Universidad Zaragoza

1542

Trabajo Fin de Máster

Kyoto and Mañana : A Computable General Equilibrium (CGE) analysis of Spanish greenhouse gas targets to 2020

Autor

Michael Bourne

Director/es

Maria-Luisa Feijoo Bello

Facultad de Economía y Empresa
2013

Kyoto and mañana: A Computable General Equilibrium (CGE) analysis of Spanish Greenhouse Gas targets to 2020

1. Introduction

The necessity for international cooperation in conceiving a global strategy to both mitigate and adapt to climate change, coupled with the absence of a sovereign international authority, bestowed upon individual governing bodies world-wide a sense of collective responsibility to engender binding and effectual policy measures. Against this background, the United Nations Framework Convention on Climate Change (UNFCCC) was created, which in turn oversaw the ratification of the Kyoto Protocol (UNFCCC, 1998). This international accord set a detailed roadmap for curbing carbon dioxide (CO2) emissions, as well as a collective basket of non-CO2 'greenhouse gas' (GHG) emissions.[1] More recently, the European Union has taken the lead in fighting climate change, by agreeing a series of further unilateral emissions cuts over the 2013-2020 period, under the auspices of its Climate and Energy Package (CEP)[2].

Amid discussions on the best way to achieve these goals, the European Union (EU) Emissions Trading Scheme (ETS) emerged for a test period in 2005-2007 and thereafter for different commitment phases from 2008-2028 (European Parliament, 2003; 2004; 2008; 2009a). The ETS created an internal trading market for CO2 emissions permits, initially allocated across a select grouping of sectors (excluding agriculture), with the intention that abatement be incentivised via charges for exceeding (gradually contracting) domestic emissions limits or revenues to more efficient firms from the sale of excess permit allocations. Individual member states distribute emissions permits subject to both the approval of the European Commission and those limits stipulated within the National Allocation Plan (NAP)[3]. When Kyoto expires, the ETS will continue to operate to extend CO2 emissions reductions to 2020 (see Table 1).

For non-ETS GHG emissions, parallel EU-wide emissions reductions are implemented up to 2012, although under a 'burden sharing agreement' Spain has been granted a softer emissions reduction target (see Table 1). Notwithstanding, in light of Spain's impressive growth between 1990-2007, some commentators estimate that its economy still faces relatively steep emissions reductions in order to meet its Kyoto commitment (Labandeira and Rodríguez, 2010; González-

---

[1] The non-CO2 gases within the remit of Kyoto are: methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Importantly, these gases have a considerably higher Global Warming Potential (GWP) than CO2.

[2] see http://ec.europa.eu/clima/policies/package/index_en.htm

[3] see http://ec.europa.eu/clima/policies/ets/pre2013/nap/index_en.htm

Eguino, 2011).[4] In the post-Kyoto period an independent 'diffuse' sector (includes agriculture) emissions target is in place up to 2020 (see Table 1).[5] A cursory examination of Spanish emissions data reveals that diffuse emissions make up 55% of all Spanish GHG emissions, of which the transport sector produces the largest proportion (accounting for more than 40% of total energy consumed in Spain) followed by the agriculture sector which itself accounts for 14% of total Spanish GHG emissions (UNFCCC, 2011). A closer look at Spain's agricultural emissions reveals that methane emissions from livestock activities constitute the largest proportion of total agricultural emissions (38%), followed by nitrous oxide from fertiliser application (34%), and carbon dioxide from petroleum usage (16%). The remaining emissions are largely nitrous oxide from manure, and small amounts of methane released during field burning in the cereals sectors.

Computable general equilibrium (CGE) representations can be employed to quantify the impact of climate change policies because of their ability to assess the interactions between many different agents and sectors across the whole economy. Unlike 'bottoms-up' engineering models, CGE 'top-down' mathematical models are able to simulate the complex linkages between the direct and indirect consequences of modeller-specified policy shocks, producing as an output a comprehensive representation (i.e., prices, outputs, costs) of the economy-wide impacts. This characteristic is particularly pertinent when examining the integrated nature of energy production and usage across industries and consumers, as well as macroeconomic impacts of policy mandated emissions targets.

The adaptability of CGE modelling has led to a range of climate change studies with varying focal points and objectives. In surveying the existing literature we observe multi-region studies (e.g. Böhringer and Rutherford, 2010), whilst differences in the decomposition of emissions gases in specific member countries has given rise to sectorally more detailed single region CGE studies (e.g. Dellink et al., 2004). As expected, the general consensus is that meeting emissions reduction targets entails a short to medium term cost, but the differences in contexts and policies modelled render direct comparison of results difficult, or of little value. A cursory review of the relevant Spanish literature (Labandeira et al., 2004; 2009; Labandeira and Rodríguez, 2010; González-Eguino, 2011) suggests that GDP falls of between 0.1% and 1% by 2012 may result from emissions restrictions.

---

[4] Spain has been permitted an emissions target of 15% above 1990 levels, rising to a projected 37% when heavy usage of Kyoto approved 'flexibility mechanisms' and carbon sinks are accounted for.

[5] In the case of agricultural practice, a proportion of its pollution is classified as point source (i.e., emitted from a single discharge point such as a pipe). However, a large proportion is non-point source (difficult to determine an emitting source), which implies a more 'diffuse' nature to its emissions.

A key issue for this study is how the agriculture sector is impacted directly from facing its own emissions reduction targets, and indirectly from facing higher energy prices as a result of other environmental policies, such as the ETS. Given the diffuse nature of agricultural emissions, how reductions targets are to be achieved is left as an internal matter in each member state (European Parliament, 2009b) and is beyond the focus of the current study. Some CGE studies (Van Heerden et al. 2006; Labandeira and Rodríguez, 2006; Labandeira et al. 2009), report limited impacts on agriculture, but only account for emissions controls on combustion, whilst not accounting for agriculture's diffuse emissions. One exception to this is a study assessing the Dutch economy by Dellink et al. (2004). The study estimates relatively sharper falls in agricultural production (-4.8%) compared with the wider economy (-2.7%) by 2050, citing the relatively higher emissions intensity in agriculture (i.e., including non-CO2 gases).

Given a general paucity of antecedents within the quantitative literature, there exists an additional need to assess the economic impacts of emissions targets on a selection of specific livestock and cropping practises. The focus on Spain is also justified by its strong growth record (pre-crisis) and the consequent sharp adjustment process it will need to follow in order to adhere to its emissions targets,[6] which is likely to have important implications on the agricultural sectors. In those Spanish case studies that exist, the CGE approach has been employed to examine the impact of meeting the Kyoto 2012 targets or other hypothetical short term policy targets (e.g. González-Eguino, 2011). A recursive dynamic CGE approach is employed in Bourne et al. (2012) which incorporates a contemporary baseline scenario to consider the emissions targets impacts of both Kyoto as well as the EU CEP in 2020. Employing a more agricultural focus, a further key feature of this study is the inclusion of all six GHGs emissions across Spanish sectors, whilst an explicit representation of EU agricultural policy mechanisms is coded to reflect the supply rigidities within EU agricultural factor and product markets and their concomitant impacts on agricultural emissions.

The current paper follows the approach in Bourne et al. (2012) with two important extensions. On the one hand, agricultural production decisions are now subject to endogenous technological adaptation in response to tightening emissions controls. This characteristic is modelled via the calibration of non linear marginal abatement cost (MAC) functions[7]. Given that different agricultural activities have differing MAC functions, the ensuing abatement costs to agricultural

---

[6] Although it is recognised that the economic slowdown precipitated by the financial crisis has had a positive effect on reduced Spanish GHG emissions.

[7] For examples of agricultural MAC curves in the literature see Schneider et al. (2007); Beach at al. 2008; Högland-Isaksson et al. (2010). For a meta-analysis see Vermont and De Cara (2010).

sectors are expected to differ considerably from earlier estimates which implicitly assume equal adaptation rates.

A further feature of this paper is the recognition of the feedback mechanism which exists between changes in global temperatures and land productivity. With some notable exceptions (e.g. Csicar et al, 2011; Steinbuks and Hertel, 2011), the majority of CGE studies do not consider the land productivity impacts which accrue under a 'no change' or *status quo* baseline scenario. Consequently, the economic costs of climate change mitigation strategies are biased downwards. The costs of climate change are famously complex and involve a great deal of both scientific and economic uncertainty. However, a first step towards incorporating such costs into CGE models such costs is made in this study through the inclusion of estimates of land productivity effects in the crops sectors.

The rest of this paper is structured as follows: in section 2 the methodology and details of simulations are presented, with findings presented in section 3. Section 4 concludes and suggests some possible areas for further research.

2. Methodology

This section presents a brief description of the model used, followed by an explanation of the major data sources, and a contribution from two collaborators (Sonia Quiroga and Zaira Fernandez-Haddad from the Universidad de Alcala) describing the econometric model they used to estimate the land productivity effects of climate change used in these simulations.

