients β^{+} and β^{-} are long-run parameters, while GDP^{+} and GDP^{-} denote scalars of decomposed partial sums.

The mathematical form of the model described in the previous paragraph (panel NARDL) is provided by the following Equation (5):

$$\Delta Y_{it} = \theta_i ECT_{it} \sum_{j=1}^{k-1} \mu^{*}{}_{ij} \Delta Y_{i,t-j} + \sum_{j=0}^{\lambda-1} \left(\sigma_{ij}{}^{*+} \Delta X^{+}{}_{i,t-j}\right) + \left(\sigma_{ij}{}^{*-} \Delta X^{-}{}_{i,t-j}\right) + \Delta GDP_{it-j}{}^{2} + \pi_i + \varepsilon_{it} \quad (7)$$

The error correction term is given by the following formula:

$$ECT_{it} = \varphi_i Enved_{i,t-j} - \left(\beta^{+} GDP_t^{+} + \beta^{-} GDP_t^{-}\right) - \gamma_\iota \Delta GDP_{it-j}{}^{2} \quad (8)$$

The fourth step in our analysis involved implementing a number of diagnostic tests to assess normality, autocorrelation, and cross-sectional dependence. These included the Jarque Bera test for normality [68], the Breusch and Pagan LM test [69], the Pesaran scaled LM test [70], and the Pesaran CD test [71] for the cross-sectional dependence, and the Granger-causality test for the short-run asymmetric dynamics.

4. Results

The next section provides the results of the methodology mentioned above and a brief discussion and comparison with the existing literature. The use of pesticides is not only affected by agricultural income due to greening policy measures but, as expected, the other way around is another plausible result. For the identification of endogeneity issues, we employed the Dimitrescou–Hurlin methodology [55]. The results of the aforementioned test are provided in the following Table 1 and are based on 430 observations.

Table 1. Causality test results of the Dimitrescou–Hurlin methodology (2 lags).

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
ENVED does not homogeneously cause GDP	2.64	0.86	0.3896
GDP does not homogeneously cause ENVED	4.07 ***	3.75	0.0002

*** rejection of null hypothesis for 1% level of significance.

The results in Table 1 show that the direction of causality runs from GDP to environmental degradation and not vice versa, as reflected in the significance of the test in the second row of the table; a result that interprets adequately the selection of environmental degradation as a dependent variable. Pesticide use is determined by multiple factors, including the adoption of Green Revolution (GR) technology, crop diversification, the average farm size, and literacy rate, while the investment in research and development (R&D) has a limiting impact on the use of pesticides. All the factors mentioned above, along with the decoupling of direct payments from production, may provide a reasonable explanation for the limited impact of pesticide use on the value added by agriculture. Despite the fact that this particular problem is multi-factorial, the present work focuses on the bivariate model ceteris paribus, and especially the responses of the agricultural users of pesticides to changes in agricultural income, since the unveiling and quantifying of this relationship may well be valuable for policy.

In the next step, which involves the panel unit root tests, we tried to find the order of integration with the assistance of three different tests, namely, the Im, Pesaran, and Shin (IPS), the Levin, Lin, and Chu (LLC), and the Fisher-ADF (F-ADF) panel unit root tests. According to our findings, the index for environmental degradation is integrated of order one (I (1)), while mixed results are derived for the variable of agriculture income. It must be noted that based on the Schwarz information criteria, the lags selection was found equal to two.

Since none of the variables is integrated of order two, this allows us to use the ARDL and the NARDL cointegration techniques in terms of the panel data (Table 2).

Table 2. Panel unit root test results.

