sustainability

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Greenhouse Gas Emissions and Economic Performance in EU Agriculture: An Empirical Study in a Non-Linear Framework

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Received: 16 August 2018; Accepted: 19 October 2018; Published: 23 October 2018

Abstract: Numerous linkages among Agriculture and climate change have been identified and validated in global terms. In European Union, the economic performance–carbon dioxide emission relationship has become a particularly high priority issue for Common agricultural policy within the last decade, attracting scientific interest. Within this socio–economic framework, the present work studies the relationship between agricultural carbon emissions equivalents and income per capita for the agricultural sector in different EU countries with the assistance of the nonlinear autoregressive distributed lag (NARDL) cointegration technique. Our findings validate the existence of a strong relationship between GHG emissions and agricultural income, since the cointegration among the two variables is established in all instances, while the asymmetric impact of agricultural income on carbon emissions may well provide policy makers with tools which when implemented, may well promote the increase of agricultural income along with GHG effect mitigation in a successful way.

Keywords: sustainable agriculture; negative externalities; GHG emissions; NARDL model

1. Introduction

The agricultural income–climate change relationship in global and European Union (EU) terms can be documented through different interlinkages while the concept of sustainability has become a high priority issue for EU agriculture [1]. The climate change–agriculture interaction is bi-directional [2]. Explicitly, climate change may affect global economic performance in the sector of agriculture through its impact on productivity [3], while on the other hand agriculture is a major contributor to global warming [1]. Other issues related to the climate change–agriculture interaction which has arisen within the last two decades include poverty and food security problems [3].

Furthermore, apart from the negative impacts, a number of positive effects of Greenhouse Gas emissions (GHG) to crop growth have also been recorded in recent literature. To be more specific, rising concentrations in the atmosphere improves agriculture in two different ways; first of all by stimulating photosynthesis and secondly by decreasing water requirements. However, the reaction of crops to carbon emissions respond depends on their physiology and other prevailing conditions such as water and nutrient availability, pests and diseases [4]. For the reasons described above, the positive impacts of the GHG effect for agriculture are expected to lead to a 16% increase in productivity corresponding to 45 million hectares in the cultivation of northern Europe focused especially on high latitudes [5] (Altieri et al., 2015).

Currently, GHG emissions from agriculture contribute with 10% to EU-28 total GHG emissions [6] (EC, 2018). This proportion is characterized by variability among EU member states. This variation is related to the size and importance of the agricultural sector in each individual country. Major concern regarding the issue of climate change has led to a decrease in GHG emissions by 23% within the last two decades. The pace through which the decrease occurs has been decreasing with a progressively limiting rate. The decreasing rate in EU GHG emissions in agriculture can be attributed to several factors, including among others an increase in productivity, decreases in cattle numbers, improvements in farm management practices and developments and implementation of agricultural and environmental policies [7] (Van Vuuren et al., 2017).

Among the solutions found for the limitation of the climate change impact of agriculture in terms of farming practices are the following [5,8] (Locatelli et al., 2015; Altieri and Nicholls 2017); (i) use of nitrification inhibitors to increase the efficiency of the nitrogen applied and at the same time reduce nitrous oxide emissions from mineral fertilizers; (ii) an efficient use of fertilization in terms of timing (iii) precision farming as a crop management concept to respond to inter- and intra-field variability in crops and last but certainly not least organic farming. A great size variation is observed not only in terms of the size of organic farming, but also in terms of growth in the total organic area. The typically best management practices that are used already may lead to lower farm emissions while also possibly leading to cost savings and increasing farm profitability. These measures provide major benefits, while the aforementioned options may be carried out at the farm level, or in some cases multiple farmers and other stakeholders ([9] Swinton et al., 2018).

Therefore, with the implementation of the particular practices we are raising agricultural productivity and income in the smallholder production sector, which in turn may drive economic transformation and growth in agriculture [10] (Schmidhuber and Tubiello 2007). Therefore, agriculture in terms of policy implementation may play a central role in the effort of climate change mitigation in the EU. Despite the fact that agriculture is a sector for which emission reduction is a priority, only a few EU countries have set quantitative targets for agriculture [11] (Fellman et al., 2018).

To synopsize, EU efforts focus on the reductions in GHG emissions without limiting the competitiveness of EU agriculture and its ability to satisfy growing global food demand, and these efforts are tightly related to agricultural income. Within this framework the present manuscript has as an objective to survey the relationship carbon emissions equivalent generated by agriculture–agricultural income in selected countries of European Union with variation in terms of the size of agriculture, of the point of economic growth as well as the behavior of the farmers regarding the implementation of specific environmental measures ([3,12] Frank et al., 2017; Kalfagianni and Kuik 2017).

In short, the main objectives of our research effort are the following;

- Detect the true nature of the relationship and the existence of non-linearities in the relationship among the variables.
- Capture asymmetric responses to positive and negative changes over both the short-and the long-run through positive and negative partial sum decompositions of the explanatory variables.
- Test the validity of the environmental Kuznets curve (ECK) hypothesis for the sector of agriculture for different EU countries.

The manuscript is organized as follows: The next section describes the existing literature, Section 3 presents the agriculture in different EU countries, Section 4 provides a subtle description of data used and the methodology on Nonlinear Autoregressive Distributed-lagged (NARDL) modelling, Section 4 outlines the results of the data process and an insight in the implications of those results, while the last section concludes.

2. Literature Review

The economic growth–environmental degradation relationship as synopsized in the environmental Kuznets curve (ECK) hypothesis has been a subject of extended study within the last couple of decades. Different methodologies and different indexes for environmental degradation have impeded the consensus on the validation of the environmental Kuznets curve hypothesis [13–18]. The interaction among environmental degradation and economic performance either in terms of a firm, a sector or economy has been mostly studied with the use of atmospheric indicators, while literature on the EKC hypothesis employs land indicators, like water ecosystems, biodiversity indicators, and freshwater indicators. The majority of the existing literature has argued that an inversed U-shape exists for the environmental degradation income per capita relationship, the steepness of which is mostly affected by income elasticity, scale, composition and technique effects, and international trade [19] (Sarkodie and Strezov 2019).

