This is a postprint version of the following published document:

Zorrilla-Muñoz, V., Petz, M., & Agulló-Tomás, M. S. (2020). GARCH model to estimate the impact of agricultural greenhouse gas emissions per sociodemographic factors and CAP in Spain. *Environment, Development and Sustainability*, 23 (3), pp. 4675-4697.

DOI: 10.1007/s10668-020-00794-y

© 2020, Springer Nature B.V

GARCH model to estimate the impact of agricultural greenhouse gas emissions per sociodemographic factors and CAP in Spain

Vanesa Zorrilla-Muñoz[1,2,3] · **Marc Petz**[4] · **María Silveria Agulló-Tomás**[2,5]

Abstract
This contribution analyses the Common Agricultural Policy (CAP) and focuses on agricultural emissions in Spain regarding sociodemographic characteristics (age and sex). Spanish CAP covers emissions regulation based on the application of agriculture management according to the EU-ETS and agricultural management (soil and energy). The analysis of the Spanish legal rules and policy identified empirical environmental attitudes as provided by the EUROSTAT and MINETUR databases between 1990 and 2013. The developed empirical–analytical GARCH model measures the impact between the soil and energy management indicators per capita based on CAP (as independent variables) and emissions per capita (as dependent variable). The selected criteria of the models are sociodemographic variables corresponding to employee in agriculture: interval of age and sex (total, men and women who work in agriculture). The research findings demonstrate high significance between emissions per age interval, sex and total population, and fertilizers, herbicides and non-renewable energy or gases consumption. The CAP's proposed use of new machinery per capita does not influence directly the reduction of emissions. The model provides a good estimation for discussion about future policy trends of EU's long-term objectives for Rural Development Policy related to CAP principles (i.e. fertilizers, pesticides, land use and energy consumption in crops), the impact of machinery in agriculture and the open debate of extending work life in agricultural older population.

Keywords GHG · Agriculture · Sociodemographic factors (sex and age) · Agricultural machinery · Emissions · Soil and energy management

✉ Vanesa Zorrilla-Muñoz
vzorrill@ing.uc3m.es

1 Department of Mechanical Engineering, University Carlos III of Madrid, Leganés, Spain

2 Institute on Gender Studies, University Carlos III of Madrid, Getafe, Spain

3 Department of Applied Economics, Autonomous University of Madrid, Madrid, Spain

4 Department of Economics, University Carlos III of Madrid, Getafe, Spain

5 Department of Social Analysis, University Carlos III of Madrid, Getafe, Spain

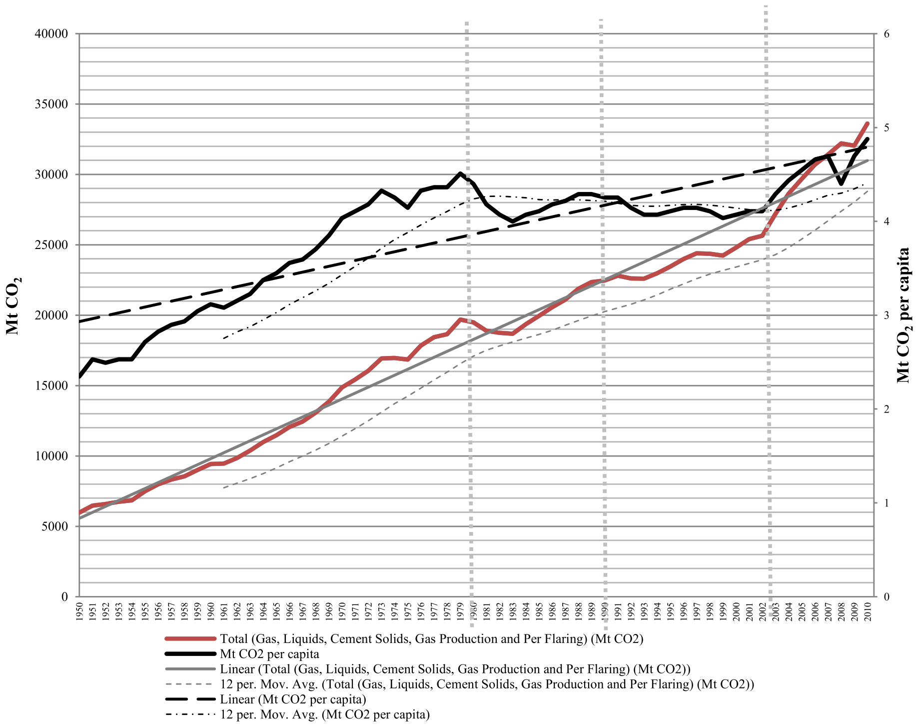

Fig. 1 Annual Global Fossil Fuel Carbon Emission since 1950: Mt of CO_2 emissions per capita and total in Mt CO_2 emissions (Boden et al. 2010)

1 Introduction

The WMO[1] (2014) recorded a worldwide increase by 34% in radiative forcing (warming effect on climate) between 1990 and 2013 because of long-lived greenhouse gases (i.e. in 2013: *carbon dioxide* (CO_2), 396.0 parts per million; *methane* (CH_4), 1824 parts per billion; and *nitrous oxide* (N_2O), 325.9 parts per billion).

Figure 1 illustrates the global greenhouse gases (GHGs) increase since 1950. The graph indicates the total of CO_2 emissions in millions of tonnes and the CO_2 emissions per capita emissions caused by fossil fuels.

Three periods characterize the global emissions: in the first period (1950–1980), CO_2 emissions per capita highly increase in accordance with the population growth. The second period (1980–2000) constitutes a period of CO_2 emissions per capita consolidation due to fossil fuels. During the third period (2000–2010), CO_2 emissions and population growth consolidated. However, the projections for CO_2 emissions are sensitive to the increase during this third phase. The increase of CO_2 emissions in the third period might correspond to several factors, like quick population and economic growth. The trend lines illustrate that total fossil fuels CO_2 emissions compared to the base year 1990 would be 34% higher in 2020, 53% higher in 2030 and 91% higher in 2050. Accordingly, the CO_2 emissions per

[1] World Meteorological Organization (WMO).

capita would be 19.21% higher in 2020, 26.5% higher in 2030 and 43.19% higher in 2050 than compared to the base year 1990.

In addition to health and global environmental effects, recent research revealed the impact of climate change on agriculture in economic dimensions or on plant adaptation (Huong et al. 2019; Fellmann et al. 2018; Aleixandre-Benavent et al. 2017; Zhang et al. 2017; Chen et al. 2016).

1.1 EU emissions trading system

Governments have implemented policies based on emissions mitigation due to the importance of environmental effects and its impact on climate change. In general, the reduction and elimination of greenhouse gases (GHGs) are central aspects for EU's emissions policy since decades. The EU generates $<10\%$ of the global GHG emissions each year and successfully continues decreasing its emissions since the implementation of the emissions trading system (ETS) based on the carbon pricing mechanisms in 2005 according to data from the Carbon Dioxide Information Analysis Center (compare Boden et al. 2010).

The EU-ETS refreshed the idea of George (1879) about the right for the exploitation of natural resources and the application of taxes[2] for this right (emission allowance/certificate) as a carbon pricing mechanism. However, the EU-ETS is more sophisticated than tax regulation: EU-ETS adopts a 'cap' (also named upper limit) as boundary element over the number of allowances and applies the method of allocating allowances by auctioning.

Caps provide the right of one tonne of carbon dioxide (CO_2), or the equivalent amount of two more powerful GHG (i.e. nitrous oxide (NO_2) and perfluorocarbons (PFCs) to each allowance. In this way, companies receive or buy emission certificates according to their requirements (COM 2014a). In sum, Europe has developed the world's biggest carbon market by the cap-and-trade mechanism (COM 2014b).

Initially, the EU-ETS was divided into two periods: the three-year period (phase I) covered from 1 January 2005 to 31 December 2007 and the five-year period (phase II) from 1 January 2008 to 31 December 2012. The EU-ETS utilizes the National Allocation Plans (NAPs) as implementation mechanism between EU Member States. Thus, '[…] for each period […], each Member State shall develop a national plan stating the total quantity of allowances that it intends to allocate for that period how it proposes to allocate them […]' (COM 2003). The EU Member States publish national and international data in public accessible databases as the result of the measure by the NAPs.

Phase I intended that the EU Member states comprehend their Kyoto emission targets regarding the United Nations Framework Convention on Climate Change (UNFCCC) (UN 1998) by compliment objectives and transparent criteria (COM 2014c) which are declared into directives. This phase covered a pilot test for the countries to prepare themselves for the next phase. The European Commission (EC) summarizes and underlines referring to the NAPs in general conclusion of phase I: 'The process was very time-consuming. The timely notification of NAPs to the Commission and timely final allocation decisions were needed to give companies certainty well before a trading period started. Another important

[2] George's theorem argues that the natural resources belong equally to all; therefore, land rent should be shared equally by people. Hence, he introduces the concept of the economic tax based on rents of the natural resources due to the allocation land. According to Stiglitz, this theorem is "[…] the single tax to finance the public good and also externalities such as carbon emissions […]" (Stiglitz 2010).

lesson was that the NAPs were too complex and not sufficiently transparent […]' (COM 2014c).