Variables	Im, Pesaran, and Shin (IPS)	Levin, Lin, and Chu (LLC)	Fisher ADF Panel Unit Root Tests	Order of Integration
Ln(ENVDEG)	2.56 (0.994)	29.86 (0.989)	42.98 (0.75)	I (1)
Ln(GDP)	−3.94 *** (0.00)	−1.58 ** (0.06)	92.2 *** (0.00)	I (0)
DLn(ENVDEG)	−7.66 *** (0.00)	−14.76 *** (0.00)	271.9 *** (0.00)	
DLn(GDP)	−21.13 *** (0.0)	−14.32 *** (0.00)	430.6 *** (0.00)	

***, ** rejection of null hypothesis for 1% and 5% level of significance. Note: ENVDEG denotes pesticide use per he and GDP denotes agricultural value-added per capita.

The next step in our analysis estimated the long- and short-run parameters with the PMG-ARDL and PMG-NARDL models. The long-run coefficients and the short-run dynamics of both models are reported in Table 3.

It is evident, based on our findings using the PMG-ARDL panel data methodology, that the existence of an environmental degradation–agricultural income relationship is validated in the long run, although this is not confirmed in the short run. The error correction term is found to be negative, statistically significant and less than one, which provides the speed of the system studied at the steady state. The NARDL estimation results illustrated above were a necessary step in order to capture the existence of asymmetries in the environmental degradation–agricultural income relationship. Based on the results, both coefficients of the negative and positive partial sums for the variable of agricultural income are found to be statistically significant, confirming their impact on the use of pesticides per hectare of cropland. Still, the decrease in agricultural income seems to have a less-substantial impact on the agricultural use of pesticides, which does validate the different effects in terms of the magnitude of the positive and negative partial sums. On the other hand, an increase in agricultural income leads to a decrease in the use of pesticides and the asymmetry is validated in the response of the dependent variable, the agricultural use of pesticides per hectare of cropland, to variations in agricultural income. Explicitly, the increase in the agricultural use of pesticides is half as much as the decrease due to variations in agricultural income.

Table 3. Short- and long-run dynamics of environmental degradation—agricultural income association for 25 EU countries with PMG-ARDL and PMG-NARDL model.

Dependent Variable: D (ENDEG) Selected Model: NARDL (4, 4, 4, 4)		Dependent Variable: D (ENDEG) Selected Model: NARDL (3, 3, 3, 4)	
Long-Run equation		Long-Run Equation	
Variable	Coefficient	Variable	Coefficient
GDP	6.87 *** (0.00)	GDP^-	1.58 *** (0.00)
GDP^2	−2.70 *** (0.00)	GDP^+	−2.39 *** (0.00)
GDP^3	0.25 *** (0.00)	GDP^2	−0.13 *** (0.00)
Short-Run equation		Short-Run equation	
ECT (-1)	−0.11 (0.003)	ECT (-1)	−0.21 (0.00)
D (ENVED (-1))	−1.17 (0.13)	D (GDPNEG)	−1.51 (0.06)
D (ENVED (-2))	0.02 (0.94)	D (GDPNEG (-1))	−5.93 (0.09)
D (ENVED(-3))	−0.6 (0.224)	D (GDP^2 (-1))	−1.109 (0.06)
D (GDP)	−1.76 (0.97)		
D (GDP (-1))	34.5 (0.712)		
D (GDP (-2))	−23.21 (0.51)		
D (GDP (-3))	−42.6 (0.31)		
D (GDP2)	−14.11 (0.86)		
D (GDP2 (-1))	−79.75 (0.52)		
D (GDP2 (-2))	55.76 (0.39)		
D (GDP2 (-3))	78.0 (0.25)		
D (GDP^3)	7.04 (0.85)		
D (GDP^3 (-1))	49.10 (0.38)		
D (GDP3 (-2))	−38.9 (0.34)		
D (GDP3 (-3))	−47.29 (0.28)		
D_2009	0.172 (0.32)		

*** rejection of null hypothesis for 1% level of significance.

On the other hand, a reduction in agricultural income leads to an increase in the use of pesticides, while an increase in agricultural income results in a decrease in pesticides' agricultural use with a double coefficient. This result is interpreted as follows: as reflected in the respective policy measures, the agro-environmental policy seems to make farmers comply with the specific standards securing eco-efficiency. Nevertheless, the reduction in pesticide use appears to be greater in the case of increases in agricultural income, implying that farmers with greater agricultural income search for alternative biocidal pesticides which are environmentally friendly but more expensive, a fact that ultimately slows down the adoption rate of environmentally friendly pesticides.

