Conciliating food security and environmental quality: new insights when mitigating agricultural greenhouse gas emissions at the EU scale

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Summary

In order to mitigate greenhouse emissions, market based instruments are promoted. This paper revisits the arbitrage between different productions at the EU scale and the potential impact of environmental policies on food security, as well as their interdependence. We introduce the pricing of GHG emissions, taking into consideration the direct emissions sourced from agriculture, related to N_2O and CH_4. The question addressed in this article consists in finding out which might be the impact of an emission tax on agricultural commodities brought to the market. By using the European agro-economic AROPAj model, the paper assesses the effects that can occur when introducing a CO_2 price on the crop and livestock production in the European Union, in the sense that some agricultural productions possibly increase when the emission tax increases. These effects are due to complex substitutions regarding crops, grasslands and fodders, both of them being related to the problem of animal feeding (on-farm recycled grain cereals, concentrates and grasslands and fodders). At the EU scale, increasing the CO_2 price leads to a reduction of the GHG emissions, and, over a limited price range, to an increase of the cereal quantities (both marketed and on-farm use cereals), a stability of oilseeds quantity, a decrease in milk and meat supply and to a strong reduction of meadows and fodders areas.

Keywords: Environmental policies, greenhouse gas emissions, food security, European Union, agriculture, climate change, CO_2 price;

1 Introduction

Over time, the complexity and variety of the relationships between climate change and agriculture has sparked many debates in the scientific literature. Depending on the climatic, environmental and economic pillars, these interdependencies have developed, into a dynamic way. According to Yohannes (2016) and Bosello & Zhang (2005), the strength of this relationship is stronger in developing countries where agricultural activities have a major role in ensuring livelihood. In the same time, these activities are influenced by environmental and climatic conditions.

Agricultural activity emits into the atmosphere large quantities of methane and N_2O resulting from nitrogen fertilizers application, for crop production (46%), cows and sheep digestion (39%), manure decomposition (10%), the processing and delivery at destination of animal products (5%) (FAO, 2013; IPCC, 2007).

In order to mitigate greenhouse gas emissions, carbon pricing plays a key role, representing the stepping stone of agri-environmental policies (OECD, 2015; Vojtech, 2010). Carbon pricing instruments (e.g. carbon taxes, crediting mechanisms and emissions trading schemes), included among these policies, are an important factor to promote economics investment in low carbon technologies and to reduce climate pollution (Kossoy et al., 2015).

According to Olesen & Bindi (2002) and Leip et al. (2010), crop quality and production, livestock production, farming systems, soils and land use are inter alia, key elements that need to be taken into consideration by policy makers in order to support the mitigation of agricultural greenhouse gas emissions. Thus, gas emissions reductions can be achieved by improving the existing production systems, which involves the implementation of the best technologies in raising and feeding animals. A reduction of nitrous oxide emissions may be obtained through modifications in manure and nitrogen use technology, as well as a rational use of crops and soil (e.g. crop rotations, carbon sequestration in soils). In order to reduce methane emissions, both the improvement of animal feeding technology and the use of manure should be taken into account. Ensuring the balance between a rising crop productivity while protecting environmental quality and an effective utilization of resources plays a crucial role (Darwin, 2001; Thornton, 2012).

Europe records one of the highest livestock densities in the world. Since 1980, cattle numbers in Europe have been continuously decreasing, while the number of pigs has stabilized and the number of poultry is increasing. Livestock, both in developed countries and especially in developing countries, are producing food goods as well as an increased production of crops for feed. However, livestock number produces pollution, leading to degradation of pastures and soil erosion. An effective policy for planning and optimization of livestock production is based on a policy of crop production, dependent on natural factors (FAO, 2012; Headey & Fan, 2010).

The question addressed in this paper consists in finding out which might be the impact of an emission tax on agricultural commodities brought to the market. Thus, the paper aims to assess the consequences of introducing a CO_2 price on the crop and livestock production in the European Union, offering new insights when mitigating greenhouse gas emissions by adopting climate-friendly policies. By using the European agro-economic AROPAj model, we analyze the trade-off between different productions at European level and the impact of environmental policies on food security.

The article analyzes the effect that occurs when imposing a CO_2 price, knowing that over the last decade, CO_2 price fluctuations ranged between 20-35 times compared to the current price on the EU-ETS market. In doing so, we introduce the pricing of GHG emissions, taking into consideration the direct emissions sourced from agriculture, related to N_2O and CH_4. The analysis is enlarged by change in livestock adjustment, taking livestock sensitiveness into consideration in the AROPAj model.

The paper is organized as follows. Section 1 containing the objectives and motivation of the article, is followed by Section 2 in which we have developed the state of art on the subject, focusing on our analysis framework, i.e. raw agricultural production allowing to ensure food security and direct GHG emissions sourced by agriculture inside the EU. Section 3 presents a short description of the AROPAj model, as well as the methodology undertaken in the paper. In order to highlight the evolution of crop and livestock production at European level, when introducing the pricing of GHG emissions, the results obtained are examined in Section 4. Critical remarks and conclusions are presented in Section 5.