During phase II, the EC concentrated its efforts on resolving the transparency and simplicity of the NAPs. Member States reviewed their administrative rules incorporated in phase I for these proposals. In addition, the EC introduced several standardized tables to summarize key information comprised in the NAPs. It is also remarkable that phase II is coinciding with the second period of Kyoto Protocol. That proves the EU and its Member States were able to proportionate and meet their emissions targets and commitments as declared under the UNFCCC and the Kyoto Protocol (COM 2014c). Furthermore, phase II adopted legislation related to the aviation sector and set the cap on allowances, where aviation is enabled to opt for both forms of allowances for compliance purposes by installations: fixed or not fixed installations (COM 2014a).

The opinion among scientists concerning emissions policy is divided: There are several authors such as Böhringer et al. (2008), Martin et al. (2014) and Vlachou (2014) who relate the difficulties and the economic efficiency losses from the application of the EU-ETS on the free allocation 'cap and trade'. In addition, these authors provide discussions about the limitation of the restricted environmental effectiveness and the significant emission reduction during phases I and II. Meanwhile, Dietz et al. (2009) and Egenhofer (2007) concentrate on the benefits of incorporating behavioural mechanism for taking household and domestic actions for promoting the rapid carbon emissions reduction. Furthermore, Egenhofer highlights the possibility to enlarge forestry projects, or enabling carbon capture and storage projects in order to improve the Clean Development Mechanism (CDM) as future mechanism under the line of the Kyoto Protocol. EC policy has implemented ETS based on the GHG reduction for the development of a low-carbon economy based on decarbonized power sector (majorly attributed to fossil fuel energy consumption) by 2050. To achieve this scenario, the EC intends to replace partially fossil fuels (i.e. transport and heating by sustainable biofuels) and proposes innovation in cluster sectors (i.e. agriculture, industry or power generation) to increase the energy efficient and to reduce CO_2 emissions. Additionally, EC expects consumption of electricity only would continue to grow at historical maximal peak rates in the next decades due to prospective improvements in energy efficiency. In summary, the EU electricity plays the central role in the low-carbon economy and electricity may implement renewable energies significantly with the continuity of supply at all times (COM 2011).

Albeit, EU-ETS has mostly focused on the application of industrial processes such as energy or transport in the past, but approaches to include the agriculture sector under the reform of the EU-ETS system since 2013 by introducing a voluntary system for farming and agriculture, and rural development (COM 2013).

1.2 Agricultural greenhouse gases in the EU and Spain

Figure 2 provides an overview of EU-28 (without transport) and EU-27 (including transport) related to the GHG emissions per capita (measured in t CO_2 equivalent) in the main source sectors from 2005 to 2012. The data compiled represent the annual emissions of CO_2 equivalent (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) per capita from EU countries. Sector data are available for the following main source categories: Energy, Industrial Processes, Solvent and Other Product Use, Agriculture, Land-Use Change and Forestry (LULUCF), Waste and Transport. The most important sector is the energy industry (i.e. combustion and fugitive emissions) with a maximum peak of 4106.59 t in t CO_2 equivalent per capita

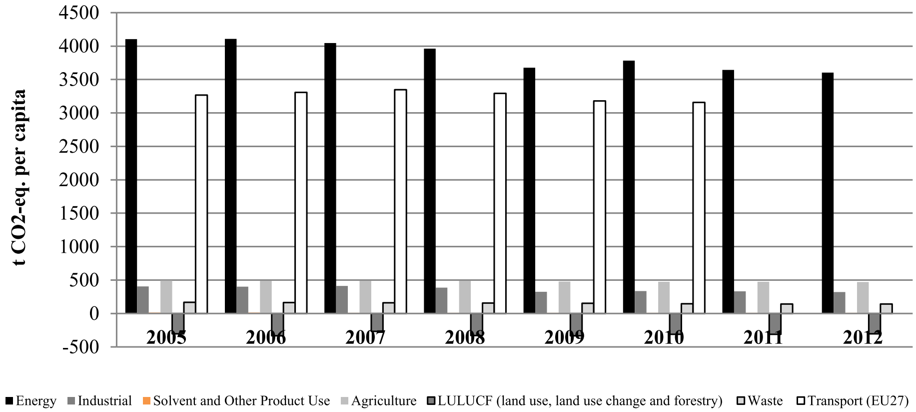

Fig. 2 GHG emissions per capita for EU28 and EU 27 (transport) in t CO_2-equivalent per capita, based on EEA (2014)

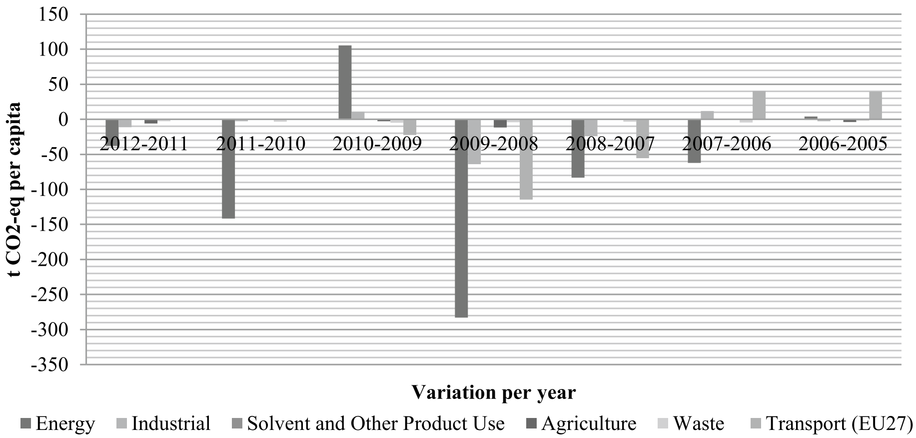

Fig. 3 Variation per year of GHG emissions in t CO_2-equivalent per capita for EU28 and EU27 (transport), based on EEA (2014)

in 2006. Furthermore, the energy industry represents 52.80% of the total EU-28 and EU-27 emissions during the period 2005–2012. Transport[3] is the second largest emission sector (2005–2012: 33.38%), followed by agriculture (2005–2012: 6.59%) and industrial processes (2005–2012: 4.98%)

Figure 3 illustrates the inter-annual variation. In general, total sector GHG emissions, without LULUCF, in the EU-28 (for transport EU-27) have decreased by 46.20% between 2005 and 2012. (Registered data indicate for 2012 a total of 4544.22 t CO_2 equivalents per capita.) Emissions representatively have been reduced by 1.28% (59 Mt CO_2 equivalents) between 2011 and 2012. The minimum peaks were reached in 2008–2009 where all sectors were affected, but especially energy, waste and industrial processes.

[3] Data for transport were available only for EU-27 and only for the years from 2005 to 2010.

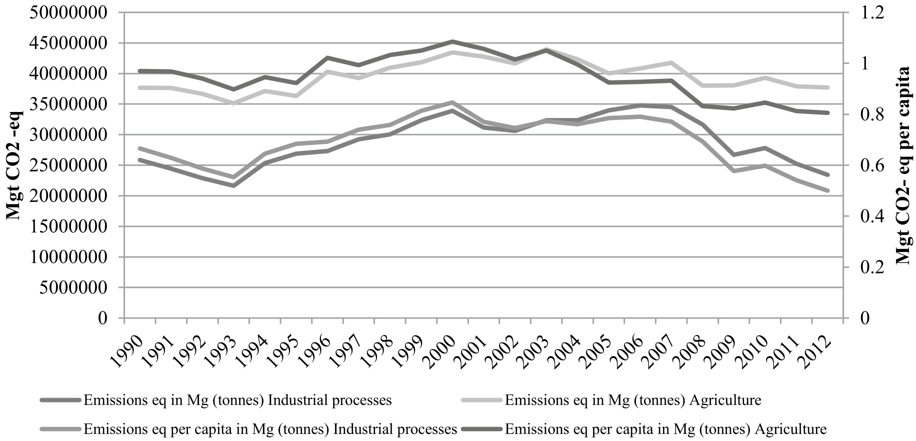

Fig. 4 Emissions and equivalent emissions for industrial processes and agriculture in Spain (1990–2012), based on EEA (2014)

The general world increase/decrease of emissions might be explained by following Tucker's (1995) argumentation that the CO_2 equivalent per capita drops if gross domestic product (GDP) per capita decreases and the economic deceleration is caused directly by a decrease in income. For this situation, the EC explains that energy and GDP trends in 2009 were the results of the economic downturn caused by the financial crisis, which produced the market's deterioration and the credit rationing, which resulted in a slowdown of private investment in all sectors (Capros et al. 2010).

However, CO_2-equivalent per capita continued growth in 2009–2010 after the decline in 2008–2009. Berghmans et al. (2014) underlines that the increase can be explained by '[…] a rebound in coal's competitiveness as a fuel for thermal power plants in Europe, particularly due to the export of the excess coal produced in the United States to Europe, and to the collapse in the carbon price in Europe, which no longer penalised coal-fired power plants in 2011 and 2012 […]'. This fact reveals the evident importance of how energy and industrial activities are contributing to the increase of emissions. Moreover, Maraseni (2009) explains the impact and general benefits (i.e. human behaviour, environmental and economic) from Australia's discussion about the relation between government strategy and introduction of an ETS in agriculture.