In the model, we included a stability dummy variable for the period after the year 2009 to capture the changes caused by the introduction of SUDP (Regulation (EC) No. 669/2009 concerning Integrated Pest Management). The particular dummy variable was used because the implementation of SUDP required a few years to be enforced, and its effects would not be visible immediately, but rather in the medium term. The square of per capita agricultural income that determines the pattern of the EKC was found to be statistically significant and negative, denoting the existence of an inverted U-shaped curve.

The results found are in line with those of Longo and York [45], who found evidence to suggest the possible existence of a pesticide EKC, since the authors interpreted the result with the fact that developed countries have been mobilized against pesticides due to their harmful effects. On the other hand, our findings are not in line with those of Ghimire and Woodward [46], who found an N-shaped relationship between pesticide under- or over-use, agronomic residual, and per capita GDP. The specific results studied how pesticide over- or under-use varies for countries with different per capita GDP and FDI stock. The different results may be attributed to different methodologies and the way the under- or over-use of pesticides is incorporated in the model's estimates.

Regarding the short-run dynamics, the asymmetric error correction mechanism (AECM) reflects the speed of recovery from short-run disequilibrium to long-run equilibrium convergence, and it should oscillate between [−1, 0] and be statistically significant. In our case, the AECM was found equal to −0.21 and statistically substantial, satisfying all the requirements mentioned above; therefore, the estimation parameter of our model is in line with the expected error corrections for procyclical variables.

The diagnostic tests' results for testing the applied model's robustness are provided in Table 3.

The normality test confirms that the model errors based on our data are not normally distributed. As far as the results of the tests concerning the null hypothesis of cross-sectional independence, and based on our findings, we conclude that it is rejected at the 10% level of significance for all the tests employed, except for the Pearson CD normal. These results are presented in Table 4.

Table 4. Diagnostic tests (normality and cross-sectional independence).

Test	Statistics (*p*-Value)
Breusch-Pagan Chi-square	493.9 (0.00) ***
Pearson LM Normal	6.89 (0.00) ***
Pearson CD Normal	0.445 (0.65)
Friedman Chi-square	39.08 (0.06) *
Normality Jarque Bera test	2057 (0.000) ***

***, * rejection of null hypothesis for 1% and 10% level of significance.

Finally, the causality test the results of which are illustrated in Table 5 is critical to policymakers in identifying the most suitable measures aimed at eco-efficiency and sustainable development in agriculture. The results confirm that environmental degradation does Granger-cause agricultural income, while an interesting finding is that only the negative partial sums in agricultural income Granger-cause in a statistically significant way the agricultural use of pesticides per hectare and not vice versa. In addition, no such result is validated for the positive partial sums of agricultural income.

The next section of the results refers to the short-run dynamics of each cross-section in our sample. To be more specific, Table A1 in the Appendix A illustrates the short-run dynamics for each country separately; the cases of Portugal, Italy, the Netherlands, Latvia, Slovakia (non-statistically significant), along with the newly entrant countries of Bulgaria, Finland, Lithuania, Slovakia, and Poland, for which the coefficient of the asymmetric mechanism is positive. This is an expected result for the newer EU member states since the adoption of agro-environmental policies concerning climate change mitigation were implemented much later. Therefore, numerous issues may have arisen while, according to Remoundou et al. [72], illiteracy, poverty, and the perception that exposure to pesticides is an inevitable part of their work may have impeded farmers' compliance with the rules concerning the reasonable use of pesticides as environmentally friendly strategies aiming at climate change mitigation.

Table 5. Results of pairwise Dumitrescu–Hurlin panel causality tests (Lag 1).