2 Background and state of the art on climate - agriculture relationships

Agriculture is one of the most exposed sectors affected by climate change. Energy, water, and land are getting increasingly scarce, emphasizing how important is the mitigation of climate change and the adaptation to it. Climate change impacts on agricultural production are region-dependent and are liable to affect food security at all levels (Gregory et al., 2005; Deering, 2014; Ludi, 2009).

As the human population increases, the concept of food security becomes more important, its definition being the subject of many debates. According to FAO (2003) *"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life"*. Achieving food security is one of the major challenges to sustainable development in the coming decades. It figures among the current objectives of United Nations (UN, 2015) to be reached in 2030. At the European level, the sustainability of agricultural activity is a key issue for increasing food security and preserving natural and environmental resources (EC, 2009; HLPE, 2012). Food and nutrition security (FNS) depends on different factors including climate (e.g. temperature, greenhouse gases, precipitation, etc.) as well as non-climate elements (e.g. policies, soil characteristics, irrigation, etc.) which can affect FNS both directly and indirectly (see Fig. 1) (Cline, 2008; Brown et al., 2015).

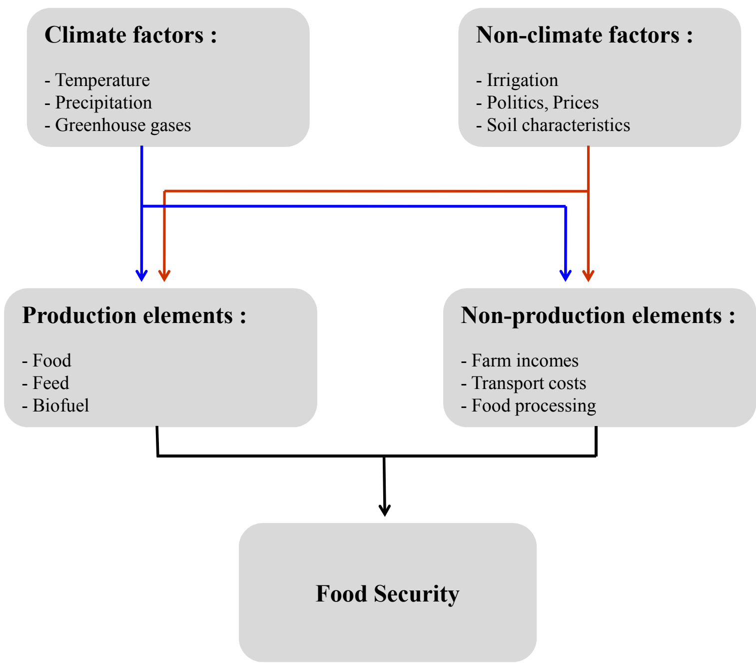

Figure 1. Overview of direct and indirect factors affecting food security linked with the AROPAj model

Agriculture depends on a number of natural climatic factors (e.g., excessive droughts, floods, storms) which strongly influence the allocation of food crops globally. Through an inefficient use of chemical and organic fertilizers, agriculture contributes to the GHG emissions, which highlights the interdependence between agriculture, climate change, agricultural production and food security. To protect the biodiversity and the environment, natural resources should be used efficiently in providing food, relying less on fertilizers and pesticides (Devereux & Edwards, 2004; Olesen & Bindi, 2002; Beddington et al., 2012). According to Jayet & Petsakos (2012), the use of fertilizers leads to nitrate pollution which ask pollution regulation policy tools to face possible unexpected effects (e.g. a tax on fertilizers leading to pollution increase, as stated in this article).

Agriculture's impetus is given by the increasing demand of food at the global level, Europe being one of the most effective and dynamic suppliers of food in the world. According to the EEA (2016), compared with other sectors, the agricultural sector emits greenhouse gasses into the atmosphere on a smaller scale. In 2010, the GHG emissions from agriculture accounted for 11.2% of total EU-27 greenhouse gas emissions. In the last three decades, the evolution of EU agricultural GHG emissions can be seen in Table 1, in which a relatively slight and recent increasing follows after a period of decreasing.

Table 1. Overview of EU-28 agricultural GHG emissions (in million tonnes CO_2-equivalent)

Year	**1990**	**1995**	**2000**	**2005**	**2010**	**2011**	**2012**	**2013**	**2014**
Agricultural GHG emissions	549	479	465	440	428	428	425	429	436

Source: European Environment Agency, 2016

The Directive 2003/87/EC created the first major carbon market in the world, establishing the European Union Emission Trading Scheme (EU-ETS) by setting a CO_2 price at the EU level. CO_2 price may appear under different forms, as either carbon taxes or emission trading systems. If the carbon taxes involve setting a CO_2 price, allowing variations of GHG emissions, cap-and-trade systems impose a limit of emissions, allowing variations of emissions allowances (OECD & WBG, 2015). A quantitative assessment of marginal abatement costs of EU agricultural GHG emissions was conducted by De Cara & Jayet (2011), emphasizing the impacts of the EU burden sharing agreement on agricultural sector. By using the AROPAj model, the authors concluded that cap-and-trade systems could provide considerable cost-savings, when meeting the overall 10% EU abatement target in comparison to the strict implementation of each country's target. However, important transfers, in particular "hot air", from EU-15 to EU countries which joined later, can occur when using BSA targets as a ground for allocating allowances in a cap-and trade system for agricultural emissions. The emission price range at which the target can be achieved is of 32–42€/tCO_2, highlighting that agricultural sector could have a major contribution to its reduction in a cost-effective manner.