Figure 4 presents the Spanish emissions for two similar sectors in comparison according to the EU data: industrial processes and agriculture. According to the graph, emission in agriculture is a median variation superior (for the period 1990–2012) to 10,392,351.29 Mg tonnes, which is equal to the median variation value of 0.248 Mg tonnes per capita.

1.3 Agriculture policy in the EU and Spain

The European Agricultural Fund for Rural Development (EAFRD) (see COM 2012a) and the Common Agricultural Policy (CAP) establish and conduct primarily the proposals of Mansholt (1952) in order to modernize farming and raise efficiency (COM 2012b) by proposing the development of competitiveness, management, quality of life and assessment of the social, economic and environmental situation. The implementation of CAP differs among EU countries. The CAP policy has been implemented in Spain since 1986

Table 1 CAP systems of EU and Spain, based on COM (2015a)

Period	Policy characteristics in	
	EU	Spain[a]
The early years (60s)	Price support Productivity improvement Market stabilization	No effects of the EU policy Rural exodus and dictatorship
The crisis years (70s/80s)	Over-production Exploding expenditure Internal frictions Supply control	Spain joined the EU in 1986 Agrarian modernization based on technology
The 1992 REFORM	Price cuts and compensatory payments Surplus reduction Income and budget stabilization	Adopting compensatory payments Reduction of several crops and specialization
Agenda 2000	Deepening the reform process Rural development	Rural development based on eco practices
CAP REFORM 2003	Market orientation Decoupling Cross-compliance Consumer concerns Environment Enlargement	Adopting decoupling Management and good application practices Environmental conditionality Modulation on payments Rural development
CAP Health Check 2008	Reinforcing 2003 Reform Dairy Quotas	Reinforcing Reform in 2012 Capping quotas and limits
CAP Reform Post-2013	Greening Targeting Redistribution End of production constraints Food chain Research and innovation	

[a]Spanish policy characteristics according to CAP implementation

(Table 1). The CAP subsidizes the protection and safeguard of farming '[…] because of its multifunctional nature and the part it plays in the economy, the environment and society in general […]' (Gorman et al. 2001). Actually, the EU has emphasized and endorsed the multifunctional agricultural character in the third CAP generation, also called the current European Model of Agriculture. Since 2003, the CAP considers that agriculture and rural areas not only are producers of agricultural commodities, but also incorporate externalities such as environmental, social goods, food security and foster animal welfare (COM 2002). For Gómez-Limón et al. (2008), these goods mainly are of economic and social character but might improve society.

By this means, the agriculture strategies for the EU policy are focused on the implementation of new agriculture market models based on environmental management, sustainability cohesion, food security and policy efficiency (COM 2015a), which is corresponding to the framework integration of the DPSIR (Driving force, Pressure, State, Impact, Response) model of agriculture opportunities. The DPSIR provides a feasible model for agricultural management (Paustian et al. 1998) by including mitigation of the pressures and risks linked to environmental damages, like emissions or management soil (among others). Moreover, the future of the EU's common agriculture policy after 2020 is based on nine principles, where 'acting against climate change' continues being the top priority principle.

2 Methodology

This study proposes an empirical–analytical general autoregressive conditional heteroscedasticity (GARCH) model based on the stylized facts of GHG per capita during the period 1990–2012, focussing the argumentation that GHG emissions depend on different factors where the social concept might influence over the mitigation of GHG emissions. Under this perspective, this research proposes traditional variables of land use and management based on soil management (use of fertilizers, fungicides, insecticides, between others) and energy management, consumption of energy from fossil fuels, coals and gases resources, and number of new machinery for the production. The research addresses the research question in the following context 'What are the results of emissions regarding sociodemographic characteristics of agricultural workers (age and sex) and agricultural management in Spain?' and 'Which are the variables that most affect GHG related to land use and management?'.

This article aims to test the following hypotheses: 'There is an effect on emissions related to agricultural management (soil and energy management) and sociodemographic characteristics of agricultural workers' based on the first research question. The stipulated hypothesis consists of two sub-hypotheses: 'New technology used in machinery (tractors, tillers and harvesters) or old technology used (defined by oil consumption) do not influence directly the emissions' and 'However, energy and fertilizers consumption influence directly the emissions'.

This research provides a statistic–analytical analysis based on public data, which includes sociodemographic characteristics and social environmental management variables. Table 2 illustrates the selected key indicators and variables related to management and emissions in agriculture based on EU CAP policy (Table 1). The research analysis estimates emissions equivalents for agriculture in Spain due to the use of fertilizers,[4] pesticides,[5] and emissions equivalents for agriculture and agricultural energy management.[6] The study collects data from Eurostat (2016) and MINETUR (2016) between 1990 and 2013.

The research adapts Tucker's (1995) theory about the variation of emissions per capita $\left(\Delta \frac{CO_2}{pop}\right)$ for the inclusion of sociodemographic aspects in the proposed model.

The GARCH model is based on the GHG equivalencies obtained by the emission conversion factor when energy data are available (Spellman 2015). Accordingly, the GARCH composes total emissions into a linear regression model. Available energy economic literature, for example Pao and Tsai (2011), proposes regression analysis to be an adequate analysis procedure for dependency of energy emissions. Emissions equivalents per capita depend directly on energy management (Table 2, variables *Z*, coals, oil, gases and electricity) and soil management (Table 2, variables *C*, *D*, *E*, *F* and *G*). The variables of energy and soil management are converted into emissions by applying physical properties of conversion factors (i.e. emissions of electricity are obtained by multiplying a coefficient per KTOE of electricity).

[4] Fertilizers include nitrogen, phosphorus, phosphate, potassium and potash.

[5] Pesticides include herbicides, fungicides, bactericides and insecticides.

[6] Agriculture and agricultural energy management include total of new tractors, tillers and cereal harvesters, consumption of energy from coals, fossil fuel oils, gases resources and non-renewable electrical resources.

Table 2 Selected key indicators, variables and metric unit

Key indicator	Variable	Metric unit
Soil management (Altieri 1995; White et al. 2014; Klein et al. 2014)	*C*: Consumption estimate of manufactured fertilizers nitrogen	Tonnes
	D: Consumption estimate of manufactured fertilizers phosphorous	Tonnes
	E: Consumption estimate of manufactured fertilizers phosphate	Tonnes
	F: Consumption estimate of manufactured fertilizers potassium	Tonnes
	G: Consumption estimate of manufactured fertilizers potash	Tonnes
	HE: herbicides	Tonnes of active ingredient
	B: Fungicides and bactericides	Tonnes of active ingredient
	S: Insecticides	Tonnes of active ingredient
Emissions (Papanicolaou et al. 2013; Bennetzen et al. 2016; Leakey 2012; Boody et al. 2005)	*H*: Agricultural gross greenhouse gas emissions [TOTAL]	Millions of CO_2 tonnes equivalent
Energy management (Tung and Pai 2015; Stout 1984; Boody et al. 2005; Meul et al. 2007)	*Z*: total new machinery for the production used (tractors, tillers and harvesters)	Millions of horsepower
	Coals: consumption of energy from coals (including coal, anthracite and agglomerated)	Kilotonne of oil equivalent KTOE
	Oil: consumption of energy from fossil fuel oils (including liquefied petroleum gas, kerosene, diesel and fuel oil)	KTOE
	Gases: consumption of energy from gases resources	KTOE
	Electricity: consumption of energy from electrical resources (non-renewable)	KTOE

Table 3 Agricultural sociodemographic characteristics analysed (in thousands)

Agricultural sociodemographic characteristics (in thousands)	[Mean ± SD]	95% Conf. interval	
		Min	Max
Total agricultural employee population	1172.91 ± 139.05	882.84	1462.96
Agricultural employee men	762.29 ± 26.69	706.62	817.98
Agricultural employee women	410.61 ± 132.46	134.29	686.91
Employee from 16 to 19 years	31.42 ± 2.61	25.96	36.87
Employee from 20 to 29 years	164.03 ± 6.00	151.51	176.54
Employee from 30 to 39 years	225.48 ± 4.02	217.10	233.86
Employee from 40 to 49 years	236.26 ± 4.67	226.51	246.01
Employee from 50 to 59 years	243.42 ± 15.35	211.40	275.44
Employee from 60 to 64 years	110.25 ± 8.81	91.87	128.62
Employee => 65 years	45.45 ± 13.73	16.81	74.09

The GARCH model estimates agricultural gross GHG emissions per capita because of the time-series character of the compiled data. This model provides a flexible structure to prove the conditional covariance matrix based on the equation of Bollerslev et al. (1988). The following equation defines the model as:

$$\left(\frac{H}{\text{pop1}}\right)_t = \alpha\left(\frac{Z}{\text{pop}}\right)_{t-1} + \beta\left(\frac{X}{\text{pop}}\right)_{t-2} + \gamma\left(\frac{\text{Coals}}{\text{pop}}\right)_{t-3} + \delta\left(\frac{\text{Oil}}{\text{pop}}\right)_{t-4} + \theta\left(\frac{\text{Gases}}{\text{pop}}\right)_{t-6} + \cdots + \varepsilon_t \quad (1)$$

where ‘pop1’ represents the variable agricultural population sex and interval of age under the selection of different models and ‘pop’ refers to the total agricultural population (per capita). The research identifies variables considering different types of agriculture population (i.e. by total, men, women and the different age intervals). The variable ‘type of population (pop1)’ represents the coefficient, which divides ‘agricultural gross GHG emissions (*H*)’.