Null Hypothesis:	**W-Stat. (*p*-Value)**
GDP^- does not homogenously cause GDP^2	5.489 *** (0.00)
GDP^+ does not homogenously cause GDP^-	11.142 *** (0.00)
GDP^+ does not homogenously cause ENDEG	1.345 * (0.1)
GDP^2 does not homogenously cause GDP^+	7.77 *** (0.00)
GDP^3 does not homogenously cause GDP^2	7.76 *** (0.00)
ENDEG does not homogenously cause GDP^-	4.04 *** (0.00)
GDP^2 does not homogenously cause GDP^-	10.27 *** (0.00)
GDP^3 does not homogenously cause GDP^-	10.23 *** (0.00)
ENDEG does not homogenously cause GDP^3	3.38 ** (0.02)
ENDEG does not homogenously cause GDP^3	3.375 ** (0.02)

***, **, * rejection of null hypothesis for 1% and 5% and 10% level of significance. Note: ENDEG denotes pesticide use per he and GDP denotes agricultural value-added per capita.

As mentioned in the present study, a significant source of pollution involves the extended use of pesticides and fertilizers with tremendous impacts on the health of plants, animals, and humans. Although the EU has one of the most stringent systems worldwide for authorizing and controlling pesticides, the implementation of the regulations is still insufficient. Implicitly, a number of laws and directives compose the legal basis for the use of pesticides. However, EU countries have to enact and apply national laws to implement the EU existing legislation.

The results of this paper confirm the existence of a long-run relationship between economic activity and environmental degradation, while a positive change in agricultural income results in a significant reduction in the use of pesticides per hectare of cropland, thereby limiting environmental degradation. On the other hand, extended environmental degradation is impeded significantly by the limited efficiency of the existing legal framework in the EU. Based on the empirical results, an asymmetry is confirmed by the magnitude of the respective variables. In other words, economic development and the agricultural use of pesticides seem to be coupled, at least in the long run, a fact that limits the effectiveness of the implementation of the agro-environmental policy measures taken. The stability dummy variable further validates this result for the period after the year 2009, since it is the year within which the concept of Integrated Pest Management was introduced with the EC Directive and the changes that followed. As far as the validity of EKC in the short run is concerned, the asymmetric mechanism is found as statistically significant with a value of −0.21, representing the speed of return to the steady-state after a shock. Furthermore, the decrease in agricultural income seems to affect the per hectare of cropland agricultural income for more than two periods, while the same is not valid for the increase in agricultural income.

Concerning the results of the short-run dynamics for each individual EU country included in our sample, the asymmetric error correction mechanism was found to be statistically significant and oscillating in the (−1, 0) interval for the majority of them, with exceptions in the cases of Portugal, Italy, the Netherlands, Latvia, Slovakia (non-statistically significant), along with the newly entrant countries of Bulgaria, Finland, Lithuania, Slovakia, and Poland, for which the coefficient of the asymmetric mechanism is positive. What is more concerning regarding the validity of the ECK, is that the sign and the statistical significance of the square of the GDP are not in line with the inverted pattern of the EKC, especially for the newly entrant countries, providing in sequence little evidence on the validity of the EKC along with the effectiveness of the CAP.

The non-validity of the EKC for the EU hypothesis is in line with the work of Hedlund et al. [12]. Nevertheless, in the present paper, the asymmetric effect is incorporated into the

EKC model and the structural stability break representing the change in the relationship due to the adoption of Integrated Pest Management. What must also be underlined is that the change in farmers' attitudes towards environmentally friendly pesticides could be attributed to their compliance with the existing agri-environmental CAP and, in particular, to the implementation of Integrated Pest Management systems. Therefore, the use of environmentally friendly substances and novel production methods might provide a permanent solution for achieving eco-efficiency in EU agricultural production.

Ultimately though, no convergence in the relationship between environmental degradation and economic performance in agriculture for the whole EU has been found, a fact that is indicative of the limited effectiveness of the IMP due to the compulsory nature of its principles. More specifically, the lack of crop-specific guidelines development and differences in the commitment level among the EU countries may justify the aforementioned finding.