The majority of the empirical studies are based on the carbon emissions, since global anthropogenic greenhouse gas emissions are mainly attributed to carbon emissions [19]. Furthermore the carbon emissions are mostly generated by sectors related to energy use, forestry, agricultural processes and land use [20]. Regarding the methodologies used, a time series analysis with the assistance of cointegration linear or nonlinear conflict results was derived [2,13,21–24].

In the case panel data the most widespread methodologies are the Pedroni cointegration technique and Fully Modified Ordinary Least Squares (FMOLS) that validated the EKC hypothesis for developed countries [25], On the other hand, Ozcan (2013) [26] rejected the validity of the ECK hypothesis [18], examine the validity of the EKC hypothesis, with respect to the relationship between economic growth and environmental sustainability in Africa, while Javid & Sharif (2016) [27] propose an autoregressive distributed lag (ARDL) cointegration method in order to evaluate the impact of financial development, per capita real income, square of per capita real income, per capita energy consumption and openness on the per capita CO_2 emissions for Pakistan during 1972–2013. Finally, Culas (2007) [28] propose a panel data method, which incorporates both cross-sectional and time series data, in order to evaluate the impact of environmental policies on the EKC relationship for deforestation across Latin American, African and Asian countries.

Concerning the sector of agriculture, a few works can be mentioned with different econometric methodologies. For instance, Coderoni and Esposti [29] analyze the long-term relationship between agricultural GHG emissions and productivity growth in order to assess emissions sustainability for Italian regional agriculture. Another recent research involved the impact of renewable and agriculture on greenhouse gas emissions [30]. According to their findings, an increase in renewable energy and agriculture leads to a decrease in CO_2 emissions, while the opposite is validated for the case of non-renewable energy. Furthermore, in the short-run Granger causality is validated from non-renewable energy to emissions and to agriculture, from economic growth to agriculture, and from agriculture to renewable energy in a direct way, implying that sustainable agriculture may promote renewable energy and decrease carbon emissions [30] (Liu et al., 2017). Another work on agriculture based on annual data and with ARDL model by Zafeiriou and Azam (2017) and Zafeiriou et al. (2017) [2,21] concluded that the adoption of environment-friendly farming practices and crops' selection does not secure high economic and environmental performance simultaneously, at least in the short run, for our sample countries. Furthermore, in the long run the existing situation asks for the modification of the agro–environmental measures adopted to make those two targets complementary and not mutually exclusive for a farmer. To be more specific, the challenge of climate change mitigation in the sector of agriculture that remains is to effectively incorporate sustainability into the agricultural operations, management, research and development [31].

The existing literature as analyzed in the present section, indicate that even though the environmental Kuznets curve hypothesis is broadly examined in a linear and non-linear framework, no previous research effort can be found to our knowledge which implements the nonlinear autoregressive distributed lag (NARDL) cointegration method for evaluating the GHG emissions—economic performance relationship for the sector of agriculture. Thus, the present research effort employs for first time a nonlinear framework with the assistance of an NARDL model in order to confirm the existence causality and asymmetric effects of a relationship among carbon emissions and economic performance in EU agriculture.

3. The Agriculture in EU Countries

The purpose of this section is to describe the sector of agriculture for the countries examined in terms of the degree of mechanization of their agriculture, the percentage of people employed in the agricultural sector, the antiquity years of agricultural machinery use, and the greening of farming as reflected in the size of organic agriculture. This section may well provide us with plausible explanations for the results of the model analyzed in Section 4.

The selection of the countries for our study was based on: (i) the significance of the sector of agriculture for the economy (proportion to total GDP) (ii) their attitude towards the environmental friendly practices and (iii) whether they are old or new members of the EU.

3.1. Bulgaria

The first country examined is Bulgaria where only 8.04% of the employed in the agriculture sector are under the age of 35 years, and 33.59% are over 64 years old. Moreover, the educational level in Bulgarian agriculture is relatively low. More than half of the employees have primary and secondary education according to the National Institute of Statistics, and only 3% of farm managers have agricultural education. The CAP and its implementation in Bulgaria require specific qualifications: Knowledge in the fields of information technology, management, environmental practices, etc.

The majority of farms are marked by low mechanization. The low level of mechanization, its absence in some of the farms and the use of old equipment in most cases (over 85% of the used equipment is older than 10 years) involves the development of primitive, low-productive and inefficient production, which poses serious constraints to competitiveness. The status of agriculture in Bulgaria, as analyzed has shown that the future development and transformation of the agricultural sector into a competitive one has proven to be a highly complex and responsible task [32] (Kagatsume and Todorova 2007). This transformation is a requirement of both European and world markets. The structure of the agricultural sector that has been established in respect to the amount of utilized agricultural area (UAA) is abnormal and does not contribute to the development of the agrarian sector in Bulgaria [33] (Todorova 2016). In 2007, 54.1% of Bulgarian farms in size are smaller than 0.5 ha, and only 0.8 percent of the farms are over 100 ha in size, i.e., more than half the farms in the country cultivated only 1.5% of the total UAA. This reveals a structure of agriculture in which small farms predominate. The main reason for the existence of such a structure is the method of land restitution in its real boundaries which was adopted. The dimensional structure of farms in Bulgaria is the factor which most greatly restricts the creation of viable farms. The small farms that are prevailing are characterized by low profitability that cannot attract young people to become involved in agriculture [34] (Nikolova). The permanent establishment of semi-commercial farms is an inhibitory factor for the formation of market-oriented farms.

Regarding the size and growth of organic farming in Bulgaria the following can be mentioned; for the time period 2012–2016, Bulgaria is one of the countries studied, exhibiting a growth in the total organic area of over 100%. Furthermore, an interesting index for the potential growth in the organic sectors for the years to come is the area under conversion as a percentage of the total organic area, which for Bulgaria is equal to 77.5% on of the largest shares recorded for EU countries [35].

3.2. United Kingdom (UK)

In the UK, the Utilised Agricultural Area (UAA) has remained quite stable, as it only lost 63,250 hectares (−0.4%) between the two reference years: It covered 64% of the country's territory in 2010, the second highest share reported within the EU-28 after the one recorded in Ireland (71%).