Table 3 illustrates the distribution of the selected characteristics and data referred to the sex and age for employment in thousand between 1990 and 2013. These agricultural sociodemographic characteristics cover the population of agricultural workers men and women and the population age distribution from 16 to > 65 years.

Table 4 represents the Pearson correlation for the variables: total agricultural gross GHG per thousands of populations (*H*) represented by (Table 2) dividing by the sociodemographic characteristics (Table 3) in correlation with:

- Total of new machinery for the production per capita (*Z*/pop),
- Consumed energy from coals per capita (coals/pop),
- Fuel fossil oil per capita (oil/pop),
- Consumption of gases (natural gas) per capita (gases/pop),
- Consumption of electrical (non-renewable) sources per capita (elec/pop),
- Consumption of fertilizers per capita (*C*/pop, *D*/pop, *E*/pop, *F*/pop, and *G*/pop), and
- Consumption of pesticides per capita (*S*/pop, *B*/pop and *HE*/pop).

Table 4 Pearson correlation between variables

	Z/pop	Coals/pop	Oil/pop	Gases/pop	Elec/pop	C/pop	D/pop	E/pop	F/pop	G/pop	S/pop	B/pop	HE/pop
H/total (men + women)	0.9375**	−0.4386**	0.9266**	0.6470**	0.8922**	0.8989**	0.6153**	0.6156**	0.7351**	0.7349**	0.7735**	0.6756**	0.8124**
H/men	0.9374**	−0.6048**	0.8809**	0.7133**	0.8486**	0.8136**	0.4071*	0.4076*	0.5665**	0.5662**	0.7133**	0.6757**	0.7186**
H/women	0.9465**	−0.4015	0.9430**	0.6416**	0.9089**	0.9236**	0.6822**	0.6824**	0.7871**	0.7870**	0.7888**	0.7052**	0.8455**
H/16–19 years population	0.9965**	−0.3437	0.9852**	0.9199**	0.9656**	0.9796**	0.9165**	0.9163**	0.9461**	0.9460**	0.8656**	0.9363**	0.9756**
H/20–29 years population	0.9772**	−0.4737*	0.9230**	0.8163**	0.8705**	0.8918**	0.5142*	0.5137*	0.6705**	0.6702**	0.6925**	0.8370**	0.8653**
H/30–39 years population	0.8283**	−0.3554	0.4836*	0.6362**	0.3989	0.4752*	0.0403	0.0401	0.1493	0.1489	0.0800	0.7160**	0.4655*
H/40–49 years population	0.7372**	−0.6820**	0.7060**	0.3069	0.6910**	0.7171**	0.4543*	0.4551*	0.5513**	0.5508**	0.5627**	0.3453	0.2112
H/50–59 years population	0.9503**	−0.6079**	0.9347**	0.6784**	0.9131**	0.9040**	0.6118**	0.6121**	0.7358**	0.7357**	0.8295**	0.6576**	0.8205**
H/60–64 years population	0.9694**	−0.4900*	0.9584**	0.7649**	0.9359**	0.9481**	0.7491**	0.7491**	0.8379**	0.8378**	0.8525**	0.7462**	0.8991**
H/=>65 years population	0.9761**	−0.4076*	0.9730**	0.7794**	0.9585**	0.9716**	0.8629**	0.8627**	0.9095**	0.7349**	0.8813**	0.8258**	0.9452**

Significance levels *($p < 0.05$) and **($p < 0.01$)

B fungicides and bactericides, *C* consumption estimate of manufactured fertilizers nitrogen, *Coals* consumption of energy from coals, *D* consumption estimate of manufactured fertilizers phosphorous, *E* consumption estimate of manufactured fertilizers phosphate, *Elec* consumption of energy from electrical resources (non-renewable), *F* consumption estimate of manufactured fertilizers Potassium, *G* consumption estimate of manufactured fertilizers potash, *Gases* consumption of energy from gases resources, *H* agricultural gross greenhouse gas emissions [TOTAL], *HE* herbicides, *Oil* consumption of energy from fossil fuel oils, *S* insecticides, *Z* total of new tractors, tillers and cereal harvesters used

The results of the obtained coefficients demonstrate that linear regression is a suitable method to analyse the available data.

3 Research findings

The GARCH model analysis compares models (I) and (II) on the basis of available data from 1990 to 2013. Table 5 illustrates the results of model (I) including the use of new tractors, harvesters and tillers (*Z*/pop) with equations from (a) to (j). Table 6 represents model (II) including energy consumption from fossil fuels (oil/pop) in major relationship to old machinery with equations from (k) and (t). Model (II) excludes in its equations between (k) and (t) the variable total of new tractors, tillers and cereal harvesters used per capita (*Z*/pop) for the emissions per population type (*H*/pop1); meanwhile, model (I) excludes vice versa in its equations between (a) and (j) the variable consumption of energy from fossil fuels oils per capita (oil/pop). The computed results suggest links between the active work population in different contexts (sex and interval of age) and the selected key indicators (compare Table 2).

The likelihood ratio test allows rejecting the null hypothesis for regressions if the statistics value is small (near zero). Thus, equations (a), (b), (k) and (l) indicate better fitting regressions in comparison with the rest of the equations due to the likelihood ratio values (closer to zero). For instance, the restrictions (a) with the likelihood ratio = −32.096 and equation (k) with the likelihood ratio = −30.886 are smaller than restriction (b) with a likelihood ratio = −39.693 and (l) with a likelihood ratio = −39.524. The most unfitting regressions are equations (d) (likelihood = −119.875), (n) (likelihood = −120.384), (j) (likelihood = −120.512) and (t) (likelihood = −120.657). The result findings are reasonable because there are a smaller number of employees aged between 16 and 19 and over 65 years.

The Akaike (AIC) and the Bayesian (BIC) information criteria provide a measure to fit the computed equations in the models. The better fitting calculated equations are (a) (AIC = 92.19219; BIC = 108.6849) and (k) (AIC = 89.77228; BIC = 106.265). Thus, AIC and BIC for equations (d), (n), (j) and (t) are worse than the other calculations.

The interpretation of all equations in both models is that there are highly significant levels regarding fertilizers and energy consumption, independently of the age population, although there are exceptions in the models: There is no relevant significance in the interval of age between 60 and 64 years. For the best equations (a) and (k), the results reveal a high significance level ($p < 0.01$) in the variables nitrogen per capita (*C*/pop), herbicides per capita (*HE*/pop), consumption of energy from gases resources (gases/pop) and consumption of electricity from non-renewable resources per capita (Elec/pop). The results demonstrate high correlation for all variables with R-squared round 0.90 or higher and white noise disturbance is different to zero.

In comparison between men and women, both models fit better for men (compare AIC and BIC). Furthermore, men and women differ in use of fertilizers (i.e. in model (II) when old machinery is used, consumption estimate of manufactured fertilizers phosphorous (*D*/pop) is 0.9100 for men and 0.4516 for women). Only the consumption estimate of manufactured fertilizers nitrogen (*C*/pop) does not differ in both sexes. In both models, men have obtained better significance levels than women; in the case of consumption of energy from coals (Coals/pop) ($p < 0.1$), they use new or old machinery. New machinery applies (*Z*/pop)

Table 5 Results of the GARCH model (I)

Independent variable	Dependent variable (*H*/pop1)									
	(a) *H*/total	(b) *H*/men	(c) *H*/women	(d) *H*/16–19 years	(e) *H*/20–29 years	(f) *H*/30–39 years	(g) *H*/40–49 years	(h) *H*/50–59 years	(i) *H*/60–64 years	(j) *H*/=>65 years
Z/pop	.6707838	1.089601*	.6989576	.8758946	1.103424*	1.342699**	.8453855	.7218655	.5843998	.5771157
	(.5550464)	(.5963415)	(.5393059)	(.6086098)	(.6047759)	(.5253347)	(.5385543)	(.6142973)	(.6156735)	(.5648188)
C/pop	.0110524***	.0087149**	.0105142***	.0061528**	.0083306**	.0066888*	.0104382***	.010906***	.0115631	.0105713***
	(.0036162)	(.0037666)	(.0034746)	(.0031254)	(.003706)	(.0036229)	(.0036624)	(.0038731)	(.0036555)	(.0034238)
D/pop	−.2997096	.3216702	−.2528724	.9283855	.2568039	.0801784	.6519578	.2792575	.1830683	.2031423
	(.9223534)	(.8648288)	(.8975552)	(.8671598)	(.7910086)	(.8101888)	(.8309768)	(.9146355)	(.9897901)	(.8353083)
E/pop	.1182019	−.1249973	.0960261	−.3967103	−.1069575	−.0275486	−.2640485	−.1127099	−.0711246	−.079016
	(.3981377)	(.3763731)	(.3876375)	(.3752975)	(.3447197)	(.3538656)	(.3612583)	(.3975145)	(.430942)	(.3643455)
F/pop	.5161933	−.007117	.526345	−.1007459	.8411271	−.1366757	-.1606567	−.0034342	−.0526067	.0024733
	(.9575312)	(.9321146)	(.9420266)	(1.048104)	(.891627)	(.9099909)	(.8636005)	(.9623003)	(1.056552)	(.0237317)
G/pop	−.400704	−.0057573	−.4062572	.0833955	−.6968569	.1141161	.1119539	−.0022121	.0378398	−.0306756**
	(.7874601)	(.76932)	(.7747508)	(.8635106)	(.7396873)	(.752653)	(.7127085)	(.7941659)	(.8716754)	(.0149971)
S/pop	.1706404	.3838087**	.1660206	.573846***	.2494933	.0853687	.4056449**	.416346**	.4439576	.5068449**
	(.204518)	(.1815071)	(.2002661)	(.1738376)	(.1649266)	(.1761853)	(.1818912)	(.1928962)	(.1987487)	(.2071665)
B/pop	.153447*	.1115716	.1593612*	.2117146***	.1448246*	.0761088	.1379553	.1399932	.1433126	.1900649**
	(.0861117)	(.0867638)	(.0840689)	(.0738722)	(.0826685)	(.0860569)	(.0868075)	(.0883999)	(.0931113)	(.0797534)
HE/pop	.5917721***	.4178413**	.5545717***	.5728763***	.4611769**	.3627878*	.2542746	.5465513***	.5911135	.4389696**
	(.1628292)	(.2095575)	(.1621422)	(.2100721)	(.1927437)	(.1878187)	(.2191581)	(.2072996)	(.198778)	(.209267)
Coals/pop	−.0984426	−.5733353*	−.1046074	−.6758215*	.3720791*	−.2443418	−.7472923**	−.5268685	−.5372249	−.5777964
	(.3083345)	(.3097064)	(.2979899)	(.3837938)	(.2268081)	(.2129377)	(.3212699)	(.3717471)	(.367316)	(.4061751)
Gases/pop	−.6611261***	−.2856278	−.667429***	−.5299831**	−.66755***	−.3678684*	−.3450656*	−.4061575*	−.4049155	−.3952141*
	(.204693)	(.2429141)	(.1904549)	(.2248463)	(.2442865)	(.2103878)	(.2049757)	(.2252207)	(.2393108)	(.2161668)