Regarding the validity of the EKC in the short term for EU agriculture in terms of individual countries, we examined the statistical significance and the sign of the square GDP per capita (level, first lag, and second lag). It was confirmed that no statistical significance for any of the coefficients of the square GDP per capita were validated for Austria, Cyprus, Finland, Ireland, Italy, Lithuania, Malta, the Netherlands, Portugal, Romania, Slovakia, and Spain. For the rest of the countries, either the level, the first or, in other cases, the second lag, was statistically significant, with the coefficients being positive or negative, a result that confirms either an inverted U or a U pattern of the EKC. More specifically, our findings may also be attributed to the differences in national plans introduced as well as their starting point in each country since there is not a homogenous plan adopted concerning the implementation of IPM practices. More specifically, concerning the newly entrant countries, like Romania, Poland, and Hungary, a few dimensions of the IPM are taken into consideration while others are ignored. For instance, Romania has not taken specific measures to reduce pesticides, while no timetable has been announced for the introduction of alternatives for the three countries. Poland is the one that focuses mainly on knowledge dissemination for the development of an IPM system, while the role of organic farming is promoted only in the case of Poland. The efforts toward IMP implementation are more intense for the case of old EU members like Germany and Denmark for the reduction in pesticide use, while this is not the case for France, where little effort has been made in this direction. Organic farming is a high priority for all the aforementioned countries, while low-risk alternatives are a high priority for action mainly in Denmark and France. As far as the rest of Mediterranean countries, including Spain, Portugal, Italy, and Greece, the lack of a mandatory adoption of practices like timetables, indicators used for IPM effectiveness, and the crop-specific use of pesticides, does explain the differences in the short-term relationships of each country. In addition, the differences in public awareness efforts, in the use of low-risk alternatives, the extent of stakeholders' involvement, and the extent of the adoption of organic farming practices provide a few reasonable explanations for the limited effectiveness of the IPM in the EU. For instance, Spain and Romania are the sole EU countries that provide specific measures for public awareness of the IPM in their national plans, while there were delays in the certification operations of a few countries such as Italy, while Bulgaria, Hungary and Romania did not provide the necessary data.

The next section provides the conclusions and policy implications for the use of pesticides in the EU.

5. Conclusions

The Environmental Kuznets Curve has been a subject of extended study, with different methodologies and different indices used as proxies for environmental degradation. The role of pesticides in environmental degradation has multiple impacts in the agricultural sector, which is why a study using only carbon emissions generated by pesticides would be incomplete. The present work focuses on EU agriculture given the efforts made by EU countries to enhance environmental quality in this sector, as reflected by the CAP implementation, that are closely linked to the interactions between agricultural land use, rural ecosystems, and the environment. The measures taken within this framework aim at integrating environmental concerns and serving sustainability purposes more efficiently. In particular, some of the efforts are promoted by the Farm-to-Fork Strategy, which has somehow replaced the IPM due to its limited efficacy, and has set initiatives for tackling climate change impacts, protecting natural resources, and enhancing biodiversity [73].

Our findings confirm the role of changes in agricultural income on pesticide use in the long run, a result that is partly in line with that of Wyckhuys et al. [74], who validated this impact for countries with advanced technologies in the agricultural sector as a result of public health risks, loss of ecological resilience, loss of farm profits, and energy consumption [74–79].

In addition, the two-way relationship found for climate change–agricultural income may well provide policy makers some insights to reduce greenhouse gas emissions, and to make agricultural resources more resilient to climate change with new technological solutions in the field of biotechnology. These developments are necessary within the framework of the EU Green Deal that aims to transform the EU into a prosperous society with a resource-efficient and competitive economy, zero net emissions of greenhouse gases by 2050, and above all, for economic growth to be decoupled from resource use [80].