The average area per holding was quite high (84 ha per farm) in 2010—it actually increased by about 5 hectares over the period under analysis, hence on average British farms were found to be the second largest within the EU-28, after Czech farms, which recorded a much larger average area (152 ha per farm). The number of people regularly working in the agriculture sector decreased (−18.8%) between 2000 and 2010, as about 97,000 people stopped working on the farms. Therefore, the labor force in the agricultural sector represented only 1.4% of the active British population in 2010, one of the lowest shares recorded among the EU Member States. Although the farm animal population decreased by 15.7% (−2.5 million LSU) for the period studied, the United Kingdom reported a value (about 13.3 million LSU) that exceeded the highest value respectively recorded within the EU-28 in 2010. Agriculture in UK is considered to be the most mechanized agricultural sector, given the large size and the increased prosperity of farming (Long. 1963). As for the labor force in this particular sector, 346,000 people were working on British farms in 2016, less than 1% of the total employment. Finally, the agricultural labor force as measured in annual work units (AWU) does not show a difference in the decrease, given that figures dropped by 22.3% from 317,280 AWU to 246,650 AWU. A last but certainly not least issue is the greening of UK agriculture as reflected to the adoption to organic farming. A downward trend is recorded for the United Kingdom (−16.9%), for the 2012–2016 period. Regarding the area under conversion as a percentage of the total organic area for the year 2016, the United Kingdom had a share of less than 10%, one of the smallest for the EU [36].

3.3. Spain

For the case of Spain in the year 2010 there were 989,800 agricultural holdings in Spain, a 23.1% drop compared to 2000 and much in line with the common trend recorded in most of the EU countries. In 2010 the UAA in Spain represented 47% of the whole territory; a decrease of 9.2% was reported when compared to the results of the previous census. In terms of the average size of the agricultural holdings, an increase of 18% was observed, shifting from an average of 20.3 ha in 2000 to 24.0 ha in 2010. The overall Spanish livestock, expressed in livestock units (LSU), only changed marginally and amounted to 14.8 million LSU in 2010, a 1% decrease when compared to 2000. In addition the employment in agriculture dropped by 8.7% between 2000 and 2010, passing from 2.4 million to 2.2 million. However, the population working in agriculture still represented 9.8% of the economically active population of Spain in 2010 [1]. According to the FSS 2010 data, there was an average of 0.52 hectares of UAA per inhabitant in Spain. This ratio indicates a decrease (−21%) compared to the one recorded during the Agricultural census in 2000, when the UAA per inhabitant was 0.66 hectares. This result is a combination of both a higher population (+14.8%) and a lower UAA (−9.2%). In addition, Spain represented one of the highest total organic areas not only in 2012 but also in the year 2016, reaching the figure of 16.9% of the total farming area [37].

3.4. Greece

The agricultural sector in Greece remains an important sector of economic activity and employment for Greece, with exports of agricultural products accounting for one third of total exports in Greece. Agriculture contributes to 4.1 percent of GDP and is characterized by small farms and low capital investment. Greece's utilized agricultural area is close to 5 million hectares, of which 57 percent is in the plains and 43 percent is in mountainous or semi-mountainous areas. There are about 150 million olive trees in the country, either in systematic orchards or scattered across the country. Lower agricultural productivity in Greece, compared to other EU Member States, is correlated to the smaller average-size of holdings. The economies of scale offered by modern farming practices have limited impact on the small plots of land typically used in Greece. Regarding the farming systems adopted in Greece and in particular organic farming presents a downward trend (-25.9%) to the already small size of the organic areas [38].

3.5. France

France is a dominant agricultural country in global terms. However officially, the share of population actively involved in farming is decreasing. On the other hand, new creative methods of marketing and agritourism have given a boost to the sector. In addition, almost half of farm income in France is generated by livestock raising, and the rest is contributed by crops. The GDP generated by agriculture (% of GDP) corresponds to 1.6407% in 2016, based on the World Bank database. In addition, the utilized agricultural area (UAA), remained quite stable within the last decade since it was only decreasing by 3.2. Therefore, agricultural land covered 43% of French national territory and was the largest across the whole EU-27 in 2010 (EU, 2018). Furthermore, the case of France represents one of the three highest total organic areas not only in 2012 but also in the year 2016, while the size of the organic area reaches 12.9% of the total farming area for the year 2016 [39].

3.6. Germany

Germany is one of the most important agricultural producers in the EU. To be more specific, Germany is second only to France in animal production and fourth following France, Italy and Spain, in vegetable production. In terms of employment, almost 10 percent of all of Germany's gainfully employed population work (2005) in the agricultural industry. However, this rate is decreasing due to modernization of the agricultural process. Furthermore, the agriculture, value added (% of GDP) in Germany was reported at 0.63432% in 2017 (World Bank data base). Germany is one of the countries with the highest size of organic area that along with Italy, France and Spain account for more than half organic land in the EU [40].

Having considered all the aforementioned issues, it would be of interest to examine the interrelationships among carbon emissions generated by agriculture and agricultural income in different EU countries with heterogeneity in the economic conditions of each country and also particularities in the farming systems. The major though common issue is the implementation of the Common Agricultural Policy and the specific agro–environmental measures as formatted within the last decade [18,19].

4. Data—Methodology

The present work uses annual data of Greece, France, Spain (all of them being Mediterranean countries) Bulgaria, a newly entrant country and two old member states with a well-organized farming sector: Germany and United Kingdom. The data employed were derived by FAOSTAT and the sample time period runs from 1970 to 2014. Implicitly, the bivariate framework being employed includes data on; carbon emissions equivalent ($CO2t$) in thousands of tonnes, generated by agriculture per 1000 hectares of Utilized Agricultural Area (UAA), as proxy for environmental degradation and the net value added per capita ($NVAt$) generated by agriculture as proxy for agricultural income. The methodology employed is the nonlinear ARDL model (non linear cointegration) introduced by Reference [41] aiming to detect the existence of non linearities and asymmetric effects in the relationship among the variables studied.