Table 5 (continued)

Independent variable	Dependent variable (H/pop1)									
	(a) *H*/total	(b) *H*/men	(c) *H*/women	(d) *H*/16–19 years	(e) *H*/20–29 years	(f) *H*/30–39 years	(g) *H*/40–49 years	(h) *H*/50–59 years	(i) *H*/60–64 years	(j) *H*/=>65 years
Elec/pop	.2728687***	.1878059***	.2726905***	.2001525***	.150559***	.1507385**	.1592669***	.2233154***	.2317825	.241795***
	(.0542265)	(.0585508)	(.0505152)	(.0530236)	(.0697787)	(.0633029)	(.0614112)	(.0522722)	(.0523087)	(.0475072)
Const	.0966213	6.331886*	2.032509	84.56555*	4.542221	43.66389**	36.04228**	8.55139	15.42657	83.28237*
	(1.207661)	(3.542725)	(3.439292)	(50.63159)	(13.72341)	(18.82863)	(15.64567)	(7.615052)	(12.59866)	(45.70917)
Likelihood	−32.096097	−39.692906	−63.483617	−119.87554	−77.484295	−67.481705	−66.357118	−68.729219	−89.525811	−120.51203
White noise disturbance	.2451368	.4618036	3.354008	368.5013	10.75813	4.675607	4.260659	5.19221	29.37514	388.5162
R^2	.99154106	.98521552	.99379608	.9990032	.99182903	.90902858	.96013106	.99226902	.99572915	.99760006
AIC	92.19219	107.3858	154.9672	267.7511	182.9686	162.9634	160.7142	165.4584	207.0516	269.0241
BIC	108.6849	123.8786	171.46	284.2438	199.4613	179.4562	177.207	181.9512	223.5444	285.5168

Standard errors are in ()

*, ** and ***, respectively, refer to the 10% ($p < 0.1$), 5% ($p < 0.05$) and 1% ($p < 0.01$) significance levels of estimated coefficients

Table 6 Results of the GARCH model (II)

Independent variable	Dependent variable (*H*/pop1)									
	(k) *H*/total	(l) *H*/men	(m) *H*/women	(n) *H*/16–19 years	(o) *H*/20–29 years	(p) *H*/30–39 years	(q) *H*/40–49 years	(r) *H*/50–59 years	(s) *H*/60–64 years	(t) *H*/=>65 years
C/pop	.0145302***	.0143501***	.0138177***	.0096417***	.0128456***	.0136611***	.0147546***	.014943***	.0140991	.0134196***
	(.0029291)	(.0031555)	(.0028827)	(.0021647)	(.00294)	(.0033343)	(.00326)	(.0030733)	(.0028332)	(.0025761)
D/pop	.3484627	.9100542	.4516676	1.667859**	1.158496	1.032105	1.05553	.7332647	.7840091	.798386
	(.8909679)	(.8552222)	(.894683)	(.8527418)	(.8447158)	(.7923548)	(.8024934)	(.8890898)	(.9828384)	(.9337972)
E/pop	−.1598121	−.3891047	−.2044682	−.7212656**	−.4960258	−.4378934	−.4418154	−.3150059	−.3368098	−.3400342
	(.3833625)	(.3714063)	(.3848487)	(.3675646)	(.3653583)	(.3449584)	(.3486365)	(.3859089)	(.4275275)	(.4052709)
F/pop	.4952817	.1336226	.3993625	−.3391708	.0259681	.2168478	−.0331708	.080283	−.2136392	−.0067925
	(.9043513)	(.9367877)	(.9047123)	(1.044475)	(.9376872)	(.9355878)	(.8587278)	(.9332078)	(1.012759)	(.0260469)
G/pop	−.4013816	−.1248326	−.3214289	.2770708	−.0364727	−.2015851	−.0034136	−.0761289	.1695683	−.0224323
	(.7443859)	(.7736425)	(.7446804)	(.8609331)	(.7741973)	(.7761567)	(.7096695)	(.7705769)	(.8355213)	(.0153191)
S/pop	.2884185*	.4461655***	.3230165**	.6267617***	.5161123***	.4267344***	.5121457***	.4216851**	.469576	.5784639***
	(.1706312)	(.1653579)	(.1650841)	(.1695001)	(.1572176)	(.14573)	(.1488639)	(.1737438)	(.1817739)	(.1858399)
B/pop	.24202***	.2306218***	.2475941***	.2810156***	.2540445***	.2357592***	.2404273***	.2241078***	.2194148	.2602839***
	(.0618534)	(.0649811)	(.0621144)	(.061323)	(.0634245)	(.0675613)	(.0651296)	(.0642465)	(.0681606)	(.0628592)
HE/pop	.5744243***	.6101459***	.5529084***	.6956946***	.5953915***	.5402628***	.3624826*	.636758***	.6299841	.47659**
	(.1504515)	(.1797528)	(.1534338)	(.1868509)	(.1638907)	(.1727817)	(.2141154)	(.1765678)	(.1845153)	(.2011581)
Coals/pop	−.309347	−.540402*	−.36118	−.7041852*	−.6268983**	−.5840311***	−.8163558***	−.4555246	−.5844579	−.6470738*
	(.2820641)	(.3103405)	(.2773153)	(.3912729)	(.300321)	(.1881372)	(.300239)	(.3650072)	(.3539498)	(.4040279)
Oil/pop	.3992246**	.4467175*	.3604134*	.2309675	.4313118**	.5436723**	.400448*	.3891954*	.2401001	.2223064
	(.1957324)	(.2314999)	(.2027633)	(.232363)	(.2200366)	(.2124904)	(.2194505)	(.2249466)	(.2223143)	(.257894)
Gases/pop	−.851932***	−.756064***	−.824607***	−.841678***	−.762271***	−.7474238***	−.5856634**	−.7456437***	−.6635724	−.5955716**
	(.1987467)	(.2697015)	(.1898637)	(.2316635)	(.2196706)	(.2254491	(.2290732)	(.2450253)	(.2696003)	(.2539986)
Elec/pop	.2100157***	.1701292***	.2125019***	.2049436***	.1617044**	.1426582**	.1317009**	.1827592***	.2141993	.2145556***
	(.0644609)	(.0625663)	(.0661254)	(.0606849)	(.0654953)	(.0649018)	(.0654789)	(.0601442)	(.0596395)	(.0686264)

Table 6 (continued)

Independent variable	Dependent variable (*H*/pop1)									
	(k) *H*/total	(l) *H*/men	(m) *H*/women	(n) *H*/16–19 years	(o) *H*/20–29 years	(p) *H*/30–39 years	(q) *H*/40–49 years	(r) *H*/50–59 years	(s) *H*/60–64 years	(t) *H*/=>65 years
Const	−.5713323	−.0563647	.537227	24.01046	5.503687	8.064587	21.57085	−1.666221	4.91856	53.22724
	(1.14021)	(3.805317)	(3.32679)	(42.65987)	(13.1921)	(20.75445)	(17.68384)	(7.902024)	(13.13158)	(47.0631)
Likelihood	−30.886141	−39.524461	−62.811602	−120.38464	−77.039621	−67.475436	−65.970736	−67.989811	−89.398808	−120.65707
White noise disturbance	.2217314	.4555364	3.170446	3.844777	10.38027	4.67684	4.126263	4.882504	29.06061	393.2266
R^2	.99235238	.9854216	.99413396	.99896	.99182903	.90907607	.96139427	.992731	.99529404	.99774667
AIC	89.77228	107.0489	153.6232	268.7693	182.0792	162.9509	159.9415	163.9796	206.7976	269.3141
BIC	106.265	123.5417	170.116	285.262	198.572	179.4436	176.4342	180.4724	223.2904	285.8069

Standard errors are in ()

*, ** and ***, respectively, refer to the 10% ($p<0.1$), 5% ($p<0.05$) and 1% ($p<0.01$) significance levels of estimated coefficient

which is used in model (I) of Table 5, and old machinery depends on oil consumption (oil/pop) which is used in model (II) of Table 6.