In the European Union, the implementation of agricultural and environmental policies is applied at the Member State level (Ignaciuk, 2015; OECD, 2015). Some of the EU Member States appear to be among the countries that manage to cope with food security. In order to see how countries face the phenomenon of food security, the Economist Intelligence Unit developed a Global Food Security Index which provides important data about global food security. In 2016, the Index shows that the US is the world leader, being the country the least vulnerable to food insecurity, followed by Ireland, Singapore, Australia, the Netherlands, France and Germany. [1]

According to data provided by Eurostat, at the EU level, France had the largest contribution to the agricultural production, representing 18% of the EU total. It is followed by Germany (14%), Italy (13%), Spain (10%), the United Kingdom (8%), the Netherlands (7%) and Poland (5%). According to (EC, 2014), of the total of almost 106 million hectares, representing the UE-28 arable land, in 2013 around 55 million hectares were cultivated with cereals, representing almost 19.2%. Over the last 10 years, in the EU has been a real increase of 27.8% in harvested cereal production. Almost half of EU cereal production, as valued in 2014, is obtained in only three countries: France (21.8%), Germany (15.5%) and Poland (9.6%). Another important crop production is represented by oilseeds, which are cultivated to obtain vegetable oil used in the food industry, biodiesel as well as an ingredient in animal feed. Oilseeds production has exceeded 35Mt in 2014. Crop production varies every year, being significantly influenced by fluctuations in climatic conditions. The multiple effects of climate change on agriculture emphasizes the necessity of decision-making process to reduce the risks in order to maintain appropriate standards of crops and promote sustainable agriculture.

3 Methodological elements

Our analysis is based on the use of prospective models able to integrate the technical and economic relations between the agricultural sector, climate and GHG emissions. The prospective

[1] http://foodsecurityindex.eiu.com.

approach does not consist in foreseeing the future, but helps us to construct it, by developing possible scenarios on the basis of analyzing the available data and to synthesize the risks and offer visions as a tool for strategic decision-making. In our analysis, we introduce the pricing of GHG emissions (expressed in k€/tCO_2 equivalent), considering the direct emissions sourced from agriculture, which are related to N_2O and CH_4. Emissions of the two major agricultural greenhouse gases are associated with different productions, as permitted by the model. In order to obtain realistic conclusions, the CO_2 price introduced (expressed in k€/tCO_2 equivalent), is limited to the interval $[0, 0.2]$. The main idea of the article is to give a price to the "carbon-greenhouse effect" and to measure the impact on the production system, over a relatively wide price range in order to have a relatively broad view of impacts, while limiting price variation in a "realistic" range. Fixing a price interval large enough, allows us to take a step back in the analysis, given the fact that a price of 50€/tCO_2 is an interesting price being already mentioned in previous analyzes (De Cara et al., 2005; De Cara & Jayet, 2011). In the same time, a price higher than 100€/tCO_2 would have important consequences on the prices of agricultural inputs and outputs, issue that is not treated here and that AROPAj model cannot process without coupling it with a partial or general equilibrium model, but whose significance has influenced us in selecting the best price range for our analysis.

The model used in this paper, namely AROPAj, is an European agro-economic model, which was originally presented by De Cara et al. (2005) and then developed by Galko & Jayet (2011). Having as initial goal to assess the impacts of the successive reforms of the Common Agricultural Policy, AROPAj was then used to analyze agri-environmental issues such as greenhouse gas emissions (Galko & Jayet, 2011; De Cara et al., 2005; De Cara & Jayet, 2011). The model simulates the agricultural supply in the European Union, being built of a set of linear programming models and focusing on the production derived from main crops and livestock, and on the demand of inputs, more precisely fertilizers and concentrated feed. Its parameters are mainly estimated from the Farm Accountancy Data Network (FADN), which consists of surveys of individual farm samples and allows to extend the use of the model for all EU Member States. One of the AROPAj objectives is the impact assessment of EU agricultural and environmental policies on agricultural systems.

AROPAj, although is a mathematical programming model, rather simple at its origin, has the capacity of incorporating simultaneously, the livestock, the crops, the grassland and the feed (both on-farm and marketed feed). In order to represent a unit of modeling for the AROPAj model and to form a group of farms that present similar characteristics, these individual farms are grouped by a clustering method in *farm types* or *farm groups*, according to different key variables (organizational form, altitude, irrigation and economic size), within every FADN region, which allows a good representation of European farming systems.

Over time, AROPAj had different versions. Our results are based on the last version of the model, the V5 for the year 2009, containing 1802 farm groups with a focus on EU-27. The simulations are conducted within the framework of the 2009 Common Agricultural Policy, with a high level of decoupling, but still with operating milk quota system. We take account of the organic nitrogen sourced by animal manure, which is a substitute to mineral fertilizers.