2.1 Model Framework

The CGE framework is ‘demand’ driven, based on a system of neoclassical final, intermediate and primary demand functions. With the assumption of weak homothetic separability, a multi-stage optimisation procedure allows demand decisions to be broken into ‘nests’ to provide greater flexibility through the incorporation of differing elasticities of substitution. Moreover, accounting identities and market clearing equations ensure a general equilibrium solution for each year that the model is run. After appropriate elasticity values are chosen to allow model calibration to the database, and an appropriate split of endogenous and exogenous variables is selected (closure), specific exogenous macroeconomic or trade policy ‘shocks’ can be imposed to key variables (e.g., tax/subsidy rates, primary factor supplies, technical change variables, or real growth in GDP and/or its components). The model responds with the interaction of economic agents within each market, where an outcome is characterised by a 'counterfactual' set of equilibrium conditions.

To improve our estimates of the supply responsiveness of agricultural activities to emissions targets in the context of supply rigidities and support policies, additional code is implemented to support the representation of the Common Agricultural Policy (CAP). This follows previous CGE agricultural studies (see, for example, Philippidis and Hubbard, 2003) and is described in Table 2. As an important driver of (carbon dioxide) emissions, modifications are also made to the intermediate and final demands energy nests (Burniaux and Troung, 2002). Energy demands are separated from non-energy demands, where in the production nest they are treated as part of value added (rather than intermediate inputs) owing to the important relationship between (energy using) capital and energy. Furthermore, electrical and non-electrical (i.e., coal, gas, oil, bio-fuels) demands are in separate nests. For producers, this implies that primary energy (unlike electricity) can also be used as a 'feedstock' input into other industries (i.e., fertilizer, refining of raw energies) rather than directly consumed as an energy source.

Changes in GHG emissions are assumed to be directly proportional to four driving mechanisms in the model (Rose and Lee, 2009): industrial processes (i.e., output), land use[8] and intermediate and final demands for fuels.[9] As a result, firms have some flexibility to mitigate their combustion emissions via substitution toward cleaner energy sources or less energy intensive capital, while process emissions can be reduced either by a contraction in industry output, or by end-of-pipe abatement determined by the MAC curve. Additional endogenous tax wedges, measured in Euros per metric tonne of CO2 equivalent, are inserted into the model code on each of the four drivers to capture the 'shadow costs' of reducing emissions (for sectors outside the ETS scheme), whilst the permit price for the ETS sectors (see below) is held exogenous and shocked according to data and projections (see below). For the MAC curves, 'end-of-pipe' abatement (see van Regemorter, 2005) response is calibrated to the data taken from GAINS through the use of a flexible functional form based on the work of De Cara and Jayet (2006). As a result, a more stringent emissions reduction target will (*ceteris paribus*) drive a higher 'shadow cost' to farmers in order for the target to be met, with the magnitude of this cost dependent on the steepness of the farmers' MAC curves – i.e. the ease with which they can modify their production techniques in order to reduce emissions. In crop farming, for example, this could mean applying nitrogen fertiliser more strategically, rather than simply using less fertiliser, which would reduce

---

[8] Methane released from rice-growing

[9] For example, vegetable industry emissions from combustion of petrol are in direct proportion to intermediate input usage of petrol; production 'process' emissions vary with industry output.

land productivity. In the model, this end-of-pipe abatement then reduces the emissions factor associated with a specific emissions source, which in turn is also a function of the trend observed over the period 1990-2007. In other words, each emissions factor is made up of two components – an exogenous trend extrapolated from the available data (baseline and policy scenario), and endogenous, price-driven abatement (policy scenario only).

Kyoto emissions reductions to 2012 are modelled by exogenous annual linear reductions in the number of domestic permits issued for the ETS sectors and the relevant emissions quota for non-ETS sectors. Spain is assumed to be a 'price taker' within the ETS (i.e., small country assumption), such that the permit price is held exogenous in all years. Following Labandeira and Rodriguez (2010), net imports of additional permits from other EU Member States by Spanish industries adjust endogenously subject to domestic demand conditions (determined by macroeconomic data and projections), gradual reductions in the exogenous supply of domestic permits, and year-on-year exogenous changes in the permit price. The purchase/sale of permits from/to other EU members is subsequently recorded as an additional import/export in the national accounts, adjusting the trade balance, and subsequently Spanish GDP. In keeping with the EU's decision to initially allocate the majority of permits for free (employing a 'historical' emissions criterion), ETS permit allocation up to 2012 is via a 'grandfathering' method, whilst in the subsequent period (2013-2020), an increasing proportion of permits are auctioned at different rates (depending on the sector). Permit allocation is modelled by refunding the proportion of the cost incurred by firms in 'buying' grandfathered permits via a lump-sum subsidy payment, as set out in Edwards and Hutton (1999) and Parry (2002). Thus, in a given year, if 40% of a sector's permits are auctioned, only 60% of the cost is refunded. Revenue raised from the auctioning of permits is paid, along with taxes on non-ETS sector emissions, to the government as tax revenue.[10] In the non-ETS sectors, the relevant abatement cost adjusts endogenously depending on the exogenous macro emissions targets. From 2013, a separate requirement for the diffuse sectors comes into force and their emissions quotas are adjusted accordingly.

Given the lack of relevant Spanish data sources, calibration is facilitated through usage of substitution and expenditure elasticities from the standard GTAP version 8 data base (Aguiar et al., 2012). In the energy module, substitution elasticities from GTAP-E econometric estimates for developed countries are employed. Following Dixon and Rimmer (2002), export demand elasticities are calibrated to upper level GTAP Armington elasticities, whilst the transformation elasticities for land (between uses) are taken from Keeney and Hertel (2009). Central tendency

---

[10] There are various hypothetical options for revenue recycling of environmental tax revenues ('double dividend') which lie beyond the scope of this study.

estimates of labour supply elasticities for Spain are taken from Fernándes-Val (2003) whilst for agro-food products, private household expenditure elasticities are taken from a study by Moro and Sckokai (2000) on Italian households stratified by wealth.

2.2 Data

To support the construction of the accompanying CGE Spanish database, the input-output (IO) tables (year 2007) published by the Instituto Nacional de Estadística (INE) are a principle source of secondary data (INE, 2010). These data are supplemented by institutional accounts data from INE on direct taxes, social security contributions, savings, fiscal deficit etc. to make up a social accounting matrix (SAM) for Spain (see Pyatt and Round (1985) for a detailed explanation of SAMs). Importantly, the conditions imposed by the IO/SAM framework underlie the fundamental accounting conventions of the CGE model. For the purposes of this study, the aggregation focuses principally on agricultural activities, whilst remaining sectors are those identified within the EU ETS, the non-agricultural ‘diffuse sectors’ (see Table 1), and ‘residual’ manufacturing and services activities. The model has three broad factors (capital, labour and agricultural land), of which labour is further subdivided into ‘highly skilled’, ‘skilled’ and ‘unskilled’ employing labour force survey data (INE, 2009a).

Additionally, to explore the distributive effects of policy changes, Household Survey Data (INE, 2009b) permit a disaggregation of private household purchases for up to eight distinct disposable income groupings.[11]

UNFCCC (2011) Spanish submissions data on emissions are separated into fuel combustion; fugitive emissions; industrial processes; solvent and other product usage; land use, land use change and forestry (LULUCF); waste emissions; and agricultural emissions. The data set includes concordance by industry activity, although in some cases further disaggregation is required to map to the model sectors. For combustion emissions, UNFCCC data is combined with energy usage data from the International Energy Agency (IEA, 2011), and intermediate input data from the Spanish IO database (INE, 2010), to map emissions by (i) fuel type; (ii) industry and (iii) source (i.e., domestic/imported). Fugitive and industrial process emissions are assigned to specific IO industries following Rose and Lee (2009), whilst solvent and other product emissions all originate from the chemical industry. Waste emissions are apportioned between the IO sectors of market and non-market sanitation services, whilst LULUCF emissions are excluded from the

---

[11] It should be noted that at the current time, no attempt is made to insert factor ownership shares by households.

current analysis.[12] Finally, Spanish agricultural emissions by activity are, in general, clearly disaggregated into specific agricultural activities within the UNFCCC database, although nitrogen run-off from agricultural soils is assigned employing additional data on land usage (MARM 2008) and nitrogen uptake for specific crops (MARM 2010). Finally, data for the MAC curves comes from the International Institute for Applied Systems Analysis' (IIASA) 'GAINS' model[13], which provides estimates of the cost and abatement potential for each currently available emissions reduction technology in the agricultural sector, for all Annex 1 countries, and some others. Abatement technologies available in Spain include feed changes and anaerobic digestion plants for livestock emissions, and the use of nitrification inhibitors and precision farming techniques for crops sector emissions from fertilisers. A detailed description of the technologies covered, and the methodology used, can be found in Höglund-Isaksson et al. (2010a).

2.3 Yield Changes

Statistical models of yield response have proven useful to evaluate the sensitivity of land productivity to climate change (Parry et al., 2004; Ciscar et al., 2011; Iglesias et al., 2010). This methodology is applied to the eight most representative crops, in terms of area and value, in the Ebro basin. The Ebro river basin is located in the northeast of the Iberian Peninsula; with an area of 85000 km^2 and a mean annual runoff of 16.92 km^3 yr^{-1}, and is the largest basin in Spain.