The major advantages of the particular methodology are the estimation simplicity, the greater flexibility in relaxing the assumptions that the time-series should be integrated of the same order while it provides the potential to identify with accuracy the absence of cointegration, linear cointegration and nonlinear cointegration [42].

Prior to the implementation of the nonlinear cointegration (NARDL model) we implemented a break unit root test. Until now a number of different unit roots has been used such as the Augmented Dickey Fuller (ADF test), Phillips Perron (PP test), Elliot, Rothenberg, and Stock (ERS test), Ng and Perron (NP), and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) tests, with occasionally conflict results.

The conflict results may be attributed to the existence of structural change in a time series which in turn causes bias to the unit root test results. Due to this observation, a large quantity of literature has been developed outlining various unit root tests that remain valid in the presence of a break [43].

In the present manuscript we employ a modified augmented Dickey-Fuller test allowing for levels and trends that differ across a single break date [44,45]. Different types of the aforementioned methodologies were used and the results are provided in the results' section.

In most studies, when causality and linear cointegration confirm that the dependent variable is expected to respond in a symmetric way to increases and decreases of the independent variable we employ the linear unrestricted Error Correction Model as provided by Equation (1).

$$\Delta Cem_t = \mu + \rho_{Cem} CO_{2t-1} + \rho_x Y_{t-1} + \sum_{i=1}^{p-1} a_i \Delta CO_{2t-1} + \sum_{i=0}^{q-1} \beta_i \Delta Y_{t-1} + \varepsilon_t \quad (1)$$

In the present manuscript this is not the case and therefore we employ the NARDL model through which cointegration non linearities and causality are simultaneously detected. For that reason, a decomposition of the net value added (NVAt) into its positive and negative partial sums was preceded, while the generated sums are provided by the following equations;

$$NVA_t^+ = \sum_{j=1}^{t} \Delta NVA_j^+ = \sum_{j=1}^{t} \max\left(\Delta NVA_j, 0\right) \ and \ Y_t^- = \sum_{j=1}^{t} \Delta NVA_j^- = \sum_{j=1}^{t} \min(\Delta NVA_j, 0)$$

Therefore, the Error correction Model is taking the following form when partial sums of the exogenous variable are taken into consideration.

$$\Delta Cem_t = \mu + \rho_{Cem} Cem_{t-1} + \theta^+ NVA^+{}_{t-1} + \theta^- NVA^-{}_{t-1} + \sum_{i=1}^{p-1} a_i \Delta Cem_{t-1} + \sum_{i=0}^{q-1} (\omega^+{}_i \Delta YNVA^+{}_{t-1} + \omega^-{}_i \Delta NVA^-_{t-1}) + \varepsilon_t \quad (2)$$

The superscripts (+) and (−) in Equation (2) stand for the positive and negative partial sums decomposition as defined above.

The symbols p and q denote the respective lag orders for the dependent variable and the exogenous variable in the distributed lag part, respectively. In particular, the long-run symmetry can be tested by using a Wald test of the null hypothesis that

$$\theta^+ = \theta^-$$

Computing the positive and negative long-run coefficients as follows:

$$L_{NVA^+} = -\frac{\theta^+}{\rho_{Cem} \quad L_{NVA^-}} = -\frac{\theta^-}{\rho_{Cem}}$$

The short-run adjustments to the positive and negative shocks affecting the level of the carbon emissions generated by agriculture, are captured by the aforementioned parameters respectively.

The long run (LR) and the short run (SR) symmetry can both be tested by using a Wald test, while the short-run adjustments to the positive and negative shocks affecting the dependent variable, are captured by the parameters $\omega^+{}_i$ and $\omega^-{}_i$ respectively.

Finally, the traditional (linear) ECM as mentioned above can be used if both null hypotheses of short-run and long-run symmetry cannot be rejected.

The rejection of either the long-run, or the short-run symmetry will lead to the estimation of a cointegrating NARDL model with SR & LR asymmetry as follows:

$$\Delta Cem_t = \mu + \rho_{Cem} Cem_{t-1} + \rho_y Y_{t-1} + \sum_{i=1}^{p-1} a_i \Delta Cem_{t-1} + \sum_{i=0}^{q-1} (\omega^+{}_i \Delta NVA^+{}_{t-1} + \omega^-{}_i \Delta NVA^-_{t-1}) + \varepsilon_t \quad (3)$$

$$\Delta Cem_{2t} = \mu + \rho_{CO2}Cem_{t-1} + \theta^{+}YNVA^{+}{}_{t-1} + \theta^{-}NVA_{t-1} + \sum_{i=1}^{p-1} a_i \Delta Cem_{t-1} + \sum_{i=0}^{q-1} (\omega_i \Delta NVA_{t-1}) + \varepsilon_t \quad (4)$$

In short, the NARDL model may estimate the short-run dynamics through the distributed lag part and the long-run dynamics through a single cointegrating vector. Asymmetries can be captured not only in the short run but also in the long run. And last but not least the cointegration test that applies to the unrestricted model is an F-test on the joint hypothesis that the coefficients of the lagged level variables are jointly equal to zero [46].

5. Results and Discussion

The first step in our effort to study the relationship among carbon emissions equivalent and per capita agricultural income is to exclude the existence of I(2) and higher degree of integration variables for each individual country in order to proceed to the second step. The results are provided in Table 1.

Table 1. Results of breakpoint ADF unit root test.