In the AROPAj model, the supply level and the input demand are chosen by each farm group k in order to maximize the total gross margin (π_k). The generic form of the model for farm group k can be represented as follows:

$$\begin{aligned} \max_{x_k} \quad & \pi_k(x_k) = \max \; g_k.x_k & \\ & s.t. \quad A_k.x_k \leq z_k & (\lambda_k) \\ & \qquad\quad x_k \geq 0 & (\mu_k) \end{aligned}$$

where x_k represents the vector of producing activities for farm group k, namely the area of each crop, the number of animals in each category, the on-farm production and consumption, the production of meat and milk and the quantities of purchased animal feed. The greenhouse gas emissions are a component of x_k, being calculated endogenously in the model. g_k is the vector of valuations in the gross margin (i.e. the variable costs associated with fodder crops or purchasing costs, corresponding to animal feed). λ_k and μ_k are dual variables defined as Lagrange multipliers. All of these elements are fonctions of parameters which are estimated through econometric methods and completed by technical information.

In the model, the overall production is limited by the constraints indicated by A_k, which is the matrix of input-output coefficients and z_k, which is the formal representation of the "resource vector". Among these constraints, relevantly to the analysis developed in this paper, we mention the crop rotation constraints, permitting the re-allocation of the land to the different crops but in the limits of what is agronomically acceptable. Other important constraints regard the animal feed requirements (as detailed by De Cara et al. (2005) and De Cara & Jayet (2011)) and the implementation of the Common Agricultural Policy instruments, the availability of utilized agricultural area (UAA) being limited for each type group. The number of animals per category is allowed to vary within an interval which is parametrized, as a livestock adjustment. It is also possible to allow a greater variation of animal capital. Thus, in our paper, we have introduced a livestock adjustment of $\pm 15\%$ and $\pm 25\%$, for all animal capital categories (intermediate bovine categories being free to adapt under demographical limits).

In AROPAj, thirty-two crop producing activities have been introduced, covering a large part of the EU agricultural land. In the model, crops are divided into three categories: (i) crops that can be either sold or on-farm consumed (i.e. cereals), (ii) crops that can only be on-farm-consumed (e.g. fodder, pastures) and (iii) crops which are intended to be sold. Agricultural area is composed by arable land for crops, grassland and meadows. The model allows the substitution between crops (and between crops and grasslands). Regarding the livestock, AROPAj includes thirty-one animal categories, the cattle representing the most significant part, followed by sheep, goats, swine, and poultry.

The AROPAj calibration process is based on MonteCarlo and gradient algorithms. This pretend a large number of AROPAj runs, each run being iteratively based on re-evaluated parameters.

The emission accounting method closely follows the Intergovernmental Panel on Climate Change Guidelines (2001b), which eases inter-country comparisons of emission inventories. In particular, it combines the use of country-specific activity data (e.g. animal numbers, crop area, fertiliser use, manure management systems, etc.) and emission factors. In the model, each source of GHG emissions is linked to the relevant activity variables at the representative-farm level.

The IPCC parameters for each EU Member State, can be found in the respective National Report of GHG Inventories, more specifically in the Tables 4 "Sectoral Report for Agriculture". These are submitted on a yearly basis to the United Nations Framework Convention on Climate Change (UNFCCC).

The computation of GHG emissions relies on linear relationships between emissions and activity data through the use of emission factors for each source of emissions. The IPCC provides a common reporting framework and the country-specific activity data and emissions from national inventories are reviewed by a panel of international experts.

There are five main processes through which the agricultural activities contribute directly to GHG emissions: N_2O emissions from agricultural soils; N_2O emissions from manure management; CH_4 emissions from manure management; CH_4 emissions from enteric fermentation; CH_4 emissions from rice cultivation. N_2O emissions from agricultural soils can be further disaggregated in direct emissions and indirect emissions. A total of 11 emission sources are computed, (See Table 2) which may be further divided by animal category or animal waste management systems when relevant (De Cara et al., 2005).

For ruminants (cattle, in particular), reducing GHG emissions involves the improvement of the efficiency of animals through the use of fodder and better feed formulation that can reduce the methane CH_4 generated during digestion and the CH_4 and N_2O by manure decomposition. It

Table 2. Summary of GHG emission sources accounted for in AROPAj model

EMISSION SOURCES	ACTIVITY DATA
N_2O Agricultural Soils	
Direct emissions	
Use of synthetic fertilisers	N Fertiliser application based on per-crop fertiliser expenditure
Manure application	N Excretion by animals linked to animal numbers
Biological N fixation	Production of N-fixing crops
Crop residues	Crop residues returned to soils
Animal production	N Excretion by grazing animals
Indirect emissions	
Atmospheric deposition	Total N inputs
Leaching and run-off	Total N inputs
N_2O Manure management	N Excretion by animal and management system
CH_4 Manure management	Feed energy intake
CH_4 Enteric fermentation	Feed energy intake
CH_4 Rice cultivation	Rice area

also aims to improve the selection and health of animals, resulting in fewer and more productive animals, allowing the reduction their number. Switching to sources of food whose production is less energy consuming and to more sustainable energy sources, would enable additional reductions.