The selected crops are alfalfa, wheat, rice, grapevine, olive, potato, maize and barley. To characterize crop yield for these Mediterranean crops, we estimate linear regression models by ordinary least squares (OLS) linking bio-physical and socio-economic factors, through the introduction of environmental, hydrological, technological, geographical and economic variables. Later, these models are used to assess climate change effects on crop yield. We use a Cobb-Douglas production function for eight main crops in the area using historical data (1984-2002). A Cobb-Douglas specification was chosen because of its intuitive interpretation in terms of elasticities, as well as its simplicity and validity (Zellner et al., 1966, Giannakas et al., 2003) and its acceptance in agricultural economics literature (Lobell et al., 2005, 2006; Quiroga et al., 2011). The specified model for the eight crops has the general form:

$$lnY_t = \alpha lnY_{t-1} + \beta_0 + \beta_1 L_t + \beta_2 Mac_t + \beta_3 Mac_{t-n} + \beta_4 Altitude_t + \beta_5 Area\_ebro_t + \beta_6 Irrig\_area_t +$$

---

[12] Whilst the UNFCCC data provide a figure for the total sequestration of land, due to data limitations, we were unable to disaggregate this sequestration potential between agricultural land types and forestry land. Moreover, due to the difficulty in valuing forestry land, the model does not have a land factor in the forestry sector.

[13] http://www.iiasa.ac.at/web/home/research/researchPrograms/GAINS.en.html

$$+ \beta_7 Irrig_t + \beta_8 Irrig_t^2 + \beta_9 \, Prec_{it} + \beta_{10} T\_Max_{it} + \beta_{11} T\_Mean_{it} + \beta_{12} Fr_{it} + \beta_{13} Dro_t + \varepsilon_t$$

where the dependent variable ($\ln Y_t$) is the natural logarithm of the crop yield for a site in year t, and the explanatory variables are described in Table 3. For more detail on the construction of this variable set, see Quiroga, et al. (2011). This function is not unique and varies among crops and zones, so the selection of explanatory variables for model specification is important. To facilitate the improvement of particular model estimation for each crop, 95% confidence intervals were estimated assuming normality of the residuals, and significant relations were included in the estimated model. The whole process to estimate this model as well as variables selection and test can be found also in Quiroga, et al. (2011). In this case, the coefficients of the model have to be interpreted as semi-elasticities given the model presents a semi-logarithmic transformation.

In order to simulate agriculture yield changes, we use projections of temperature and precipitation from global circulation models (GCMs). These climate data are from the ClimateCost project (Christensen et al., 2011). A set of 26 climate change runs to 2020 have been considered in this study. There are twelve runs for the A1B scenario and fourteen runs for the E1 scenario. The medium-high non-mitigation baseline scenario (A1B) of the IPCC SRES implies roughly a global temperature increase of 4ºC by 2100, compared to the pre-industrial level. The mitigation scenario (E1) implies a global temperature change at about 2°C above pre-industrial levels.

Table 4 illustrates the yield changes generated from the different runs of climate scenarios. As we mention above, the implications of this impact assessment exercise is crop specific. We can note that these scenarios imply yield changes, ranging from -21.83% for barley to more than 15% for alfalfa. In general, barley, olive and wheat present important losses of crop productivity, whereas grapevine does not suffer major losses in yield performance. For all runs of both climate scenarios, rice shows increases of crop yield in 2020 and in most of the cases, alfalfa also present gains in crop productivity; however, these two are mostly irrigated crops, and a significant drawback of the current analysis is its failure to account for water scarcity. Other limitations include imperfect data (representative climate stations), restrictions of the models to represent complex reality (statistical models of yield response simplify the climate, agricultural, and social effects on crop yield), and uncertainty about the future (climate scenarios).

3. Scenario design and results

Under the auspices of the IPCC's scenario design, associated land productivity estimates generated employing the methodology described in section 2.3 are used to guide our scenario design. This paper employs two groups of scenarios, each consisting of three policy experiments. In the first group, it is assumed that no action is taken to stabilise or reduce GHG emissions (A1B), with global temperatures rising by 4°C. In the second group (E1), sufficient action is taken to contain the global temperature increases to 2°C by 2100. Within each of the two IPCC groups there are approximately 12-14 outcomes, which reflects the degree of scientific uncertainty which frequently surrounds climate modelling. Thus, each group in our study contains a 'worst-case', 'best-case' and 'average' outcome experiment based on our estimates of the associated land productivities.

As a consequence, the results section will be split into two parts. The first part will compare effects *between* each group of scenarios, by looking at the 'average' scenario in which all 2020 EU emissions targets are met[14], and the 'average' baseline. This is in order to meet our primary goal of exploring the effects of the EU's targets on the Spanish economy and, specifically, the agriculture sector. The second part includes some analysis of the range of results produced *within* each group. This comparison reflects the reality of climate science which works in terms of differentiated scenarios rather than a specific outcome.

3.1 Policy Effects

This first part of the results section attempts to put aside, for the moment, the complexities of climate science by taking for the baseline 'no-action' simulation an average of the (12) different estimates of land productivity effects for each crop under the A1B group of scenarios, and for the 'emissions control' simulation, an average of the (14) estimates under the E1 group of scenarios, thus giving us simply a no-action baseline, and an emissions-control scenario to measure against it. The section begins with an overview of the major macroeconomic results, and proceeds to a more focussed analysis of results in the agricultural sector.

3.1.1 Overview

As expected, the Spanish economy faces a short to medium-run economic cost with the implementation of the Kyoto and EU environmental targets, as evidenced by reductions in all real

---

[14] An assumption is made that meeting these targets is associated with the E1 stabilisation scenario

macro indicators and rises in general price indices (see table 5). In meeting Kyoto targets by 2012, Spanish GDP falls 0.4% in the policy scenario with concurrent general price rises of 1.0%. By 2020, GDP and general price changes are exacerbated further (-1.7% and 3.2%, respectively). Spain's relative macroeconomic contraction depresses both employment (-1.8%) and real wages (-0.9%), with supply-elastic 'unskilled' labour (used heavily by the agricultural sector) suffering more from the employment fall (-4.2%), whilst inelastic 'highskilled' labour witnesses a real wage drop of 1.9%. In terms of economic welfare (real incomes), by 2020 household utility falls, though slightly more so for the lowest income grouping (-3.0%) compared with the highest income grouping (-2.2%), indicating the potential regressivity of the environmental policy. This is because lower income households spend a larger share of their incomes on energy, where household energy costs have risen cumulatively by 48% (not shown) by 2020 compared with the baseline.

Since the effect of the emissions quota reductions is to raise the cost of GHG emitting energy inputs and processes, the energy sectors (excluding the electricity industry to an extent) perform badly, in line with expectations. The greatest output fall (results not shown) is suffered by the heavy emitting waste industry (23.9%), whilst coal (23.5), gas (11.9%), oil (11.4%), and transport (9.9%) industries also witness notable output declines by 2020.

In Figure 1, the annual evolution of (endogenous) emissions between 2007 and 2020 is estimated. Emissions under the ETS increase slightly in 2009 despite the recession due to the dramatic fall in permit price, whilst ETS emissions surge in 2011-2012, and again in 2012-2013, due to the accession of aviation and chemicals industries, respectively.

From 2013 onwards, ETS emissions continually rise in spite of a steadily rising (exogenous) permit price and a decreasing domestic allocation of permits, as pan-EU permit trading (i.e., imports) plays an increasingly pivotal role in accommodating downwardly ratcheted domestic emissions targets for Spanish sectors within the ETS. Indeed, we estimate that Spain increases its imports of emissions permits from 24 million in 2007 to 45 million in 2020.[15]

3.1.2. Agriculture

The stated purpose of this paper is to explore the distribution of emissions reductions across the agricultural sectors, in the light of their respective MAC curves. To this end it will be worthwhile here to comment on the MAC curves themselves, as well as the trends observed in the

---

[15] In other words, we argue that the MAC for Spain is higher than other EU members given that it has further to go in order to meet its stipulated emissions reduction targets.

baseline, which also form an important part of the story in terms of what happens once the emissions reductions are imposed.

Figures 2 and 3 show the GAINS data, and the MAC curves calibrated for the model, for the two principle sources of agricultural greenhouse gas emissions: methane from livestock production, and nitrogen oxide from crop fertiliser[16]. The first thing to note is that for methane emissions from livestock (Fig. 3), a significant proportion of emissions can be abated at a relatively low price. These 'low-hanging fruit' come from changes in feed, and an initial phase of anaerobic digestion plants, as documented by Högland-Isaksson et al. (2010b). Once these low-cost options have been maximised, the price of abatement rises quickly, as further reductions from either strategy are much more costly. Of importance for this study though, is that the steep rise in costs does not come until after more than 20% of methane emissions have been abated. Since around 87% of livestock GHG emissions[17] are methane (the rest being N2O) (UNFCCC, 2011), this implies that livestock sectors are likely to play a significant role in meeting the 10% reduction target. Meanwhile, for fertiliser emissions in the crops sectors, the price rises more quickly early on, so even within the 10% reduction necessary, low-cost 'end-of-pipe' abatement is hard to find. However, unlike in the livestock sectors, crops growers have some capacity to substitute away from their polluting inputs – fertilisers – by using more land, or labour. Essentially, the lack of low-cost end-of-pipe options in the crops sectors is balanced by the possibility of reducing use of the polluting input, whilst the inability to use less of the polluting input in the livestock sectors is balanced by the availability of low-cost end-of-pipe abatement options. These two effects, and their interaction, make it very difficult to predict where the brunt of the emissions reductions will fall, and it is to be hoped that this study can contribute to the current knowledge on that subject.