Variables	Trend/Break Specification	T—Statistic	Critical Values (5%)	Break Date
		Bulgaria		
cembul	Both/trend	−2.446296	−4.524826	2006
NVA_{bul}	Intercept/intercept	−1.444585	−4.193627	1991
		France		
cem_{fr}	Both/Both	−3.653095	4.616123	1985
NVA_{FR}	Both/Both	−4.270830	4.616123	1999
		Greece		
cem_{gr}	Both/Both	−4.183147	4.616123	1985
NVA_{GR}	Both/Intercept	−2.906720	−4.859812	1987
		Spain		
cemsp	Both/Intercept	−4.603551	−4.859812	2007
NVA_{SP}	Both/Intercept	−4.291036	−4.859812	1988
		Germany		
CEE_{GER}	Both/Intercept	−4.439	−4.8598	1991
NVA_{GER}	Intercept/Intercept	−3.509	−4.443649	1985
		United Kingdom		
CEE_{uk}	Intercept/Intercept	−2.976	−4.443649	1999
NVA_{UK}	Intercept/Intercept	−3.486451	−4.443649	1986
		Bulgaria		
Δcembul	Both/trend	−4.832198 **	−4.524826	1993
ΔNVA_{bul}	Intercept/Intercept	−10.19594 ***	−4.734858	1990
		France		
Δcemfr	Both/Both	−7.047084 ***	4.616123	1987
ΔNVA_{FR}	Both/Both	−7.173298 ***	4.616123	1995
		Greece		
Δcemgr	Both/Both	−4.993328 **	4.616123	2009
ΔNVA_{GR}	Both/Intercept	−6.880485 **	−4.859812	2003
		Spain		
Δcemsp	Both/Intercept	−9.868212 ***	−4.859812	2005
ΔNVA_{SP}	Both/Intercept	−5.787173 ***	−4.859812	2003
		Germany		
Δcem_{GER}	Both/Intercept	−6.368473 ***	−4.859812	1992
ΔNVA_{GER}	Both/Intercept	−7.557033 ***	−4.443649	2011
		United Kingdom		
Δcemuk	Intercept/Intercept	−6.186 ***	−4.443649	1996
ΔNVA_{UK}	Both/Intercept	−7.545339 ***	−4.443649	2009

** denotes reject of unit root hypothesis in 5% level of significance; *** denotes reject of unit root hypothesis in 1% level of significance.

According to the results derived all the time series surveyed are I(1) implicitly non stationary in levels but stationary at first differences. The particular result provides us with the potential to implement the NARDL methodology provided the non validation of the time series employed as I(2).

Another issue to be discussed concerning the results illustrated in Table 1 involves the breaks validated for the variables studied. To be more specific, for the case of carbon emissions equivalent and for the countries studied including Bulgaria, France, Greece, Spain, and United Kingdom the break was validated for the following dates; 2006, 1985, 1985, 2007, 1991, 1999 respectively. For the case of carbon emissions the existence of the structural breaks may well be attributed either to Kyoto Protocol, Paris agreement and efforts organized aiming at climate change mitigation. On the other hand and regarding the net value added for the sector of agriculture, the indicated break dates for the aforementioned countries are the following ones respectively; 1991, 1999, 1987, 1988, 1985, 1986. The most common factor for the existence of the validated structural breaks and in particular for the variable of the agricultural income involve Cap reform either in 1990 or Agenda 2000, while the small changes may be attributed either to news dissemination or as a subsequent result. Furthermore, as country specific conditions, for the case of UK the foot-and-mouth disease (1985) can be mentioned, as well the changes in the political situation in Bulgaria (1991).

In addition, it is interesting to make a thorough analysis to the break date confirmed by the break unit root tests as provided in Table 1.

The next step in our analysis includes testing the existence on long or short run asymmetries in the behavior of the relationship among carbon emissions equivalent generated by agriculture and agricultural income.

The results of confirmation regarding the long run and short run asymmetry with the assistance of the Wald test for all the sample countries are provided in Table 2.

Table 2. Results of the long run and short run symmetry tests for the sample EU countries (carbon emissions as dependent variable).

Pair of Variables	Long Run W_{LR}	Short Run W_{SR}	Conclusion
Cembul–$NVA_{BUL/cap}$	2.019015 * (0.0522)	1.729280 * (0.0952)	NARDL with LR and SR asymmetry
Cemfr–$NVA_{FRL/cap}$	8.634360 ** (0.0004)	9.645271 ** (0.0001)	NARDL with LR and SR asymmetry
Cemgr–$NVA_{GR/cap}$	−1.638810 (0.1186)	−2.806545 **(0.0121)	NARDL with LR symmetry and SR asymmetry
Cemsp–$NVA_{SP/cap}$	1.987999 * (0.0596)	−1.996244 * (0.0574)	NARDL with LR and SR asymmetry
CEE_{GER}–$NVA_{GER/cap}$	−3.083814 ** (0.0071)	3.084209 ** (0.0071)	NARDL with LR and SR asymmetry
CEE_{UK}–$NVAUK_{P/cap}$	1.9527 * (0.098)	7.166741 ** (0.0004)	NARDL with LR and SR asymmetry

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 1% level of significance. The parentheses denote the *p*-values.

The existence of dummy variables in the formation and evolution of the particular relationship has seemingly played a pivotal role, since a number of events can be recorded such as the entrance of each individual country to the EU, the fall of ex socialist political institutions as well as changes and reforms in the Common Agricultural Policy, including among others the greater concern regarding issues of GHG emissions mitigation (the introduction of agro–environmental policy measures with a major focus on the adoption of greening farming practice and satisfaction of sustainability criteria, as well as the extensive use of alternative energy sources in the farming process (including bioenergy and others).

For all the reasons mentioned above, detecting the existence and validating dummy variables is a very important step in the methodology process.

In order to detect the existence of the dummy variables, we initially estimate the NARDL model without using any dummy variables and with the existence of Bai Perron tests, we trace potential structural breaks. To be more specific, we test the null hypothesis of no breaks against a specific number of breaks (Bai and Perron 2003). Actually, the particular tests and their simulations' findings provide useful tools to the researchers through model selection processes and for the construction of confidence intervals for the break dates (in case multiple breaks exist) [45].

Initially we have to mention that the NARDL model for the case of Bulgaria validated the role of structural breaks as pivotal, with the assistance of Bai Perron process. Explicitly, the significance of impulse dummy variables confirms the impact of events on the formation of agricultural income: The first dummy variable validated as statistically significant corresponds to a structural break in 1986. Within that year poor harvests in 1985 and 1986 have been recorded, which in turn have led to grain imports of 1.8 and 1.5 million tons, respectively. The second dummy variable 1991 carried through the privatization of agricultural land may be attributed either to (a) the Assembly of European Fruit and Vegetable Growing and Horticultural Regions (AREFLH) supported the initiatives in favor of European regulation or to (b) the development of the renewable energy expansion in 1991. In a similar way to the other post-socialist regimes in eastern Europe, Bulgaria found the transition to capitalism more difficult than expected. In the year 2002 the privatization of agricultural land occurred, while in the same year AREFLH encouraged the initiatives supporting European regulation and in April 2013 the Assembly introduced the first Guidelines of European Practices in Integrated Production.