When introducing an emission tax, the farmers, who are endogenously represented in the model, can react in different ways in order to reduce their emissions (e.g. changes in animal feeding, the reduction of animal number or modifications of area allocation among crops).

CH_4 from enteric fermentation is straight related to the animal feeding. Feeding relies on filling animal requirements in terms of energy and proteins. They are provided thanks to different kinds of feeds: crops products, raw feeds and concentrated feeds. Each animal specie needs a special intake of energy and proteins. This need changes with respect to the age of the individual, its physical condition, its daily activity, its potential production and the growth objectives. For animal feeding, which is endogenous, farmers can use fodder feed from their own crops or purchased concentrates.

4 Results

By using the AROPAj model, we assess the effects of introducing a CO_2 price on the main crop and livestock productions at the EU level, as well as individually for some of the EU countries. The results obtained are focused inter alia on cereal quantity and area (for both marketed and on-farm use cereals), oilseeds quantity and area, livestock, feed quantity, nitrogen fertilizer consumption, meadows, fallows and fodders area.

By increasing the environmental value through the CO_2 price, leads to an increase of the environmental quality (i.e. an increase of the reduction of GHG emissions), but in the same time, it interestingly results in an increase of the supply for some of the agricultural products. Series of illustrations are provided in appendix in order to emphasize the following analysis.

At EU-27 level, both nitrous oxide and methane emissions decrease when the CO_2 price increases, but CH_4 reduction operates faster and stronger, compared to N_2O (See Fig. 5 and 4). Increasing the CO_2 price also leads to a reduction of the meat quantity (See Fig. 7).

According to our results, an increase of the CO_2 price leads to an increase of the cereal quantity for a limited price augmentation, followed by a decrease of the cereal quantity above this limit price. Thus, for a CO_2 price lower than 25€/tCO_2, the marketed cereals quantity (e.g. wheat, maize, barley) is increasing at the EU-27 level. At a price higher than 25€/tCO_2, it starts to decrease (See Fig. 10). Given the weight of cereals in the EU's agricultural production, is useful to know how the cereal area and quantity evolve when we impose an emission tax, because according to EC (2014), in the European Union, cereals were cultivated on one-third of its agricultural area (177 million hectares) and represented one-quarter of the crop production value and for one-eighth of the total value of its agricultural products. The harvested production of cereals in the EU Member States, in 2013, represented aprox. 307 million tonnes.

The marketed cereals quantity appears to have a similar evolution in the case of France, Spain and Poland (See Fig. 19, 28 and 27), the production increasing when rising CO_2 price to the value of around 30-50€/tCO_2, then it decreases when the CO_2 price increases. For Germany and United Kingdom, this effect takes place until a CO_2 price level of aprox. 100€/tCO_2 (See Fig. 26 and 24). In Romania, the increase of the CO_2 price leads to a decrease of the marketed cereal quantity (See Fig. 22). In the case of Italy, imposing a CO_2 price has very little influence on the marketed cereals quantity, while in the Netherlands, its trend is atypical compared with other countries, being characterized by constant evolutions followed by sudden and sharp declines (See Fig. 23 and 25). The livestock adjustment in Germany, Romania and Poland has a stronger influence on the evolution of the marketed cereals quantity by reference to other countries, where it is not significant.

For animals feeding, as sources are used either on-farm cereals or commercialized concentrates. For a CO_2 price of 50€/tCO_2, we can observe that at the EU-27 level, as well as in Spain, Italy or the Netherlands, the marketed feed production is superior to the on-farm cereals production, while in France and Germany, the quantity of on-farm use of cereals is lower compared to the marketed feed (See Fig. 2).

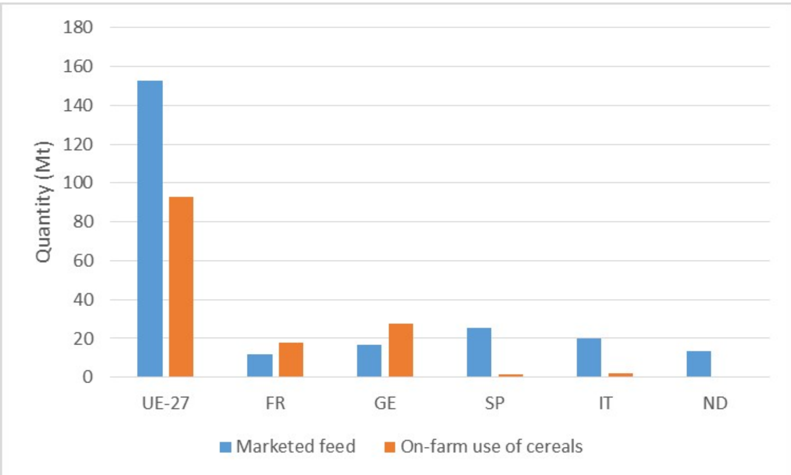

Figure 2. Marketed feed vs. On-farm use of cereals

According to our results, for a limited price range The quantity of on-farm use of cereals, as well as the marketed cereals quantity, increases until a CO_2 price level of 100-150€/tCO_2 and then decreases, result met in the case of UE-27 (See Fig. 11), Germany, France, United Kingdom, Poland. In the Netherlands, the quantity increases slowly at the beginning, then it registers a sharp increase until a CO_2 price level of 150€/tCO_2 (See Fig. 18). On the other hand, in countries like Spain, Italy, an increase of CO_2 price leads to a reduction of the quantity of on-farm use of cereals. The oilseeds quantity presents a stable evolution at the European level until a CO_2 price level of 50-60€/tCO_2, after which it decreases (See Fig. 13). The marketed feed quantity, in France and the Netherlands, after a constant evolution, starts to increase sharply at a CO_2 price level of aprox. 150€/tCO_2 (See Fig. 17 and 21).