Also important in analysing the effects of the emissions policy, is what the likely trends in the Spanish agriculture would be without it. Here we see (Table 6) output falling in the sugar sector as a result of the reductions in intervention prices. Barley is the only cereal sector to increase its production as a result of the decoupling of agricultural payments, while the movement is generally towards non-cereal crops such as fruit, vegetables and olives, and output falls in cattle and sheep farming as their subsidies are also decoupled. Here we see the central role played by the CAP in setting the framework within which the emissions target must be met, and thus significantly affecting the distribution of reductions. In addition to the discussion of MACs above, it should be borne in mind that there are certain sectors in which emissions will fall 'naturally' as

---

[16] only a small amount of rice is grown in Spain, thus the MAC curve for methane from rice growing is not shown here

[17] in CO2 equivalent

a result of falling output in the baseline, though this will be offset by other sectors which are growing in the baseline.

Figure 4 shows how emissions for the major groups of agricultural industries are affected under the *policy* scenario relative to the baseline. By this measure, the relative fall in emissions is greatest in the olives industry, followed by cereals and the livestock sectors (with the exception of poultry, which has a negligible amount of emissions), with smaller relative falls in fruit and vegetables. In quantity terms, emissions from fruit and vegetable production are much lower than those from cereals, olives, and livestock, so this result is not surprising, and suggests all of the major emitters in Spanish agriculture will have to contribute to ensure the target is met. However, it is interesting to note that the emissions restrictions appear to reinforce trends which were already visible in the baseline in terms of a movement away from cereal production towards other crops. Despite the fall in emissions from olives relative to the baseline, both output and emissions increase in absolute terms in this sector in the *policy* scenario. In general terms, the cereals sectors – and olives – reduce their emissions by substituting land and labour for fertiliser use. Whilst this is partly offset by the expanding fruit and vegetables sectors, which increase their use of fertiliser and resultant emissions, in the benchmark year the majority of emissions come from cereals and olives, so the dominant effect is a reduction in crop emissions, although end-of-pipe abatement plays a minor role due to the lack of low costs options in these sectors. For the livestock industries, meanwhile, falling output in the cattle and sheep sectors contribute to 'natural' emissions reductions, whilst the availability of low-cost abatement options means emissions factors fall significantly in most of the livestock sectors. These results can be seen in table 7, which shows the changes in output, emissions, fertiliser use (where relevant), primary factor use, and emissions factors in the major agricultural sectors in the policy scenario.

3.2 Land Productivity Effects

As shown in table 4, the olives, wheat and barley sectors witness the largest declines in land productivity from changing temperatures, whilst vineyards and feed crops (alfalfa) suffer the smallest declines, with the latter actually seeing an increase in yields in the more optimistic scenarios. It is important to note that these results are based on the assumption that land can be irrigated without restrictions on water use. Given current and predicted water scarcity in the Spanish mainland (see, for example, Iglesias et al. 2010), future work would need to deal with this issue more fully. Given the weight of emissions from olives, wheat and barley in the agricultural total, this extension to the model is of some importance, as we would expect declining land productivity to limit the reduction in fertiliser intensity. Indeed, declining productivities lead to higher effective land rents to farmers in the wheat, barley and olives sectors. In the most pessimistic scenario, effective land rents rise by, respectively 15%, 21% and 30% for these three crops relative to the most optimistic scenario – a result which is consistent across the two groups of scenarios. According to our hypothesis, as a result of such land rent rises, these industries should contribute less to the overall effort to meet the emissions reduction target, since rising land rents drive substitution towards fertiliser, but this result is not clear. Emissions from olive growing do rise slightly from the most optimistic scenario to the least, but there is no similar effect on emissions from wheat or barley, and no discernible impact on the cost of meeting the overall emissions reduction target. This suggests the results are relatively robust to the degree of uncertainty present in climate science, in the short- to medium-term.

4. Conclusions and further work

The results of this study suggest that the decoupling of payments during this transition period for the CAP helps the agricultural sector to meet its emissions reduction target, as it encourages production of less fertiliser-intensive fruit and vegetables at the expense of cereals. Since low-cost end-of-pipe abatement options are limited for N2O emissions from fertiliser use, this movement, and the substitution away from fertiliser towards labour and capital, look to be the principal ways in which crops sectors will contribute to meeting the agricultural industry's 10% 'diffuse sector' target. By contrast, the livestock sectors have few options for substitution (see my comment above on this issue in section 3.1.2), but by taking advantage of some of the low-cost, end-of-pipe abatement options, these industries still have a significant part to play in meeting the target.

The changes in crop land productivity seem to have little effect on the distribution of emissions reductions across agricultural industries. There are some land price effects, but in terms of emissions and the structure of production, the results seem consistent across the various land productivity scenarios. This is clearly influenced by the fact that our scenarios only run until 2020, and the effect of climate change on yields will most likely be small in such a short timeframe, with the degree of uncertainty also being smaller. Projecting further forward would create its own problems though. In addition to the greater levels of uncertainty in making any economic projections into the more distant future, there is much less certainty about what climate policy will look like in Spain (and the rest of the EU) post-2020. A key advantage of our short- to medium-term simulation is that the climate policies relevant to the period are clearly defined, thus the land productivity extension should be seen as an attempt to improve the realism of the scenarios, rather than a core component of the model.

The first priority for further work is to expand and improve the MAC curves. The current curves are based on a small number of data points, and yet they play a crucial role in the model results. Whilst this continues to be an avenue of further research, at the current time, to the best of the authors' knowledge, other secondary data estimates specific to the Spanish crops and livestock sectors are not available. A second area of great interest would be to improve the treatment of water as a resource in the model. The issue of water is of vital importance for Spanish agriculture, particularly for the fruit and vegetable sectors which, according to our results, are likely to expand in the near future. Although these crops are less fertiliser intensive than cereals or olives, they have significant water requirements which call their sustainability into question. The author is keen to deal more fully with this issue in the near future.

References

AGUIAR, A., MCDOUGALL, R., NARAYANAN, B.G., Eds., 2012. *Global Trade, Assistance, and Production: The GTAP 8 Data Base*, Center for Global Trade Analysis, Purdue University. Available online at: https://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp

BEACH, R.H., DE ANGELO, B.D., ROSE, S., LI, C., SALAS, W., DEL GROSSO, S.J., 2008. Mitigation potential and costs for global agricultural greenhouse gas emissions. *Agricultural Economics*, 38, 109-115.

BÖHRINGER, C., RUTHERFORD, T. F., 2010. The Costs of Compliance: A CGE Assessment of Canada's Policy Options under the Kyoto Protocol. *The World Economy* 33, 177–211.

BOURNE, M., CHILDS, J., PHILIPPIDIS, G., FEIJOO, M., 2012. Controlling greenhouse gas emissions in Spain: what are the costs for the agricultural sectors? *Spanish Journal of Agricultural Research,* Vol 10(3), 567-582.

BURNIAUX, J., TROUNG, T., 2002. GTAP-E: An energy-environmental version of the GTAP model. *GTAP Technical Paper* No.16, Purdue University, USA.

CHRISTENSEN, O.B., GOODESS, C.M., HARRIS, I., WATKISS, P., (2011). European and Global Climate Change Projections: Discussion of Climate Change Model Outputs, Scenarios and Uncertainty in the EC RTD ClimateCost Project. In WATKISS, P., (Editor), 2011. *The ClimateCost Project. Final Report. Volume 1: Europe*. Stockholm Environment Institute, Sweden.

CISCAR, J.C., IGLESIAS, A., FEYEN, L., SZABÓ, L., VAN REGEMORTER, D., AMELUNG, B., NICHOLLS, R., WATKISS, P., CHISTENSEN, O.B., DANKERS, R., GARROTE, L., GOODESS, C.M., HUNT, A., MORENO, A., RICHARDS, J., SORIA, A., (2011). Physical and economic consequences of climate change in Europe environmental sciences. *PNAS-Proceeding of the National Academy of Sciences of the United States of America*, 108: 2678-2683.

DE CARA, S., JAYET, P-A., 2006 Mitigation of greenhouse gas emissions in EU agriculture: An assessment of the costs of reducing agricultural emissions and enhancing carbon sinks in agricultural soils. Institut National de la Recherche Agronomique, UMR Economie Publique INRA INA-PG, France.