The major objective of developing sustainable farming is to produce and consume safe and quality food, and also to use available resources in an environmentally responsible manner, reducing costs, and minimizing the impact on the environment. It was also to promote the development of renewable energy expansion, particularly in the years 2008 to 2010. Within this framework in the next Table 3 we estimated the NARDL model for the agriculture of Bulgaria.

Table 3. NARDL estimation results for Bulgaria.

Dependent Variable D (Cem_{BUL})		
Variables	**Coefficient**	**Standard Error**
C	0.721248 ***	0.111285
Cem_{BUL} (−1)	−0.332101 ***	0.050969
NVA^{+}_{BUL} (−1)	0.465118 ***	0.147957
$NVA_{BUL}{}^{-}$ (−1)	0.854085 ***	0.165330
S_2002	0.133215 **	0.060634
D $NVA_{BUL}{}^{-}$	0.594969 ***	0.129314
D Cem_{BUL} (−1)	0.544918 ***	0.131120
D NVA^{+}_{BUL} (−3)	0.411743 **	0.173579
D_2002	0.133215 **	0.060634
D $NVA_{BUL}{}^{-}$ (−4)	0.251278 *	0.122623
W_{LR}	2.019015 * (0.0522)	
L^{+} w	1.40053 *** (0.0000)	
L^{-} w	2.5776 *** (0.000)	
W_{SR}	1.729280 ** (0.0952)	
Pss	49.32123 *** (0.00000)	
ARCH	0.947372 (0.3034)	
BG	0.801545 (0.6698)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance, D-year denotes dummy variable, while S-year denotes seasonal dummy variable. The parentheses denote the *p*-values.

According to the results derived cointegration among the variables is confirmed, while no problems of heteroscedasticity or autocorrelation is validated. Finally, the positive sign of the partial decomposition independent variables is illustrative of a positive impact on carbon emissions generated by agriculture in case a change (either positive or negative change) in agricultural income occurs. Asymmetry in the long term as well as in the short term is validated while the sign of the relationship confirms the non-validity in Kuznets environmental curve.

Regarding France as the second country, being ranked as the European Union's largest producer and the second largest exporter has been a strong motivation for the selection of that particular country in the sample of the present work. However, this competitiveness has been put into peril within the last decade due to a number of factors, including the following (Faostat and World Bank Statistics):

The dismantling of the Common Agricultural Policy that had a strong impact on French and European farmers due to a stronger exposure to price volatility; The emergence of large agricultural powerhouses, such as Brazil, China or India, which have the ability to maintain their prices by social or environmental dumping; Last but certainly not least, is the loss of competitiveness of French agriculture within the European Union, due to fiscal and social harmonization, as well as higher employment costs in France.

Within this general framework we employed the nonlinear ARDL methodology, the results of which are provided in Table 4.

Table 4. NARDL estimation results for France.

Dependent Variable D (Cem_{FR})		
	Coefficient	**Standard Error**
C	1.364	0.341
CEM_{FR} (−1)	−0.479	0.123
$NVA_{FR}{}^{+}$ (−1)	−0.265	0.0964
$NVA_{FR}{}^{-}$ (−1)	−0.208	0.106
@TREND	−0.0042	0.001
D $NVA_{FR}{}^{+}$ (−5)	0.158	0.087
D $NVA_{FR}{}^{-}$ (−7)	−0.233	0.101
D $NVA_{FR}{}^{+}$ (−6)	0.189	0.0934
D $NVA_{FR}{}^{+}$ (−4)	0.163	0.090
D $NVA_{FR}{}^{-}$ (−5)	−0.216	0.120
W_{LR}	−2.31 ** (0.0344)	
L^{+} w	−0.553 *** (0.000)	
L^{-} w	−0.434 *** (0.000)	
W_{SR}	3.212 *** (0.00370	
Pss	53.07 *** (0.00000)	
ARCH	0.74 (0.39)	
Qlb(12)	8.1809 (0.611)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance. The parentheses denote the *p*-values.

According to the results derived, we may see that only the time trend is found to be statistically significant in terms of time variables, cointegration among the variables surveyed is validated, while no Arch effects have been detected. An important issue that has to be underlined is that the negative impact of a change in agricultural income leads to a decrease in carbon emissions. Evidently, this result is indicative of validity for the Environmental Kuznets curve hypothesis, a result that is in line with that of Iwata et al. (2010) that also confirmed the validity of EKC for the whole economy taking into consideration also the role of nuclear energy in carbon emissions mitigation.

Another Mediterranean country that is also used in our sample that has a strong agriculture sector in terms of the EU is Spain. The estimation results of the NARDL model for the sector of agriculture in Spain are provided in Table 5.

Cointegration is validated for the data employed and for the case of agriculture according to our findings a result that is in line with the findings of previous studies on Spain though in terms of a whole economy. To be more specific previous studies confirmed that per capita GDP and CO_2 emissions are non-linearly cointegrated, providing support for the existence of the EKC hypothesis in Spain [47,48]. Furthermore, no heteroscedasticity or autocorrelation is validated while the impact of changes in agricultural income leads to a negative sign change in carbon emissions. Also asymmetry is validated in the long run as well as in the short run.

Table 5. NARDL estimation results for Spain.