The 20–39 years agers have comparatively a higher significance level in the use of new machinery than the rest of the population (*Z*/pop with $p < 0.1$ for 20–29 years and *Z*/pop with $p < 0.05$ for 30–39 years).

There are also differences due to the inclusion of new tractors, tillers and cereal harvests used per capita (*Z*/pop) for the age range of 30–39 years (equations (f) and (p)). The significances increased when *Z*/pop is not used (for insecticides per capita (*S*/pop), fungicides and bactericides per capita (*B*/pop) and consumption of energy from coals per capita (Coals/pop with $p < 0.01$).

Finally, the use of new machinery in model (I) (Table 5) has reduced significance in the application of insecticides (*S*/pop) in comparison with model (II) with fossil fuel consumption (Table 6).

4 Discussion

The European discussion about emissions focuses on the substitution between oil and old machinery (i.e. Low-Carbon Technology Roadmap). According to that, this paper highlights that oil is not the only variable influencing emissions in agriculture: consumption electricity of non-renewable resources and gases, herbicides and fertilizers such as nitrogen has a high influence on emissions per capita. Specifically, the research findings demonstrate that emissions are directly influenced by the consumption estimate of manufactured fertilizers per capita (*C*/pop), herbicides per capita (*HE*/pop), consumption of energy from gases resources (Gases/pop) and consumption of energy from non-renewable electrical resources per capita (Elec/pop). These results coincide with the open debate about land use and management, where European policy has identified farmers as main drives of good practices to develop an innovative and sustainable agriculture. In this context of good practices, it should be underlined that Paustian et al. (1998) mentioned the importance of agriculture to mitigate emissions by considering changes in land use and management, which contribute to the sustainable intensification (Schulte et al. 2014; Coyle et al. 2016). In addition, OECD (2001) proposes a reflection of non-commodities effects by promoting land conservation, cultural heritage and animal welfare, maintaining of landscape configuration, supporting natural resources management (water, soil and air) in cultivations, eluding GHG, preventing biodiversity and underlying the rural socioeconomic development goal-oriented term of multifunctionality related to multi-dimensional framework of sustainability (Pope et al. 2017). Moreover, the OECD (2001) proposes under the concept of multifunctional agriculture by '[…] supporting natural resources management (water, soil and air) in cultivations, eluding GHG […]'.

The model points towards nitrogen as the most related fertilizer with high significance. Fertilizers consumption influences emissions. Under other perspective, recent authors have remarks that the different types of fertilization—mainly nitrogenous fertilizers (compare Fagodiya et al. 2017; Kalkhoran et al. 2019)—have increased the effects on emissions under the climate temperature conditions and water management (compare Aguilera et al. 2013; Meijide et al. 2017). This study also suggests the inclusion of a new interpretation paradigm of management with the integration of energy consumption. Future research could develop the inclusion of all indicators: soil management, water management, energy management and Mediterranean climatological conditions. Moreover, this model might be applied for future retrospective studies based on the consolidation of organic fertilizers.

The results confirm that new technology used in machinery (tractors, tillers and harvesters) or old technology used (defined by oil consumption) does not influence directly the emissions. The model considers new technology as actually implemented in Spain, but according to the GARCH research findings it seems not to be enough to mitigate emissions. In addition, traditional energy consumption (coals, gases and non-renewable electricity) could affect directly the emissions independently of the interval of age or sex. Within this context, Europe regulation related to wheeled agricultural or forestry tractors is seeking to harmonize the process of machinery certification in a new grade of European vehicle fleet of an environmentally sustainable future. Thus, implementation of renewable energy (i.e. crop–biofuels or electricity of renewable resources) could mitigate the emissions as EC has proposed through the directives of 2030 Energy Strategy, which could be integrated by the policymakers for the wheeled agricultural and forestry tractors.

Although previous authors analyse the impact of emissions and demonstrate the correlation between population and emissions (i.e. Heilig 1994; Tucker 1995; Gaffin and O'Neill 1997; Meyerson 1998; Cramer and Cheney 2000; Shi 2003; Cole and Neumayer 2004; Jogerson and Clark 2010; Menz and Kühling 2011; Bento and Moutinho 2016; Apergis and Payne 2017; Patiño et al. 2019), there are few agricultural studies available proposing GHG per capita analysis. Previous researches (i.e. Liddle and Lung 2010; Menz and Welsch 2012; Okada 2012; Liddle 2013, 2014) define sociodemographic variables in relation to emissions. Moreover, few authors analyse the impact of age population (i.e. Yu et al. 2017), but Zagheni (2011) has demonstrated that age of population affects directly the emissions results: older age could help to reduce global emissions. This paradigm could be addressed to agriculture. The innovation of this article is to consider agricultural emissions per capita and sociodemographic variables of farmers (sex and age interval). The results of this paper demonstrate that older persons could not affect directly emissions in agriculture. (Population between 60 and 64 years has no significance on the model.) This social concept is related to environmental friendly agricultural management,[7] such as the non-fertilizers use, the certified land area cultivated and the new technology use in machinery (e.g. tractors, tillers and harvesters), which define social environmental initiatives based on policy characteristics according to CAP implementation. Therefore, a discussion may focus on the concept of leisure activities in rural population of older farmers (Agulló-Tomás 2000).

While the models indicate that emissions and farmers' sociodemographic characteristics are associated with soil and management variables, the explanatory value of these models is limited. The GARCH model indicates significance in the cases of emissions by fossil fuels (in particular oil), which is associated with new and old machinery (tractors, tillers and harvesters). However, the model does not stipulate research findings on real emissions' share in the agricultural sector. Furthermore, more variables regarding farmers' should be tested (i.e. different range of age in women, flat of used land, behavioural decisions to use fertilizers, ecological awareness of farmers, etc.). The models are limited in the available data which future research might develop, i.e. analysis of emissions per capita regarding the different agriculture crops types in Spain. Additionally, the authors propose to explore the farmers' environmental attitudes and management and how these practices might modify the trends (i.e. if new machinery is used with insecticides sprayers,

[7] Agricultural management evolves farmers' practices to adapt land use and production practices in order to contribute GHG mitigation, adaptation to climate change and to improve the environment (OECD 2012).

efficiency of insecticides increase and consequently, emissions could be mitigated by qualitative methodology).

Summarizing, the model confirms the hypothesis about the direct effect on emissions regarding the selected indicators (soil and energy management) and farmers' sociodemographic characteristics as the results demonstrate. In particular, this paper demonstrates that middle-age men population has more influence in the GHG per capita in Spanish agriculture, which is reasonable because the working population in agriculture is mainly middle-age men (see Ministry of Agriculture, Fisheries and Food 2017). This confirms that middle-age men are managed land use.

Finally, Spain has mentioned the importance to consider the agricultural opportunities regarding environmental sustainability in the post-CAP 2020,[8] but there is not yet a strategic policy available with the potential of emissions mitigation. Albiac et al. (2017) suggest adjustment of crop fertilizations and forest of management sequestration as potential measures to decide for a policy implementation for the GHG mitigation. However, this study reveals that these measures could not be sufficient in the fight against the real reduction of emissions. There is an important impact on emissions due to soil management (i.e. herbicides and fertilizers) and energy management based on consumption from non-renewable energy management and gases, among others. This means that the models probes that Spanish farmers continue making practices of non-environmental friendly management which need to be reflected in the environmental sustainable Spanish agricultural policy.

5 Conclusions and policy implications

This research achieves the objective of testing emissions according farmers' sociodemographic characteristics, especially by considering men, women and the different interval of age related to key indicators based on multifunctional agriculture (soil and energy management). The research findings confirm the theory that machinery emissions are produced due to the estimated use (Gathorne-Hardy 2016), land management related to product consumption (non-renewable energy resources, coals or gases) and the use of fertilizers and pesticides.

The approach of the models tests the hypothesis on the influence of energy and fertilizers in emissions and the use between new or old machinery, and the research results demonstrate that there is no direct relationship to emissions. Thus, farmer's attitudes over land use would contribute to the reduction of GHG without the dependency on the use of machinery (tractors, harvesters and tillers) on the consumption of fertilizers and energy.

The results obtained by the models represent a good estimation basis to discuss future policy trends (i.e. EU's 2020, 2030 and 2050 strategies). Moreover, the research findings contribute to estimate the long-term objectives for EU's rural development policy related to multifunctional principles by '[…] fostering the competitiveness of agriculture; ensuring the sustainable management of natural resources, and climate action; and achieving a balanced territorial development of rural economies and communities including the creation and maintenance of employment […]' (COM 2015b), and to consider the social responsibility (Pellizzoni 2005; Holm and Halkier 2009) in agricultural activities.

[8] See congress celebrated in Zafra, on 29 and 31 May 2019: https://www.mapa.gob.es/es/pac/la-arquitectura-verde-de-la-PAC-POST-2020-eco-esquemas/.