DELLINK, R.B., HOFKES, M.W., VAN IERLAND, E.C., VERBRUGGEN, H., 2004. Dynamic modelling of pollution abatement in a CGE framework. *Economic Modelling* 21, 965-989.

DIXON, P., RIMMER, M., 2002. *Dynamic General Equilibrium Modelling for Forecasting and Policy*, North Holland Press, Elsevier.

EDWARDS, T. H., HUTTON, J. P., 1999. The allocation of carbon permits in one country: a general equilibrium analysis of the United Kingdom, *Department of Economics Working Paper*, University of Warwick.

ELBEHRI, A., PEARSON, K., 2005. Implementing bilateral tariff rate quotas in GTAP using GEMPACK. *GTAP Technical Paper* No.18, Purdue University, USA.

EUROPEAN PARLIAMENT, 2003. Directive 2003/87/EC of the European Parliament and of the Council.

EUROPEAN PARLIAMENT, 2004. Directive 2004/101/EC of the European Parliament and of the Council.

EUROPEAN PARLIAMENT, 2008. Directive 2008/101/EC of the European Parliament and of the Council.

EUROPEAN PARLIAMENT, 2009a. Directive 2009/29/EC of the European Parliament and of the Council.

EUROPEAN PARLIAMENT, 2009b. Decision 406/2009/EC of the European Parliament and of the Council, p. 2, paragraph 6.

FERNÁNDES-VAL, I., 2003. Household labour supply: Evidence for Spain. *Investigaciones Económicas* 27(2), 239-275.

FONDO ESPAÑOL DE GARANTIA AGRARIA (FEGA), 2010. Informes sobre la financiación de la PAC en España. Available online at http://www.fega.es/PwfGcp/es/accesos_directos/informes/infdw_total_ayudas_percibidas_feaga.jsp [Sept 2010].

FRANDSEN, S.E., GERSFELT, B., JENSEN, H.G., 2003. Decoupling support in agriculture, impacts of redesigning European agricultural support. *Review of Urban and Regional Development Studies* 15(2), 106-131.

GIANAKAS, K., TRAN, K., TZOUVELEKAS, V., 2003. On the Choice of Functional Form in Stochastic Frontier Modeling. *Empirical Economics*, 28: 75-100.

GONZÁLEZ-EGUINO, M., 2011. Los costes de mitigar el cambio climático: Un análisis dinamico de equilibrio general aplicado. *Revista de Economía Aplicada* 56(XIX), 89-121.

HÖGLUND-ISAKSSON, L., WINIWARTER, W., TOHKA, A., 2010a. Potentials and costs for mitigation of non-CO2 greenhouse gas emissions in the European Union until 2030: Results. *Report to the European Commission, DG Climate Action*. IIASA.

HÖGLUND-ISAKSSON, L., WINIWARTER, W., WAGNER, F., KLIMONT,Z., AMANN, M., 2010b. Potentials and costs for mitigation of non-CO2 greenhouse gas emissions in the European Union: Methodology. *Report to the European Commission, DG Climate Action*. IIASA.

IGLESIAS, A., MOUGOU, R., MONEO, M., QUIROGA, S. (2010). Towards adaptation of agriculture to climate change in the Mediterranean. *Regional Environmental Change* 11 (Suppl 1): S159-S166.

INSTITUTO NACIONAL DE ESTADÍSTICA (INE), 2009a. La encuesta anual de estructura salarial. Available online at http://www.ine.es/jaxi/menu.do?type=pcaxis&path=/t22/p133/cnae09/serie/&file=pcaxis [Oct 2010].

INSTITUTO NACIONAL DE ESTADÍSTICA (INE), 2009b. La encuesta continua de presupuestos familiares. Available online at http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft25/p458&file=inebase&L=0 [Oct 2010].

INSTITUTO NACIONAL DE ESTADÍSTICA (INE), 2010. Marco Input-Output 2007. Contabilidad Nacional de España. Instituto Nacional de Estadísticas. Available online at http://www.ine.es/daco/daco42/cne00/cneio2000.htm. [Oct 2010].

INTERNATIONAL ENERGY AGENCY (IEA), 2011. International Energy Agency database. Available online at http://data.iea.org/IEASTORE/DEFAULT.ASP [Oct 2010].

KEENEY, R., HERTEL, T.H., 2005. GTAP-AGR: A framework for assessing the implications of multilateral changes in agricultural policies. *GTAP Technical Paper* No.24, Purdue University, USA.

LABANDEIRA, X., LABEAGA, J.M., RODRÍGUEZ, M., 2004. Green Tax Reforms in Spain. *European Environment* 14(5), 290-299.

LABANDEIRA, X., LABEAGA, J.M., RODRÍGUEZ, M., 2009. An Integrated Economic and Distributional Analysis of Environmental Policies. *Energy Policy* 27(12), 5776-5786.

LABANDEIRA, X., LINARES, P., RODRÍGUEZ, M., 2009. An Integrated Approach to Simulate the Economic Impacts of Carbon Emissions Trading. *Energy Journal* 30, 217-237.

LABANDEIRA, X., RODRÍGUEZ, M., 2006. The Effects of a Sudden CO2 Reduction in Spain. In: *Economic Modelling of Climate Change and Energy Policies* (DeMiguel, C.; Labandeira, X.; Manzano, B.), Ed Edward Elgar, Cheltenham, UK, pp.79-92.

LABANDEIRA, X., RODRÍGUEZ, M., 2010. Wide and Narrow Approaches to National Climate Policies: a Case Study for Spain. *Climate Policy* 10(1), 51-69.

LIPS, M., RIEDER, P., 2005. Abolition of raw milk quota in the European Union: A CGE analysis at the member country level. *Journal of Agricultural Economics* 56(1), 1-17.

LOBELL, D. B., ORTIZ-MONASTERIO, J. I., ASNER, G. P., MATSON, P. A., NAYLOR, R. L., FALCON, W. P., (2005). Analysis of wheat yield and climatic trends in Mexico. *Field Crops Research*, 94: 250–256.

LOBELL, D. B., ORTIZ-MONASTERIO, J. I., (2006). Regional importance of crop yield constraints: Linking simulation models and geostatistics to interpret spatial patterns. *Ecological Modelling*, 196: 173–182.

MORO, D., SCKOKAI P., 2000. Heterogeneous preferences in household food consumption in Italy. *European Review of Agricultural Economics* 27(3), 305-323.

NARAYANAN B.G., WALMSLEY T.L., 2008. *Global trade, assistance and production: GTAP 7 data base*. Centre for Global Trade Analysis, Purdue University, USA.

ORGANISATION FOR ECONOMIC COOPERATION AND DEVELOPMENT (OECD), 2003. The effects of quantitative constraints on the degree of decoupling of crop support measures. Directorate for Food Agriculture and Fisheries, Committee for Agriculture. Available online at http://www.oecd.org/dataoecd/14/3/34996009.pdf [November 2010].

PARRY, I., 2002. Adjusting Carbon Cost Analyses to Account for Prior Tax Distortions. *Resources for the Future Discussion Paper* 02-47.

PARRY, M.A., ROSENZWEIG, C., IGLESIAS, A., LIVERMORE, M., FISCHER, G., (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change*, 14: 53-67.

PHILIPPIDIS, G., HUBBARD, L., (2003) Agenda 2000 reform and its impacts on Member States: A note. *Journal of Agricultural Economics,* 54 (3), 479-486.

PYATT, G., ROUND, J.I., Eds. (1985). *Social accounting matrices: a basis for planning.* Washington DC: The World Bank. http://documents.worldbank.org/curated/en/1985/09/439689/social-accounting-matrices-basis-planning

QUIROGA, S., FERNÁNDEZ-HADDAD, Z., IGLESIAS, A., (2011). Crop yields response to water pressures in the Ebro basin in Spain: risk and water policy implications. *Hydrology and Earth System Sciences*, 15(2): 505-518.

RENWICK, A., SANJUÁN, A.I., PHILIPPIDIS, G. (2007) Defra-Tap: Tailoring the GTAP Model for Defra, Department of Environment, Food and Rural Affairs (DEFRA).

ROSE, S., LEE H-L., 2009. Non-CO2 greenhouse gas emissions data for climate change. In: Economic *analysis of land use in global climate change policy* (Hertel, T.W., Rose, S.K. and Tol R.S.J.), Ed Routledge, Oxford, UK.

SCHNEIDER, U.A., MCCARL, B.A., SCHMID, E., 2007. Agricultural sector analysis on greenhouse gas mitigation in US agriculture and forestry. *Agricultural Systems*, 94, 128-140.

STEINBUKS, J., HERTEL, T.H., 2011. The optimal allocation of global land use in the food-energy-environement trilemma. *GTAP Working Paper* No.64, Purdue University, USA.

UNFCCC, 1998, *Kyoto Protocol to the United Nations Framework Convention on Climate Change,* United Nations Framework Convention on Climate Change.

UNFCCC, 2011. Greenhouse Gas Data Inventory. United Nations Framework Convention on Climate Change. Available online at http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php [Feb 2011].