Another issue related to the present work involves the data employed and the relationship estimated. The pesticide use per hectare of cropland has been employed as a proxy for environmental degradation, which serves the objective of this research. The methodology employed allows us to focus on how changes in pesticide use interact with agricultural income, and to derive policy implications for how to apply a quantity that promotes economic growth and at the same time does not worsen the environment significantly. Thus, the IMP as well as Farm-to-Fork strategy goals may be achieved by taking into consideration how income growth may direct pesticide-use practice, and how other policy measures may be imposed in order to allow eco-efficiency to become achievable [18].

The bivariate model estimated could be thought of as insufficient, although our main intention was to focus on the interlinkages among the two variables while the use of total pesticides is documented [74] as the pesticide treadmill, since it refers to the total annual volume regardless of product type, toxicity, or environmental specificity. This concept has become widespread due to the continuous appearance of novel pesticides with different toxic compounds, pesticide-induced pest resurgence, and insecticide resistance development [81,82]. The significance in monetary terms and in health and environmental impacts, and the tradeoffs among them, have been studied in the present work, while the use of alternative products may well serve as a means for satisfying the target set by the CAP and other mechanisms promoting climate mitigation and agro-food security [82,83].

The relationship estimated and the EKC validity for different EU countries varies. Therefore, regional-specific tools are needed to promote eco-efficiency in agriculture. The most significant are the national action plans (NAP) aiming to establish quantitative objectives, measures, and timeframes to reduce the risks and impacts of pesticide use on human health and the environment, and to encourage the development and introduction of integrated pest management and of alternative approaches or techniques in order to reduce the dependency on and the risks posed by the use of plant-protection products. Implementing a national plant-protection program to reduce pesticide use in agriculture will require the combined education of farmers and the public, while all governments should modify their current policies, such as commodity and price-support programs, as well as all other measures that may well dissuade farmers from employing crop rotation and other sound agricultural practices [74–79]. As mentioned above, the measures taken do not always solve the problems and, to the contrary, can increase the incidence of pest problems and pesticide use (i.e., Spain and France). Novel practices and environmentally friendly pest control products could provide effective tools to reduce the environmental degradation caused by chemical pesticides [82]. However, this should be based on research that will require significant investments.

Another finding that requires country-specific handling in terms of pesticide use and general agro-ecological practices is the variability of the relationship estimated for the different EU countries. More specifically, the individual EU countries alike would benefit only if they can effectively translate agro-ecology science into practice. For instance, the use of environmentally friendly products may serve as a low-cost solution for environmental protection and sustainable 'green' growth. However, it is more than difficult to balance the societal benefits and the environmental damage of pesticide use in the sector of agriculture since there is no win–win option for the solution of this problem. The scientific value of the present work stands on the provision of information on pesticide use that, along with environmental release or human exposure, may well enrich interdisciplinary 'systems' approaches that can promote agro-ecology needs, having incorporated growers' aspirations.

Finally, it is important to notice the role of the stakeholders in the EU effort towards sustainability. For the objective of a reduction rate of 55 per cent in GHG emissions by 2030 to be realistic, monetary motivation is a requirement; the European Innovation Partnership—EIP-AGRI in the EU [83], Farmer Field Schools from FAO [83], and other Agroecosystem Living Labs [84]—are current approaches that assist with the trade-offs for all stakeholders. In addition, the EIP-AGRI is believed to act as a parameter to promote economic sustainability in the CAP effectively [84,85]. To synopsize, the agricultural policy implemented should make more efforts in this direction, encouraging the transition towards low-impact farming and emboldening member states to implement low-input farming.

A subject of future research could be the study of agricultural income–environmental degradation with the pesticide-usage intensity per farmer as the proxy for environmental degradation, while alternative methodologies like BVAR and wavelet analysis may be employed. A comparison of low- and high-income countries could also be conducted to provide insight into the global nature of the problem and the efficacy of the different policy measures that have been implemented.

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Appendix A

Table A1. Short-run dynamics for each individual EU country.