The areas evolution of the main crops (e.g. cereals, grasslands, fallows, fodders, industrial crops, oilseeds), in the EU, depending on the CO2 price, for a livestock adjustment of 25%, is illustrated in Figure 3. At EU-27 level, results show that increasing the CO_2 price leads to a decrease of grasslands and fodders area (See Fig. 9 and 14), but to an increase of fallows area (See Fig. 8). This can be explained by the fact that the reduction of the meadows and fodders areas is offset by the increase of fallows area. In the Netherlands, the grasslands area starts to decrease sharply at a price level of aprox. 120€/tCO_2 (See Fig. 16). The cereal area, at the EU-27 level, as well as in France, for example, increases at a CO_2 price below 60€/tCO_2 (See Fig. 12 and 20). The same situation appears in the case of Germany, UK and Poland, but at a higher CO_2 price, around 100€/tCO_2. On the other hand, a different trend can be observed in Spain, Italy, France, where an increase of the CO_2 price results in a significant decrease of the cultivated area with cereals.

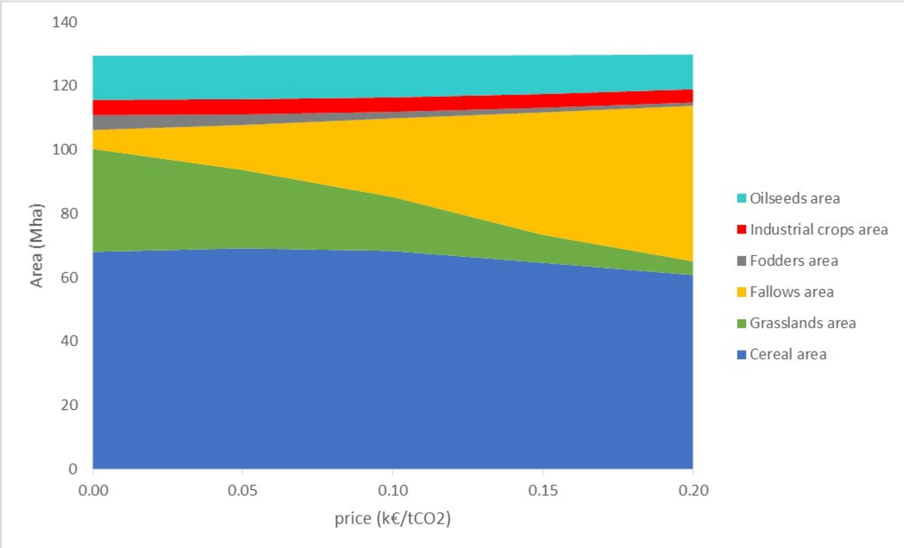

Figure 3. Areas evolution of major crops depending on CO2 price in EU-27

In the livestock sector, in EU-27, our results show that the two adjustment curves of 15% and 25% intersect at a CO_2 price level of aprox. 50€/tCO_2. This proves that the number of livestock decreases faster at a livestock adjustment of 25%, when we increase the CO_2 price (See Fig. 6). In the Netherlands, same trend can be observed, but the two adjustment curves don't intersect (See Fig. 15).

With regard to Member States, certain results are due to the fact that some countries are covered in AROPAj model, by a small number of farm groups and therefore the results issued from linear programming are very "stepwise" in some cases (e.g. Netherlands). Given the contrast effects between countries, we obtained interesting results that allowed us to analyze the disparities between EU members.

At the European Union scale, increasing the CO_2 price leads to a reduction of the GHG emissions, and, over a limited price range, to an increase of the cereal quantities (both marketed and on-farm use cereals), a stability of oilseeds quantity, a decrease in milk and meat supply and to a strong reduction of meadows and fodders areas.

5 Critical remarks and conclusions

This paper has further strengthened the statement according to which the climate change and agriculture are two interdependent processes. It emphasizes that the results obtained must be taken into account not only in the framework of scientific research, but also by decision-makers and market operators.

It is a certainty that the agricultural sector will be strongly impacted by climate change, being very important for farmers to perceive the potential effects of climate change on agriculture and to be able to anticipate those effects in order to maximize their agricultural production. In addition, as well as price feedbacks, climate change and GHG emissions (to which agriculture contributes) will lead agriculture to adapt. Price feedbacks require general or partial equilibrium models which may be linked to our agricultural supply model (see Galko & Jayet (2011) for an attempt). The analysis of climate change adaptation calls for other integrated modeling approaches for which some previous work has be done (Leclère et al., 2013). These economic and climatic changes may strongly impact GHG emissions and policies designed to reduce them. Doing so, our results could be altered.