VAN HEERDEN J., GERLAGH, R., BLIGNAUT, J., HORRIDGE, M., HESS, S., MABUGO, R., MABUGO, M., 2006. Searching for Triple Dividends in South Africa: Fighting CO2 Pollution & Poverty while Promoting Growth. *Energy Journal* 27(2), 113–141.

VAN REGEMORTER, D., 2005. The GEM-E3 model, model description.

http://www.gem-e3.net/download/GEMmodel.pdf

VERMONT, B., DE CARA, S., 2010. How costly is the mitigation of non-CO2 greenhouse gas emissions from agricultura? A meta-analysis. *Ecological Economics* 69, 1373-1386.

ZELLNER, A., KMENTA, J., DRÉZE, J., (1966). Specification and estimation of Cobb-Douglas production function models. *Econometrica*, 34: 784-795.

TABLE 1.
Emissions Reduction Schemes and their Coverage

Scheme and Targets	**Industrial coverage**	**Gas coverage**
EU ETS: Domestic permit EU wide ETS emissions reduction of 8% on 1990/1995 levels by 2012 (Kyoto 2007-2012). Different base years are employed for different greenhouse gases. Burden sharing allows Spanish reduction to 15% above 1990 levels. Under the CEP, ETS emissions reduction of 21% on 2005 levels by 2020.	2007-2020: Coal, Oil, Gas, Petrol, Electricity, Metals, Paper, Glass, Ceramics, Cement and Lime	CO2 (plus PFCs from Metals from 2013 onwards)
	2012-2020: Aviation	CO2
	2013-2020: Chemicals	CO2, N2O
(up to 2012) Non-ETS: Kyoto stipulates the same percentage targets as the ETS to 2012.	Non-ETS industries non-CO2, Other Manufacturing (including food processing), Transport, Chemicals (up to 2011), Agriculture, Waste, Aviation (up to 2012).	CO2, CH4, N2O, HFCs, PFCs, SF6
(2013-2020) Diffuse sectors: EU Emissions down by 10% on 2005 levels by 2020. Spanish target identical to the EU average (i.e., -10%).	Transport, Buildings, Agriculture, Waste	CO2, CH4, N2O, HFCs, PFCs, SF6
(2013-2020) Non-ETS, non-diffuse sectors: Maintain Kyoto emissions limits to 2020.	Food Processing, Services and Manufacturing n.e.c.	CO2, CH4, N2O, HFCs, PFCs, SF6

TABLE 2.
Common Agricultural Policy

Common Agricultural Policy (CAP) Modelling and Baseline Policy Shocks

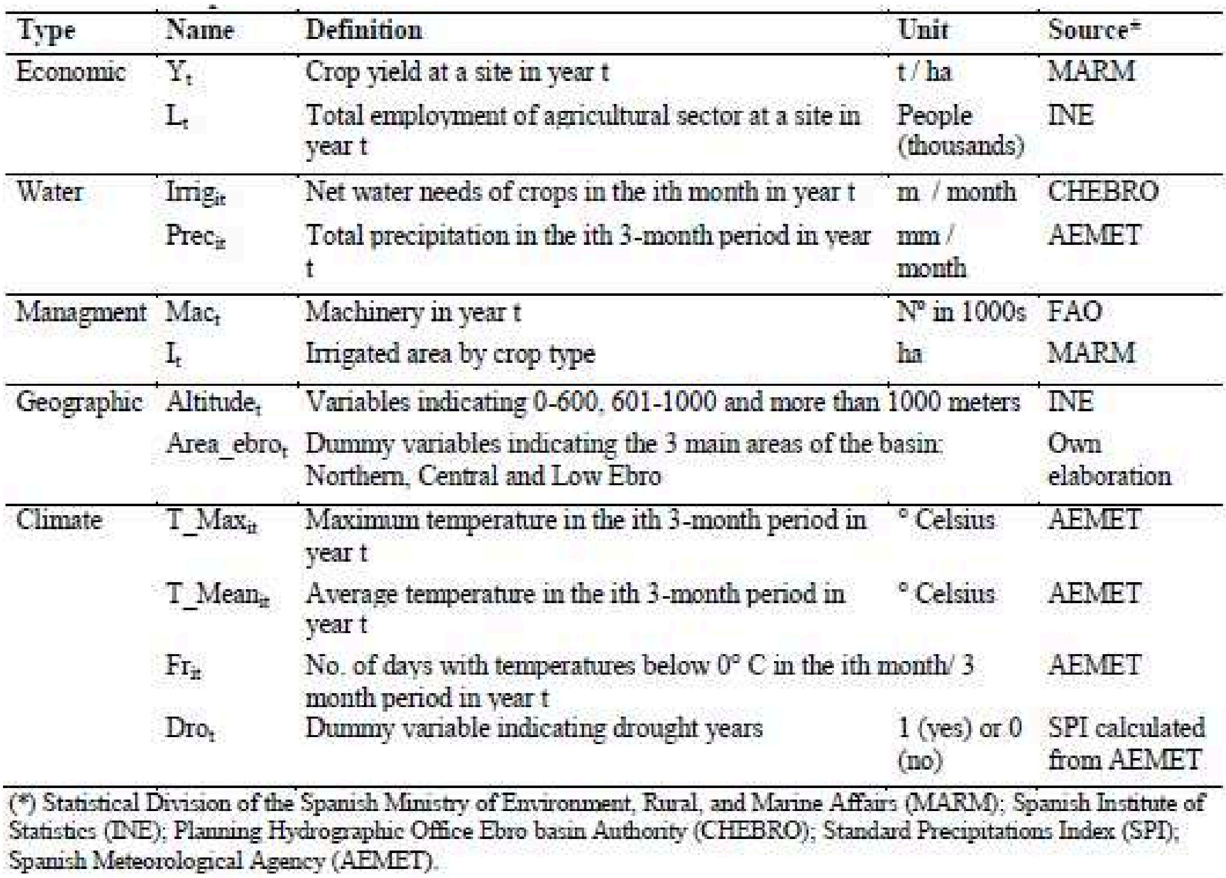
A. Modelling

In the model data, coupled support payments to the agricultural sector are characterised as subsidies on land (e.g., set-aside and area payments) capital (e.g., headage premia on livestock, investment aids), production (e.g., production aids, stock purchases) and intermediate input subsidies (seed payments, irrigation aids, distribution and marketing payments, etc.). Given the policy evolution of the CAP, sector specific payments are gradually decoupled year on year and reconstituted as a Single Farm Payment (SFP), which is introduced as a uniform subsidy rate on the land factor (Frandsen *et al.,* 2003). Intervention prices are modelled as changes to trade protection whilst pillar I modulation payments are implemented year on year as a direct payment to the 'agricultural farm household', which collects all agricultural policy payments and returns on agricultural value added. Employing inequality constraint step functions (Elbehri and Pearson, 2005), production quotas are modelled for raw sugar and milk (Lips and Rieder, 2005), as well as Uruguay Round constraints on export quantities and subsidy expenditure. In agricultural factor markets, the movement of heterogeneous land types between agricultural sectors is governed by a three nested elasticity of transformation function (OECD, 2003), whilst a land supply curve is incorporated within the model code based on an econometric specification (Renwick *et al.*, 2007).

B. Policy Shocks

- Introduction of the Single Farm Payment – year on year shocks (2008-2015) taken from historical data (FEGA, 2010). Complete decoupling of agricultural payments by 2015.
- Modulation implemented based on historical data (FEGA, 2010). Modulation projections assumed to rise to 3% by 2015. Given the structure of the agricultural industry in Spain and the small farms exemption, historical data reveals that Spain's modulation rate is below the EU policy prescribed rate (1% a year from 4% in 2006 to 10% in 2012) (FEGA, 2010). Consequently, we assume that the modulation rate rises to 3% by 2015. Pillar II Modulation payments transferred to farm household income function.
- Dairy (2008) and sugar (2008-2010) intervention price reductions.
- Export subsidy changes based on historical data (2008-2009) (FEGA, 2010)
- 2% increase in EU wide milk quota sanctioned by the EU (April 2008). Year on year 1% increases (2009-2014). Abolition 2015.

Table 3: Description of variables



Type	Name	Definition	Unit	Source*
Economic	Y_t	Crop yield at a site in year t	t / ha	MARM
	L_t	Total employment of agricultural sector at a site in year t	People (thousands)	INE
Water	$Irrig_{it}$	Net water needs of crops in the ith month in year t	m / month	CHEBRO
	$Prec_{it}$	Total precipitation in the ith 3-month period in year t	mm / month	AEMET
Managment	Mac_t	Machinery in year t	Nº in 1000s	FAO
	I_t	Irrigated area by crop type	ha	MARM
Geographic	$Altitude_t$	Variables indicating 0-600, 601-1000 and more than 1000 meters		INE
	$Area\_ebro_t$	Dummy variables indicating the 3 main areas of the basin: Northern, Central and Low Ebro		Own elaboration
Climate	T_Max_{it}	Maximum temperature in the ith 3-month period in year t	° Celsius	AEMET
	T_Mean_{it}	Average temperature in the ith 3-month period in year t	° Celsius	AEMET
	Fr_{it}	No. of days with temperatures below 0° C in the ith month/ 3 month period in year t		AEMET
	Dro_t	Dummy variable indicating drought years	1 (yes) or 0 (no)	SPI calculated from AEMET

(*) Statistical Division of the Spanish Ministry of Environment, Rural, and Marine Affairs (MARM); Spanish Institute of Statistics (INE); Planning Hydrographic Office Ebro basin Authority (CHEBRO); Standard Precipitations Index (SPI); Spanish Meteorological Agency (AEMET).