References

Aguilera, E., Lassaletta, L., Sanz-Cobena, A., Garnier, J., & Vallejo, A. (2013). The potential of organic fertilizers and water management to reduce N2O emissions in Mediterranean climate cropping systems. A review. *Agriculture, Ecosystems and Environment, 164,* 32–52. https://doi.org/10.1016/j.agee.2012.09.006.

Agulló-Tomás, M. S. (2000). *Mayores, actividad y trabajo en el proceso de envejecimiento y jubilación: una aproximación psico-sociológica*. Madrid: IMSERSO. Retrieved on January 10, 2019 from: https://www.imserso.es/InterPresent2/groups/imserso/documents/binario/436mayoresacttrab.pdf.

Albiac, J., Kahil, T., Notivol, E., & Calvo, E. (2017). Agriculture and climate change: Potential for mitigation in Spain. *Science of the Total Environment, 592,* 495–502. https://doi.org/10.1016/j.scitotenv.2017.03.110.

Aleixandre-Benavent, R., Aleixandre-Tudó, J. L., Castelló-Cogollos, L., & Aleixandre, J. L. (2017). Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). *Journal of Cleaner Production, 147,* 406–418. https://doi.org/10.1016/j.jclepro.2017.01.112.

Altieri, M. A. (1995). *Agroecology: The science of sustainable agriculture*. Boca Raton: Westview Press.

Apergis, N., & Payne, J. E. (2017). Per capita carbon dioxide emissions across US states by sector and fossil fuel source: Evidence from club convergence tests. *Energy Economics, 63,* 365–372. https://doi.org/10.1016/j.eneco.2016.11.027.

Bennetzen, E. H., Smith, P., & Porter, J. R. (2016). Agricultural production and greenhouse gas emissions from world regions—The major trends over 40 years. *Global Environmental Change, 37,* 43–55. https://doi.org/10.1016/j.gloenvcha.2015.12.004.

Bento, J. P. C., & Moutinho, V. (2016). CO_2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. *Renewable and Sustainable Energy Reviews, 55,* 142–155. https://doi.org/10.1016/j.rser.2015.10.151.

Berghmans, N., Chèze, B., Alberola, E. & Chevallier, J. (2014). The CO_2 emissions of the European power sector: Economic drivers and the climate-energy policies' contribution. In *CDC climat research working paper.* CDC climat. Retrieved from: https://www.i4ce.org/download/the-co2-emissions-of-the-european-power-sector-economic-drivers-and-the-climate-energy-policies-contribution/.

Boden, T. A., Marland, G. & Andres, R. J. (2010). *Global, regional, and national fossil-fuel CO_2 emissions.* Oak Ridge, Tenn., USA: Carbon Dioxide Information Analysis Center. Oak Ridge National Laboratory, U.S. Department of Energy.

Böhringer, C., Koschel, H., & Moslener, U. (2008). Efficiency losses from overlapping regulation of EU carbon emissions. *Journal of Regulatory Economics, 33,* 299–317. https://doi.org/10.1007/s11149-007-9054-8.

Bollerslev, T., Engle, R. F., & Wooldridge, J. M. (1988). A capital asset pricing model with time-varying covariances. *The Journal of Political Economy, 96*(1), 116–131. https://doi.org/10.1086/261527.

Boody, G., Vondracek, B., Andow, D. A., Krinke, M., Westra, J., Zimmerman, J., et al. (2005). Multifunctional agriculture in the United States. *BioScience, 55*(1), 27–38. https://doi.org/10.1641/0006-3568(2005)055%5b0027:MAITUS%5d2.0.CO;2.

Chen, S., Chen, X., & Xu, J. (2016). Impacts of climate change on agriculture: Evidence from China. *Journal of Environmental Economics and Management, 76,* 105–124. https://doi.org/10.1016/j.jeem.2015.01.005.

Cole, M. A., & Neumayer, E. (2004). Examining the impact of demographic factors on air pollution. *Population and Environment, 26,* 5–21. https://doi.org/10.1023/B:POEN.0000039950.85422.eb.

COM. (2002). *Towards sustainable farming. A mid-term review of the common agricultural policy* [Online]. Retrieved on March 6, 2017 from: https://ec.europa.eu/commission/presscorner/detail/en/IP_02_1026.

COM. (2003). Directive 2003/87/EC of the European parliament and of the council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Paris.

COM. (2011). *Communication from the Commission to the European Parliament, The council, The European Economic and Social Committee and the Committee of the Regions. A Roadmap for moving to a competitive low carbon economy* in 2050 COM/2011/0112 final ed.

COM. (2012a). Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and Amending act(s): Regulation (EC) No 1463/2006; Regulation (EC) No 1944/2006; Regulation (EC) No 2012/2006; Regulation (EC) No 146/2008; Regulation (EC) No 74/2009; Regulation (EC) No 473/2009; Regulation (EC) No 1312/2011.

COM. (2012b). *The common agriculture policy: A story to be continued.* Luxembourg: Office for Official Publications of the European Communities.

COM. (2013). *Overview of CAP reform 2014–2020* [Online]. Retrieved on March 6, 2017 from: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/agri-policy-perspectives-brief-05_en.pdf.

COM. (2014a). *Climate action. Allowances and caps* [Online]. Retrieved on February 20, 2019 from: http://ec.europa.eu/clima/policies/ets/.

COM. (2014b). *Climate action. International carbon market* [Online]. Retrieved on February 15, 2019 from: http://ec.europa.eu/clima/policies/ets/.

COM. (2014c). *Climate action. National allocation plans* [Online]. Retrieved on February 21, 2019 from: http://ec.europa.eu/clima/policies/ets/.

COM. (2015a). *The history of the CAP* [Online]. Retrieved on January 12, 2017 from: http://ec.europa.eu/agriculture/cap-history/index_en.htm.

COM. (2015b). *Policy overview 2014–2020* [Online]. Retrieved on January 20, 2017 from: http://enrd.ec.europa.eu/enrd-static/policy-in-action/cap-towards-2020/rdp-programming-2014-2020/policy-overview/en/policy-overview_en.html.

Coyle, C., Creamer, R. E., Schulte, R. P., O'Sullivan, L., & Jordan, P. (2016). A functional land management conceptual framework under soil drainage and land use scenarios. *Environmental Science and Policy, 56,* 39–48. https://doi.org/10.1016/j.envsci.2015.10.012.

Cramer, J. C., & Cheney, R. P. (2000). Lost in the ozone: Population growth and ozone in California. *Population and Environment, 21,* 315–338. https://doi.org/10.1007/BF02436134.

Dietz, T., Gardner, G. T., Gilligan, J., Stern, P. C., & Vandenbergh, M. P. (2009). Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences, 106*(44), 18452–18456. https://doi.org/10.1073/pnas.0908738106.

EEA. (2014). EEA greenhouse gas—data viewer based on National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism. Retrieved on September 15, 2019 from: https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer.

Egenhofer, C. (2007). The making of the EU emissions trading scheme: Status, prospects and implications for business. *European Management Journal, 25,* 453–463. https://doi.org/10.1016/j.emj.2007.07.004.

EUROSTAT. (2016). *Database* [Online]. Retrieved on March 2, 2017 from: http://ec.europa.eu/eurostat/data/database.

Fagodiya, R. K., Pathak, H., Meena, B. L., Meena, R. K., & Nagdev, R. (2017). Need to estimate the net global warming potential of nitrogenous fertilizers. *Adv Plants Agric Res, 6*(4), 00220. https://doi.org/10.15406/apar.2017.06.00220.

Fellmann, T., Witzke, P., Weiss, F., Van Doorslaer, B., Drabik, D., Huck, I., et al. (2018). Major challenges of integrating agriculture into climate change mitigation policy frameworks. *Mitigation and Adaptation Strategies for Global Change, 23*(3), 451–468. https://doi.org/10.1007/s11027-017-9743-2.

Gaffin, S. R., & O'Neill, B. C. (1997). Population and global warming with and without CO_2 targets. *Population and Environment, 18,* 389–413. https://doi.org/10.1007/BF02208514.

Gathorne-Hardy, A. (2016). The sustainability of changes in agricultural technology: The carbon, economic and labour implications of mechanisation and synthetic fertiliser use. *Ambio, 45,* 1–10. https://doi.org/10.1007/s13280-016-0786-5.

George, H. (1879). *Progress and poverty*. New York: E.P. Dutton & Company.

Gómez-Limón, J. A., Picazo-Tadeo, A. J., & Martínez, E. R. (2008). Agricultura, desarrollo rural y sostenibilidad medioambiental. *CIRIEC-ESPAÑA, 61,* 103–126.

Gorman, M., Mannion, J., Kinsella, J., & Bogue, P. (2001). Connecting environmental management and farm household livelihoods: The rural environment protection scheme in Ireland. *Journal of Environmental Policy and Planning, 3*(2), 137–147. https://doi.org/10.1002/jepp.76.

Heilig, G. K. (1994). The greenhouse gas methane (CH 4): Sources and sinks, the impact of population growth, possible interventions. *Population and Environment, 16,* 109–137. https://doi.org/10.1007/BF02208779.

Holm, L., & Halkier, B. (2009). EU food safety policy. *European Societies, 11*(4), 473–493. https://doi.org/10.1080/14616690802592589.