Variables	Austria	Bulgaria	Croatia	Cyprus	Czechia	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland
ECT (-1)	−0.41 *** (0.00)	0.347 *** (0.00)	−0.23 *** (0.00)	−0.35 *** (0.00)	−0.89 *** (0.00)	−0.51 *** (0.00)	0.51 *** (0.00)	0.93 *** (0.0)	−0.27 *** (0.00)	−0.2 * (0.1)	−0.31 *** (0.00)	−0.93 *** (0.00)	0.06 * (0.09)
D (GDP_neg)	−3.7 (0.06)	0.66 *** (0.000)			−2.56 *** (0.00)	−2.46 ** (0.04)	−14 *** (0.00)					−1.00 *** (0.00)	
D (GDP_0neg (-1))		−0.92 V (0.00)					−0.76 *** (0.00)					−0.51 *** (0.00)	
D (GDP_neg1 (-2))		−0.15 *** (0.00)			1.54 *** (0.00)		0.07 *** (0.00)					−0.96 *** (0.00)	
D (GDP_neg (-3))													
D (GDPpos)		0.75 *** (0.000)				−1.25 *** (0.01)	−0.8 *** (0.00)				−1.1 ** (0.03)	−1.98 *** (0.00)	
D (GDPpos (-1))		−0.88 *** (0.000)			−2.6 *** (0.00)		−0.8 (0.000)					−1.0 *** (0.00)	
D (GDPpos (-2))		0.243 *** (0.000)				0.18 *** (0.00)	−0.32 *** (0.00)			−3.2 * (0.09)		−0.65 *** (0.00)	
D (GDPpos (-3))													
GDP2						−0.38 *** (0.00)	0.2 *** (0.000)		1.05 *** (0.0)	−1.08 ** (0.01)		−0.6 *** (0.00)	
D (GDPˆ2) (-1))		0.28 *** (0.000)	−0.035 *** (0.00)		−1.99 *** (0.00)	−0.34 (0.00)	−0.22 (0.00)		1.8 (0.01)		1.13 (0.01)	−0.1 (0.000)	
D (1992)	−0.36 *** (0.0)	−0.12 *** (0.00)											
D (GDPˆ2 (-2))		−0.301654	−0.03 (0.00)		−1.02 (0.00)		−0.7 (0.00)		0.8 (0.04)	−0.06 (0.06)	0.4 (0.03)	−0.103 (0.00)	

Table A1. *Cont.*

Variables	Italy	Latvia	Lithuania	Malta	The Netherlands	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden
ECT (-1)	−0.56 (0.29)	−0.01 ** (0.1)	0.96 (0.91)	−0.23 *** (0.00)	−0.17 (0.40)	0.35 *** (0.00)	−0.0 (0.40)	−0.76 *** (0.00)	−0.59 (0.26)	0.417 *** (0.00)	−0.13 ** (0.01)	−0.08 ** (0.04)
D (GDP_neg)						0.73 *** (0.00)						
D (GDP_neg (-1))		1.72 * (0.08)										
D (GDP_neg1 (-2))												0.14 *** (0.00)
D (GDP_neg (-3))												
D (GDPpos)						0.95 * (0.05)						−0.29 * (0.08)
D (GDPpos (-1))		3.04 ** (0.01)										
D (GDPpos (-2))												0.13 *** (0.00)
D (GDPpos (-3))												
GDP2		−0.64 ** (0.020)										−0.08 *** (0.00)
D (GDP^2) (-1))	−10.3 (0.09)	0.86 (0.102)				0.15 *** (0.000)					4.12 *** (0.00)	−0.62 *** (0.000)
D (1992)												
D (GDP^2 (-2))		1.59 *** (0.00)				0.17 *** (0.00)					6.88 *** (0.00)	−0.046 *** (0.006)

*, **, *** rejection of null hypothesis for 10%, 5% and 1% level of significance respectively. Note: ENDEG is the dependent variable and denotes pesticides use per he; GDP denotes agricultural value-added per capita. D indicates first differences, pos refers to positive partial sums, neg refers to negative partial sums, GDP2 refers to agricultural income per capita, and (-1)–(-3) indicates the lags of the exogenous variables.

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