Table 4. Changes on crop yields

Scenario	Runs code*	Alfalfa	Wheat	Rice	Grapevine	Olive	Potato	Maize	Barley
A1B	BCM2_1	-0.19	-8.09	2.74	-0.81	-7.38	-5.94	-5.29	-10.94
A1B	CNCM3_1	2.85	-12.67	5.02	-1.48	-8.51	-9.58	-7.71	-17.48
A1B	DMIEH5_4	2.47	-8.68	4.06	-1.35	-12.45	-7.92	-8.26	-12.87
A1B	EGMAM_1	-0.21	-10.60	4.62	-1.45	-11.08	-9.15	-8.22	-15.13
A1B	EGMAM_2	1.24	-11.35	5.31	-1.50	-8.95	-9.86	-8.13	-16.70
A1B	EGMAM_3	3.94	-9.07	4.85	-1.12	-10.10	-8.70	-8.35	-14.21
A1B	HADGEM_1	5.41	-12.08	5.95	-1.76	-8.55	-10.40	-8.32	-17.76
A1B	INGVSX_1	2.07	-11.73	4.44	-1.58	-19.94	-9.71	-11.25	-15.47
A1B	IPCM4_1	-0.19	-11.09	4.61	-1.48	-7.85	-8.94	-7.03	-15.72
A1B	MPEH5_1	-1.05	-9.11	4.14	-1.54	-11.76	-8.43	-7.85	-13.11
A1B	MPEH5_2	6.94	-9.00	3.95	-1.49	-14.37	-7.60	-8.58	-12.55
A1B	MPEH5_3	-0.35	-9.45	3.65	-1.64	-6.84	-7.41	-5.34	-12.77
E1	CNCM33_2	0.37	-6.41	2.22	-1.16	-4.64	-4.58	-3.44	-8.72
E1	DMICM3_1	0.05	-10.34	4.40	-1.09	-6.80	-8.62	-6.52	-14.47
E1	DMICM3_2	6.26	-10.37	4.18	-1.25	3.78	-6.79	-2.44	-14.68
E1	EGMAM2_2	5.16	-11.45	5.26	-1.31	-11.13	-9.60	-8.99	-16.74
E1	EGMAM2_3	4.49	-9.40	4.43	-1.22	-9.72	-8.18	-7.53	-13.62
E1	HADCM3C_1	2.98	-13.35	6.62	-2.22	-7.95	-11.51	-8.76	-20.01
E1	HADGEM2_1	3.03	-11.03	5.35	-1.76	-6.51	-9.36	-7.25	-16.61
E1	INGVCE_1	15.02	-11.50	5.22	-1.58	-0.35	-8.01	-4.44	-16.11
E1	IPCM4v2_1	5.03	-16.01	6.97	-2.30	-5.41	-12.23	-7.70	-21.83
E1	IPCM4v2_2	10.73	-13.62	5.59	-1.80	-6.11	-9.74	-6.57	-17.91
E1	IPCM4v2_3	9.43	-14.04	6.43	-1.93	-16.73	-11.58	-11.88	-19.97
E1	MPEH5C_1	6.77	-13.11	5.92	-2.17	-11.57	-10.64	-9.16	-18.71
E1	MPEH5C_2	6.68	-8.64	3.73	-1.05	8.25	-5.73	-0.15	-11.77
E1	MPEH5C_3	3.06	-14.18	6.26	-1.97	-19.67	-12.38	-12.61	-19.42

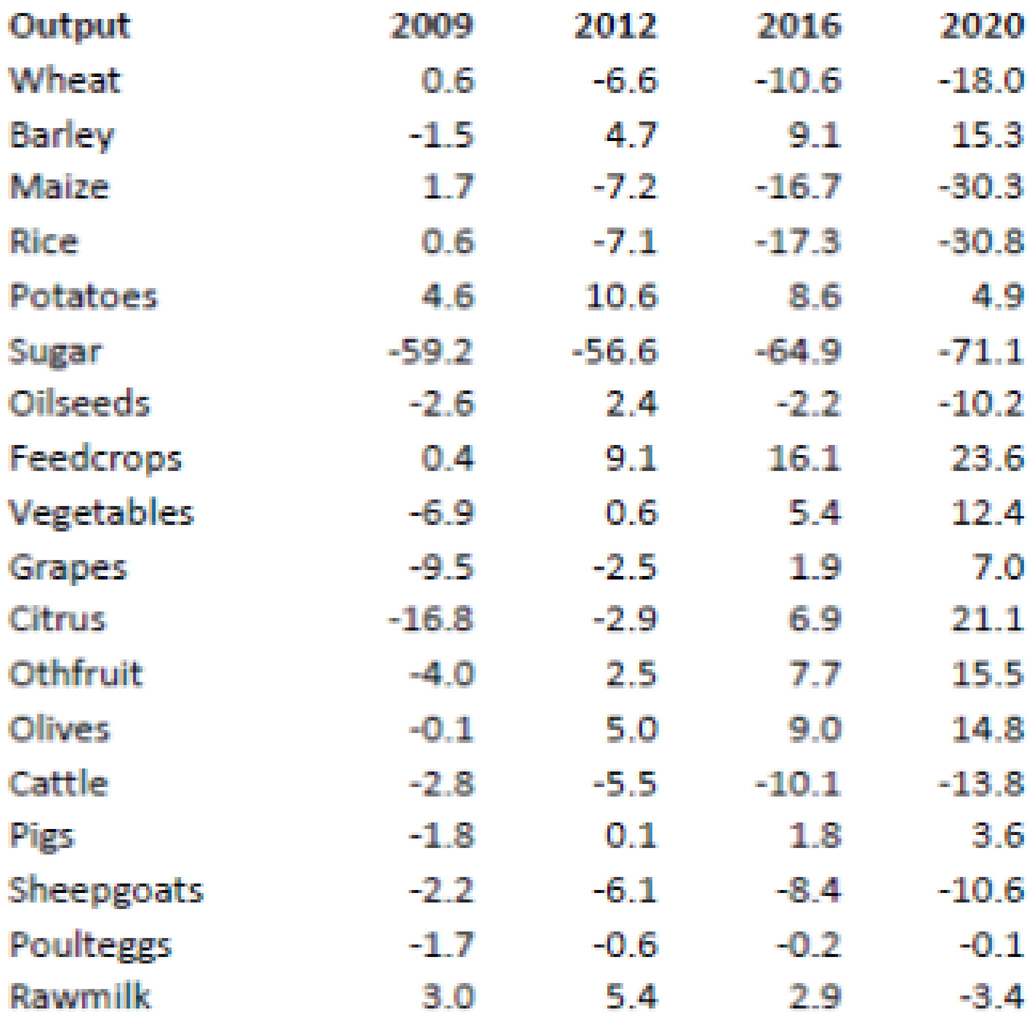
(*) See http://www.climatecost.cc/ for more detail.

TABLE 5.

Aggregate Impacts (%) from Emissions Reductions Targets in Spain vs. the Baseline.