Present results obtained show the effects that can occur when introducing a CO_2 price on the crop and livestock production in the European Union, in the sense that some agricultural productions possibly increase when CO_2 price increases. This effect is due to the substitutions between crops, grasslands and fodders, both of them being related to the problem of animal feeding (on-farm recycled grain cereals, concentrates and grasslands and fodders).

Some key elements should be taken into account. First, reduction costs of GHG abatement differ between methane and nitrous oxide, through their different sources, knowing that these two gas are both sourced by livestock and crop activities. Secondly, the substitutions between feed (on-farm cereals, fodders and grasslands, marketed concentrates) make the analysis difficult and interesting. This is one of the strengths of our model to take account of this wide range of feeding materials (at the farm -cereal-grains and fodders-, simple or compound concentrates).

In the absence of taking into account the carbon sequestration in soils, favorable to grassland, the animals that consume the grassland constitute "a problem" rather than "a solution" when attempting to reduce greenhouse gas emissions of agricultural origin. This important point is not still considered in our analysis.

As the EU is an important economic player, a larger scale analysis should take into account a “leakage effect”. This is due to the fact that it could lead to a change in prices and a displacement of the production, and even in case it will not modify the prices, we can produce elsewhere, thus an increase of the agricultural prices in Europe adds to all this complexity. Within the European Union, it is necessary for all countries to implement environmental policies, otherwise emissions reductions achieved by some countries would be offset by those that do not apply the policies or fail to reduce their emissions. At the same time, these policies should not lead to a decrease in agricultural production. The European legislation should integrate the cross-effects between Member States, and with the rest of the world.

At last, the relations between agriculture, GHG emissions and climate involve water, which is likely to become a major problem in Europe and could play a significant role in the analyzes to be carried out to complement the present paper. Current work is undertaken in this direction.