Dependent Variable D (CEESP)		
	Coefficient	**Standard Error**
C	−0.256 ***	0.0665
CEESP (−1)	0.392 ***	0.0776
NVA +SP (−1)	−0.267 ***	0.0415
NVA −SP (−1)	−0.213 ***	0.058
D CEESP (−1)	−0.827 ***	0.125
S_2003	−0.057 **	0.027
D NVA +SP (−1)	0.186 **	0.086796
S_1998	0.124 ***	0.031
S_1997	0.064 **	0.0267
D CEESP (−2)	−0.406 ***	0.107
D NVA −SP (−1)	0.402 ***	0.132
D_2007	−0.0532 *	0.0287
D NVA −SP (−5)	0.240 *	0.127
WLR	1.988 * (0.0596)	
L^{+} w	−0.680 *** (0.0000)	
L^{-} w	−0.5430 *** (0.0000)	
WSR	−1.997 * (0.0574)	
Pss	48.67 *** (0.000)	
ARCH	0.0059(0.9388)	
BG	1.893(0.3882)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance D-year denotes dummy variable, while S-year denotes seasonal dummy variable. The parentheses denote the *p*-values.

Greece is another sample country for which agriculture does play a significant role in the economy, with changes occurring within the last decades since the tertiary sector including tourism, is becoming the main contributor to the Greek economy. The results derived for the case of Greece are provided in Table 6.

Table 6. NARDL estimation results for Greece.

Dependent Variable D (CEE_{GR})	**Coefficient**	**Standard Error**
C	2.599 ***	0.255
CEE_{GR} (−1)	−2.396 ***	0.239
NVA_{GR} (−1)	−0.0835 ***	0.019
@TREND	−0.0032 ***	0.0009
S_1978	−0.073 ***	0.0124
S_2009	−0.063 ***	0.018
D $NVA_{GR^{-}}$ (−6)	0.431 ***	0.05
D $NVA^{-}{}_{GR}$ (−1)	0.3271 ***	0.052
D $NVA_{GR}{}^{+}$ (−3)	0.177 ***	0.0278
D $NVA_{GR}{}^{+}$ (−6)	−0.1292 **	0.0587
D CEE_{GR} (−4)	1.029 ***	0.1558
D CEE_{GR} (−1)	1.496 ***	0.192
D CEE_{GR} (−3)	0.945 ***	0.186
D $NVA^{-}{}_{GR}$	0.0804 ***	0.0273
D $NVA_{GR}{}^{+}$ (−4)	−0.126 **	0.051
D NVA^{-} (−4)	0.183 ***	0.0376
D NVA^{-} (−2)	0.232 ***	0.055
D CEE_{GR} (−2)	0.967 ***	0.22
W_{LR}	−1.639 (0.119)	
L w	0.0349 *** (0.0000)	
W_{SR}	−2.8065 *** (0.0121)	
Pss	167.35 *** (0.000)	
ARCH	0.0594 (0.8163)	
Qlb(12)	15.823 (0.226)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance D-year denotes dummy variable, while S-year denotes seasonal dummy variable. The parentheses denote the *p*-values.

According to our findings, for the model estimated, no problems of heteroscedasticity or autocorrelation have been detected. Furthermore, asymmetry in the short run but not in the long run is validated for the case of Greece. The initiation of economic crisis in 2009 and the entrance of Greece in the EU seems to have played a statistically significant role in the formation of the carbon emissions–agricultural income relationship. Furthermore, a negative relationship among agricultural income and environmental degradation in terms of carbon emissions equivalent generated by agriculture is validated, and therefore the aforementioned process does not provide us with clear results on the validation of the EKC hypothesis.

Last but certainly not least, the sample includes recorded findings for two strong economies: Germany as an old member in the European Union and the UK which has recently become a non-member of the EU. Both have strong agricultural sectors that are adopting environmental friendly practices.

The results for the aforementioned countries Germany and United Kingdom are provided in the next Tables 7 and 8 respectively.

Table 7. NARDL estimation results for Germany.

Dependent Variable D (CEE_{GER})		
	Coefficient	**Standard Error**
C	1.601 ***	0.332
NVA^{-}_{GER} (−1)	−1.031 ***	0.188
NVA^{+}_{GER} (−1)	−0.78 ***	0.155
CEE_{GER} (−1)	−0.226 ***	0.060
D_1992	−0.368 ***	0.059
@TREND	−0.023 ***	0.006
D CEE_{GER} (−7)	−0.136	0.104
D NVA^{-}_{GER} (−1)	0.298 *	0.151
D CEE_{GER} (−1)	0.113	0.083
D NVA^{+}_{GER} (−5)	0.464 ***	0.181
D CEE_{GER} (−6)	−0.223	0.140
D NVA^{+}_{GER} (−1)	0.586 **	0.187
D NVA^{-}_{GER} (−5)	−1.007 ***	0.201
D CEE_{GER} (−5)	−0.983 ***	0.174
D NVA^{-}_{GER}	0.112 **	0.046
D NVA^{+}_{GER} (−4)	1.168 ***	0.197
D NVA^{-}_{GER} (−2)	0.497 **	0.186
D CEE_{GER} (−3)	−0.822 ***	0.141
D NVA^{-}_{GER} (−6)	−1.155 ***	0.274
D_1986	−0.155 **	0.064
D NVA^{-}_{GER} (−4)	−0.4395 **	0.176
D_1998	−0.202 **	0.069
D NVA^{+}_{GER} (−6)	0.3497 *	0.163
D NVA^{+}_{GER} (−3)	0.517 **	0.159
D_2004	0.315 ***	0.059
D NVA^{+}_{GER}	−0.956 ***	0.203
W_{LR}	3.419159 * (0.0644)	
L^{+} w	−3.451 *** (0.000)	
L^{-} w	−4.561 *** (0.000)	
W_{SR}	19.404 *** (0.000)	
Pss	12.24735 *** (0.0016)	
ARCH	5.751 (0.1244)	
BG	6.710857 * (0.0763)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance D-year denotes dummy variable, while S-year denotes seasonal dummy variable The parentheses denote the *p*-values.

Table 8. NARDL Estimation results for the United Kingdom.