Huong, N. T. L., Bo, Y. S., & Fahad, S. (2019). Economic impact of climate change on agriculture using Ricardian approach: A case of northwest Vietnam. *Journal of the Saudi Society of Agricultural Sciences, 18*(4), 449–457. https://doi.org/10.1016/j.jssas.2018.02.006.

Jogerson, A. K., & Clark, B. (2010). Assessing the temporal stability of the population/environment relationship in comparative perspective: A cross-national panel study of carbon dioxide emissions, 1960–2005. *Population and Environment, 32,* 27–41. https://doi.org/10.1007/s11111-010-0117-x.

Kalkhoran, S. S., Pannell, D. J., Thamo, T., White, B., & Polyakov, M. (2019). Soil acidity, lime application, nitrogen fertility, and greenhouse gas emissions: Optimizing their joint economic management. *Agricultural Systems, 176,* 102684. https://doi.org/10.1016/j.agsy.2019.102684.

Klein, T., Holzkämper, A., Calanca, P., & Fuhrer, J. (2014). Adaptation options under climate change for multifunctional agriculture: A simulation study for western Switzerland. *Regional Environmental Change, 14*(1), 167–184. https://doi.org/10.1007/s10113-013-0470-2.

Leakey, R. R. (2012). Multifunctional agriculture and opportunities for agroforestry: implications of IAASTD. In P. K. Ramachandran Nair & D. Garrity (Eds.), *Agroforestry-the future of global land use* (pp. 203–214). New York: Springer.

Liddle, B. (2013). Consumption-driven environmental impact and age structure change in OECD countries: A cointegration-STIRPAT analysis. *Demographic Research, 24,* 749–770. https://doi.org/10.4054/DemRes.2011.24.30.

Liddle, B. (2014). Impact of population, age structure, and urbanization on carbon emissions/energy consumption: Evidence from macro-level, cross-country analyses. *Population and Environment, 35*(3), 286–304. https://doi.org/10.1007/s11111-013-0198-4.

Liddle, B., & Lung, S. (2010). Age-structure, urbanization, and climate change in developed countries: Revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Population and Environment, 31*(5), 317–343. https://doi.org/10.1007/s11111-010-0101-5.

Mansholt, S. L. (1952). Toward European integration: Beginnings in agriculture. *Foreign Affairs, 31*(1), 106–113. https://doi.org/10.2307/20030945.

Maraseni, T. N. (2009). Should agriculture be included in an emissions trading system? The evolving case study of the Australian Emissions Trading Scheme. *International Journal of Environmental Studies, 66,* 689–704. https://doi.org/10.1080/00207230903299364.

Martin, R., Muûls, M., De Preux, L. B., & Wagner, U. J. (2014). Industry compensation under relocation risk: A firm-level analysis of the EU emissions trading scheme. *American Economic Review, 104*(8), 2482–2508. https://doi.org/10.1257/aer.104.8.2482.

Meijide, A., Gruening, C., Goded, I., Seufert, G., & Cescatti, A. (2017). Water management reduces greenhouse gas emissions in a Mediterranean rice paddy field. *Agriculture, Ecosystems and Environment, 238,* 168–178. https://doi.org/10.1016/j.agee.2016.08.017.

Menz, T., & Kühling, J. (2011). Population aging and environmental quality in OECD countries: Evidence from sulfur dioxide emissions data. *Population and Environment, 33*(1), 55–79. https://doi.org/10.1007/s11111-011-0132-6.

Menz, T., & Welsch, H. (2012). Population aging and carbon emissions in OECD countries: Accounting for life-cycle and cohort effects. *Energy Economics, 34*(3), 842–849. https://doi.org/10.1016/j.eneco.2011.07.016.

Meul, M., Nevens, F., Reheul, D., & Hofman, G. (2007). Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agriculture, Ecosystems and Environment, 119*(1–2), 135–144. https://doi.org/10.1016/j.agee.2006.07.002.

Meyerson, F. A. (1998). Population, carbon emissions, and global warming: The forgotten relationship at Kyoto. *Population and Development Review*. https://doi.org/10.2307/2808124.

MINETUR. (2016). Database [Online]. Retrieved on March 21, 2019 from: https://sedeaplicaciones.minetur.gob.es/Badase/BadasiUI/lstSeriesInformesPostBack.aspx.

Ministry of Agriculture, Fisheries and Food (2017). Capítulo 5. Demografía y asepectos sociales de agricultura y alimentación. In: Anuario de estadística 2018. Retrieved on February 12, 2019 from: https://www.mapa.gob.es/es/estadistica/temas/publicaciones/anuario-de-estadistica/2018/default.aspx?parte=1&capitulo=05.

OECD. (2001). *Multifunctionality: Towards an analytical framework*. Paris: OECD Publishing. https://doi.org/10.1787/9789264192171-en.

OECD. (2012). *Farmer behaviour, agricultural management and climate change*. Paris: OECD Publishing. https://doi.org/10.1787/9789264167650-en.

Okada, A. (2012). Is an increased elderly population related to decreased CO_2 emissions from road transportation? *Energy policy, 45,* 286–292. https://doi.org/10.1016/j.enpol.2012.02.033.

Pao, H.-T., & Tsai, C.-M. (2011). Modeling and forecasting the CO_2 emissions, energy consumption, and economic growth in Brazil. *Energy, 36,* 2450–2458. https://doi.org/10.1016/j.energy.2011.01.032.

Papanicolaou, T. N., Wacha, K. M. & Wilson, C. (2013). Exploring the role of multifunctional agriculture on the future of agriculture and rural development. *Leopold center completed grant reports*. 424. Retrieved from: https://lib.dr.iastate.edu/leopold_grantreports/424.

Patiño, L. I., Padilla, E., Alcántara, V., & Raymond Bara, J. L. (2019). The relation of GDP per capita with energy and CO_2 emissions in Colombia. Retrieved on February 16, 2019 from: https://www.recercat.cat/handle/2072/364986.

Paustian, K., Cole, C. V., Sauerbeck, D., & Sampson, N. (1998). CO_2 mitigation by agriculture: An overview. *Climatic Change, 40,* 135–162. https://doi.org/10.1023/A:1005347017157.

Pellizzoni, L. (2005). Trust, responsibility and environmental policy. *European Societies, 7*(4), 567–594. https://doi.org/10.1080/14616690500194118.

Pope, J., Bond, A., Hugé, J., & Morrison-Saunders, A. (2017). Reconceptualising sustainability assessment. *Environmental Impact Assessment Review, 62,* 205–215. https://doi.org/10.1016/j.eiar.2016.11.002.

Schulte, R. P., Creamer, R. E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C., et al. (2014). Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. *Environmental Science and Policy, 38,* 45–58. https://doi.org/10.1016/j.envsci.2013.10.002.

Shi, A. (2003). The impact of population pressure on global carbon dioxide emissions, 1975–1996: Evidence from pooled cross-country data. *Ecological Economics, 44*(1), 29–42. https://doi.org/10.1016/S0921-8009(02)00223-9.

Spellman, F. R. (2015). *Handbook of environmental engineering*. New York: CRC Press.

Stiglitz, J. E. (2010). Principles and guidelines for deficit reduction. *The Roosevelt Institute*. https://doi.org/10.2202/1553-3832.1741.

Stout, B. A. (1984). *Energy use and management in agriculture*. North Scituate: Breton Publishers.

Tucker, M. (1995). Carbon dioxide emissions and global GDP. *Ecological Economics, 15*(3), 215–223. https://doi.org/10.1016/0921-8009(95)00045-3.

Tung, Y. T., & Pai, T. Y. (2015). Water management for agriculture, energy, and social security in Taiwan. *CLEAN Soil, Air, Water, 43,* 627–632. https://doi.org/10.1002/clen.201300275.

UN. (1998). *Kyoto protocol to the United Nations framework convention on climate change.* Retrieved on February 27, 2017 from: https://unfccc.int/resource/docs/convkp/kpeng.pdf.

Vlachou, A. (2014). The European Union's emissions trading system. *Cambridge Journal of Economics, 38,* 127–152. https://doi.org/10.1093/cje/bet028.

White, P. J., Crawford, J. W., Díaz Álvarez, M. C., & García Moreno, R. (2014). Soil management for sustainable agriculture 2013. *Applied and Environmental Soil Science*. https://doi.org/10.1155/2014/536825.

WMO. (2014). Record Greenhouse Gas Levels Impact Atmosphere and Oceans. In *Press release number 1002 of the World meteorological organization.* Retrieved from: https://public.wmo.int/en/media/press-release/no-1002-record-greenhouse-gas-levels-impact-atmosphere-and-oceans.

Yu, Y., Deng, Y., & Chen, F. (2017). Impact of population aging and industrial structure on CO_2 emissions and emissions trend prediction in China. *Atmospheric Pollution Research, 9*(3), 446–454. https://doi.org/10.1016/j.apr.2017.11.008.

Zagheni, E. (2011). The leverage of demographic dynamics on carbon dioxide emissions: Does age structure matter? *Demography, 48,* 371–399. https://doi.org/10.1007/s13524-010-0004-1.

Zhang, P., Zhang, J., & Chen, M. (2017). Economic impacts of climate change on agriculture: The importance of additional climatic variables other than temperature and precipitation. *Journal of Environmental Economics and Management, 83,* 8–31. https://doi.org/10.1016/j.jeem.2016.12.001.