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6 Annexes

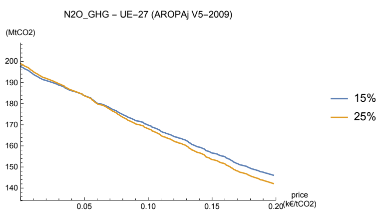


Figure 4. N_2O emissions in EU-27

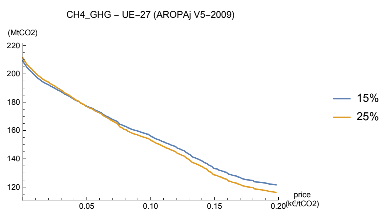


Figure 5. CH_4 emissions in EU-27

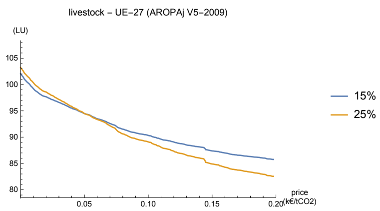


Figure 6. Livestock in EU-27

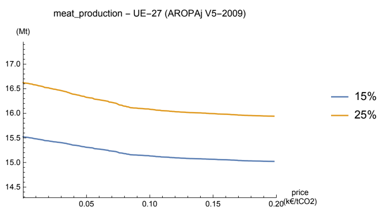


Figure 7. Quantity of meat in EU-27

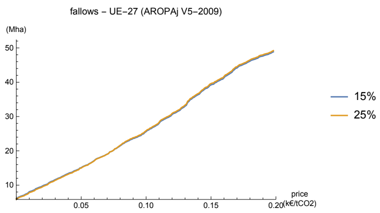


Figure 8. Fallows area in EU-27

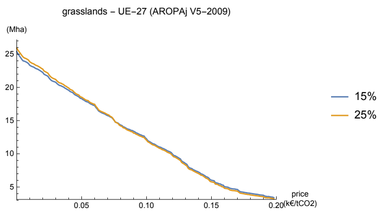


Figure 9. Grasslands area in EU-27

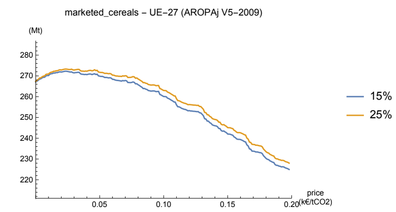


Figure 10. Marketed cereals in EU-27

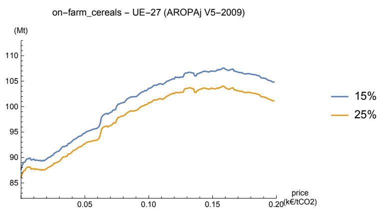


Figure 11. On-farm use of cereals in EU-27

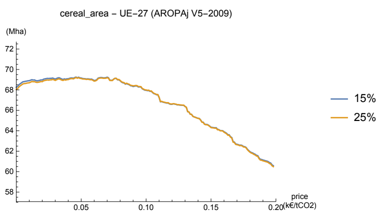


Figure 12. Cereal area in EU-27

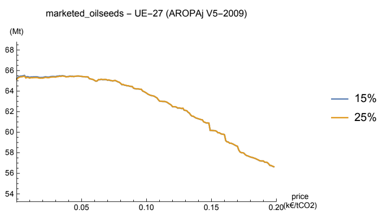


Figure 13. Oilseeds quantity in EU-27

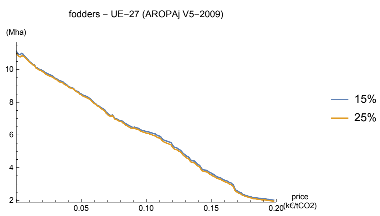


Figure 14. Fodders area in EU-27

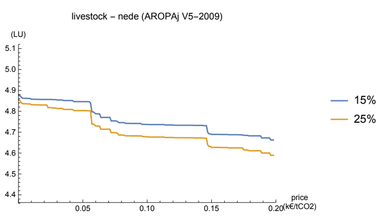


Figure 15. Livestock in the Netherlands

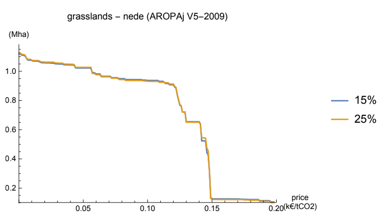


Figure 16. Grassland area in Netherlands

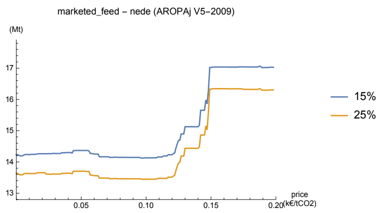


Figure 17. Marketed feed in Netherlands

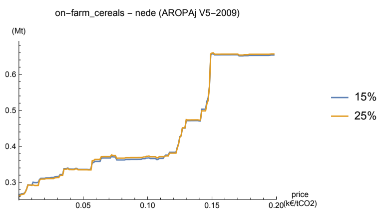


Figure 18. On-farm use of cereals in Netherlands

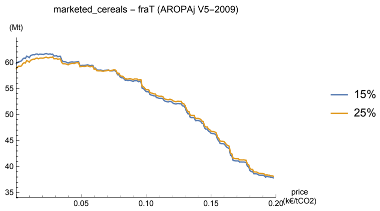


Figure 19. Marketed cereals in France

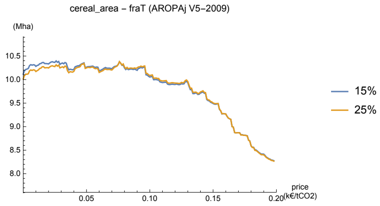
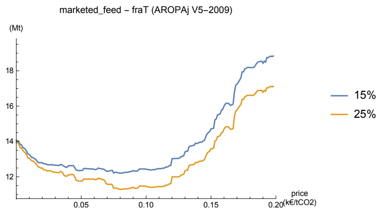


Figure 20. Cereal area in France



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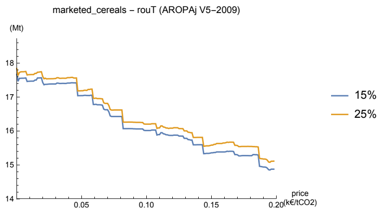

Figure 22. Marketed cereals in Romania

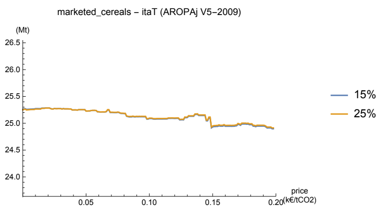

Figure 23. Marketed cereals in Italy

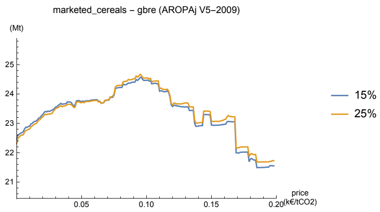

Figure 24. Marketed cereals in UK

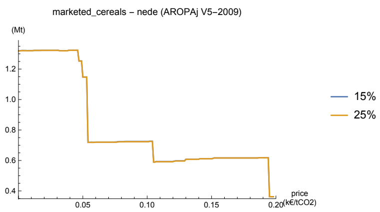

Figure 25. Marketed cereals in Netherlands

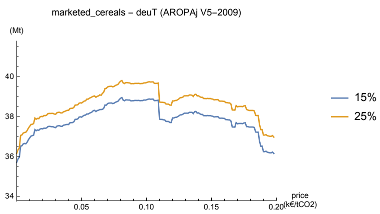

Figure 26. Marketed cereals in Germany

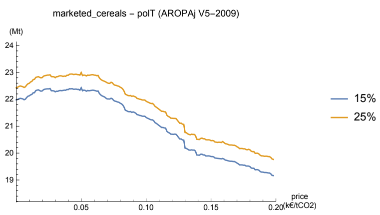

Figure 27. Marketed cereals in Poland

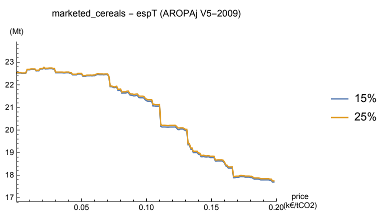

Figure 28. Marketed cereals in Spain