Variable	Coefficient	Std. Error
C	1.386358 **	0.379667
NVA^{-}_{UK} (−1)	−1.460268 ***	0.311756
NVA^{+}_{UK} (−1)	−0.347307 **	0.137026
CEE_{UK} (−1)	−0.335171 *	0.138687
$DCEE_{UK}$ (−4)	0.522842 **	0.154422
D_2006	−0.382427 ***	0.077645
$DCEE_{UK}$ (−3)	0.906940 **	0.155460
D NVA^{-}_{UK} (−5)	1.804910 ***	0.389180
D NVA^{+}_{UK} (−8)	0.766567 ***	0.151332
D NVA^{+}_{UK} (−6)	0.389050 **	0.128983
D NVA^{+}_{UK} (−7)	−1.550402 ***	0.334756
$DCEE_{UK}$ (−5)	1.279123 ***	0.229187
D NVA^{+}_{UK} (−1)	−1.116430 ***	0.198264
D NVA^{+}_{UK}	0.399833 **	0.136188
D_2000	0.636952 ***	0.103028
NVA^{-}_{UK} (−2)	1.936357 ***	0.366177
$DCEE_{UK}$ (−8)	−0.786072 ***	0.179954
NVA^{-}_{UK} (−4)	4.126965 ***	0.546447
$DCEE_{UK}$ (−1)	0.275924	0.170779
D NVA^{+}_{UK} (−3)	−0.302843	0.238409
D NVA^{-}_{UK} (−1)	2.853299 ***	0.440836
D NVA^{-}_{UK}	0.333163	0.200081
D NVA^{+}_{UK} (−4)	−1.309466 ***	0.271996
D_1993	−0.179180 **	0.066434
D NVA^{+}_{UK} (−2)	1.61081 ***	0.320704
$DCEE_{UK}$ (−6)	−1.366 ***	0.266191
D NVA^{-}_{UK} (−7)	5.135320 ***	0.776614
D NVA^{-}_{UK} (−3)	2.338461 ***	0.343106
W_{LR}		
L^{+} w	1.036737 ***(0.000)	
L^{-} w	4.358 ***(0.000)	
W_{SR}	51.362 ***(0.000)	
Pss	69.88 ***(0.000)	
ARCH	0.694(0.8746)	
BG	3.659 (0.16)	

* denotes reject of null hypothesis in 10% level of significance, ** denotes reject of null hypothesis in 5% level of significance, *** denotes reject of null hypothesis in 1% level of significance D-year denotes dummy variable, while S-year denotes seasonal dummy variable. The parentheses denote the *p*-values.

According to the results derived for the case of Germany, nonlinear cointegration among the variables employed is established and asymmetric adjustment in the long run as well as in the short run is validated. Finally, no problems of serial correlation or heteroscedasticity have been detected. Also, for the case of Germany, a number of structural breaks was validated including 1986, 1992, 1998, 2004 as statistically significant.

The last country, United Kingdom was selected as a sample country because it has a highly mechanized agricultural sector with a stable utilized agricultural area (UAA). Furthermore, the average size of a UK holding is 81 ha, which is significantly higher than much of the rest of Europe, including countries such as France and Germany, according to statistics gathered by the EU.

The estimation of NARDL model has provided us with the following results presented in Table 8.

According to the results presented above nonlinear cointegration is validated, with no problems of serial correlation or heteroscedasticity, asymmetry in the long run as well as in the short run. Furthermore, the agricultural income evidently affects the carbon emissions in a negative way, that is an increase in agricultural income leads to a decrease in carbon emissions.

To synopsize, similar results were derived for all the sample countries with the exception of the countries of Greece, and Bulgaria. Therefore the NARDL methodology has provided conflict results regarding the validity of environmental Kuznets curve for all the countries with a well-developed agricultural sector and medium to high agricultural income.

6. Conclusions

The present manuscript surveys the behavior of carbon emissions equivalent generated by agriculture as a function of agricultural income per capita for the same sector. According to our findings, cointegration among the two variables is established in all instances and asymmetric impact of agricultural income on carbon emissions equivalent (millions of tonnes) per 1000 hectares is validated in most cases. This particular result provides evidence of a strong relationship among GHG emissions and agricultural income. Therefore the non-linear relationship and the fact that the impact of positive and negative changes is not of the same magnitude are validated for our data. With the exception of the case of Bulgaria, variations in agricultural income result in a decrease of carbon emissions generated by agriculture. Furthermore, if carbon emissions increase the agricultural income increases at a far greater margin than if carbon emissions decrease. This particular result is more than evident in the case of Spain. This result provides us with an indication of a non sustainable agriculture. Furthermore, another important finding concerns Greece, where carbon emissions decrease more significantly during negative shocks compared to the positive ones.

The statistical significance of impulse dummy variables is indicative of the impact of CAP reforms and the adoption of energy policy tools on the formation of agricultural income as well as for GHG emissions mitigation. Implicitly, in most cases, crucial milestones (CAP reforms) appear to have had a negative impact on income. However, the effect of EU policies on GHG emissions mitigation is somewhat mixed, a fact that stresses the need for more effective policy tools in order to secure sustainable economic growth. In addition, the present survey provided some evidence of the true relationship among agricultural income and carbon emissions, characterized by the existence of nonlinearities. Finally, with the result showing that the two variables are highly cointegrated, effective policy tools may promote the increase of agricultural income along with GHG effect mitigation, if the complex nature is accounted for a number of issues including; differences among Member States, different responses in the short run and the long run, asymmetric responses in positive and negative shocks and many others. However, the measures taken to limit GHG emissions from agricultural sector may vary in cost-effectiveness and practicality. To be more specific, measures that should be taken in order to reduce CO_2 emissions from soils or to enhance carbon sequestration involve the maintenance of permanent pasture, conservation tillage, appropriate crop rotation and cover crops [35].

The measures designed in order to be successful must be in line with the Circular Economy (CE) Package recently adopted by European Union. Therefore, for an environmentally friendly and sustainable agriculture industry, the measures taken should aim towards the limitation of the resource use, waste reduction and promotion of sustainable production and consumption [49]. The concept of a circular economy plays a key role for the sector of agriculture in order to enable the improvement of environmental quality, economic prosperity and social equity to be accomplished, for current and future generations. This strategy will assist the agricultural firms to mitigate the GHG effect through the limitation of negative externalities, securing eco–efficiency [36,50].

Author Contributions: Author Contributions: E.Z. and I.M. conceived and designed the econometric analysis. E.Z., G.A. and K.G. wrote the paper. All the authors analyzed the data.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest.

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