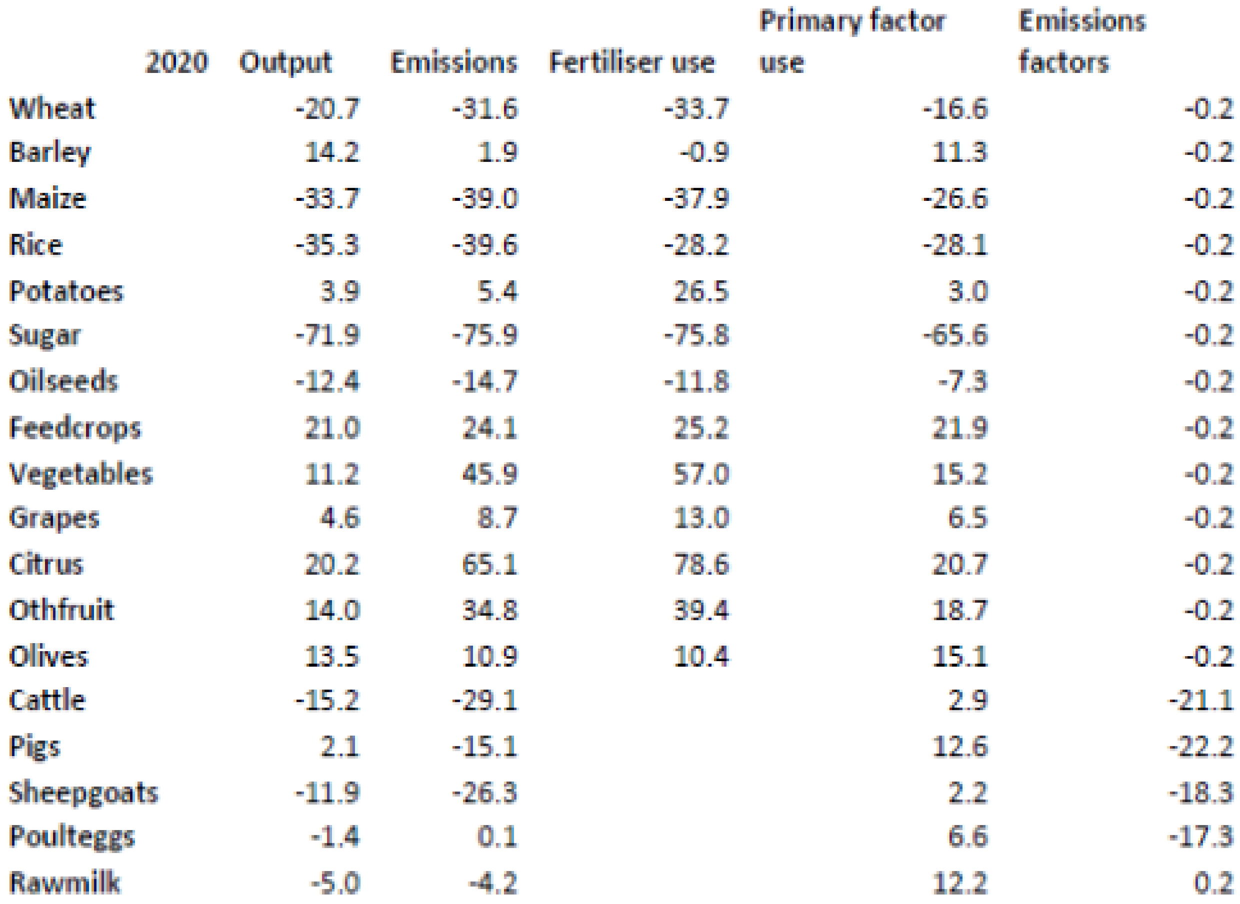
		2012	2020
Aggregate Employment	**Low Skilled**	-1.2	-4.2
	Skilled	-0,5	-1.6
	High Skilled	-0,3	-0.9
Aggregate Real Wages	**Low Skilled**	-0,2	-0,5
	Skilled	-0,5	-1.7
	High Skilled	-0.6	-1.9
Average Usage	**Capital**	-0.1	-0,2
	Labour	-0.5	-1.8
	Land	0.0	0.0
Real Returns	**Capital**	-1.4	-4.7
	Labour	-0.5	-0.9
	Land	-1.8	-4.8
Real GDP		-0,4	-1.7
Consumption		-0,4	-1.4
Investment		-1.1	-3.6
Govt. Spending		0.2	0.2
Exports		-0.5	-1.4
Imports		-0.5	-1.3
CPI		1,0	3.2
Food Price Index		0.8	1.3
Utility	**Lowest Income Group**	-1,0	-3.0
	Highest Income Group	-0.7	-2.2

Table 6: % change in output of agricultural industries in the baseline 2007-2020



Output	2009	2012	2016	2020
Wheat	0.6	-6.6	-10.6	-18.0
Barley	-1.5	4.7	9.1	15.3
Maize	1.7	-7.2	-16.7	-30.3
Rice	0.6	-7.1	-17.3	-30.8
Potatoes	4.6	10.6	8.6	4.9
Sugar	-59.2	-56.6	-64.9	-71.1
Oilseeds	-2.6	2.4	-2.2	-10.2
Feedcrops	0.4	9.1	16.1	23.6
Vegetables	-6.9	0.6	5.4	12.4
Grapes	-9.5	-2.5	1.9	7.0
Citrus	-16.8	-2.9	6.9	21.1
Othfruit	-4.0	2.5	7.7	15.5
Olives	-0.1	5.0	9.0	14.8
Cattle	-2.8	-5.5	-10.1	-13.8
Pigs	-1.8	0.1	1.8	3.6
Sheepgoats	-2.2	-6.1	-8.4	-10.6
Poulteggs	-1.7	-0.6	-0.2	-0.1
Rawmilk	3.0	5.4	2.9	-3.4

Table 7: % changes in key variables in the policy run 2007-2020



2020	Output	Emissions	Fertiliser use	Primary factor use	Emissions factors
Wheat	-20.7	-31.6	-33.7	-16.6	-0.2
Barley	14.2	1.9	-0.9	11.3	-0.2
Maize	-33.7	-39.0	-37.9	-26.6	-0.2
Rice	-35.3	-39.6	-28.2	-28.1	-0.2
Potatoes	3.9	5.4	26.5	3.0	-0.2
Sugar	-71.9	-75.9	-75.8	-65.6	-0.2
Oilseeds	-12.4	-14.7	-11.8	-7.3	-0.2
Feedcrops	21.0	24.1	25.2	21.9	-0.2
Vegetables	11.2	45.9	57.0	15.2	-0.2
Grapes	4.6	8.7	13.0	6.5	-0.2
Citrus	20.2	65.1	78.6	20.7	-0.2
Othfruit	14.0	34.8	39.4	18.7	-0.2
Olives	13.5	10.9	10.4	15.1	-0.2
Cattle	-15.2	-29.1		2.9	-21.1
Pigs	2.1	-15.1		12.6	-22.2
Sheepgoats	-11.9	-26.3		2.2	-18.3
Poulteggs	-1.4	0.1		6.6	-17.3
Rawmilk	-5.0	-4.2		12.2	0.2

FIGURE 1.
The Evolution of Emissions over Time

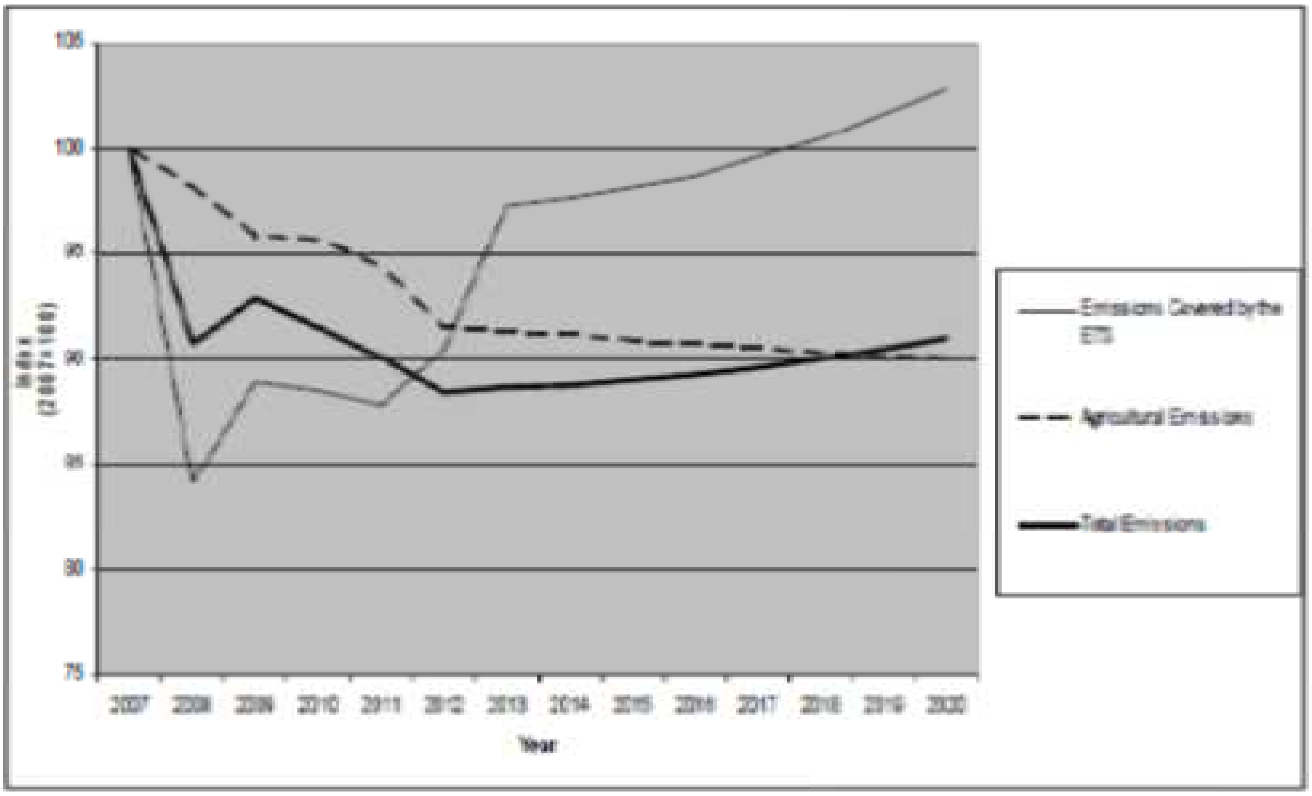


Figure 2: Calibrated MAC curve for livestock CH4 emissions.

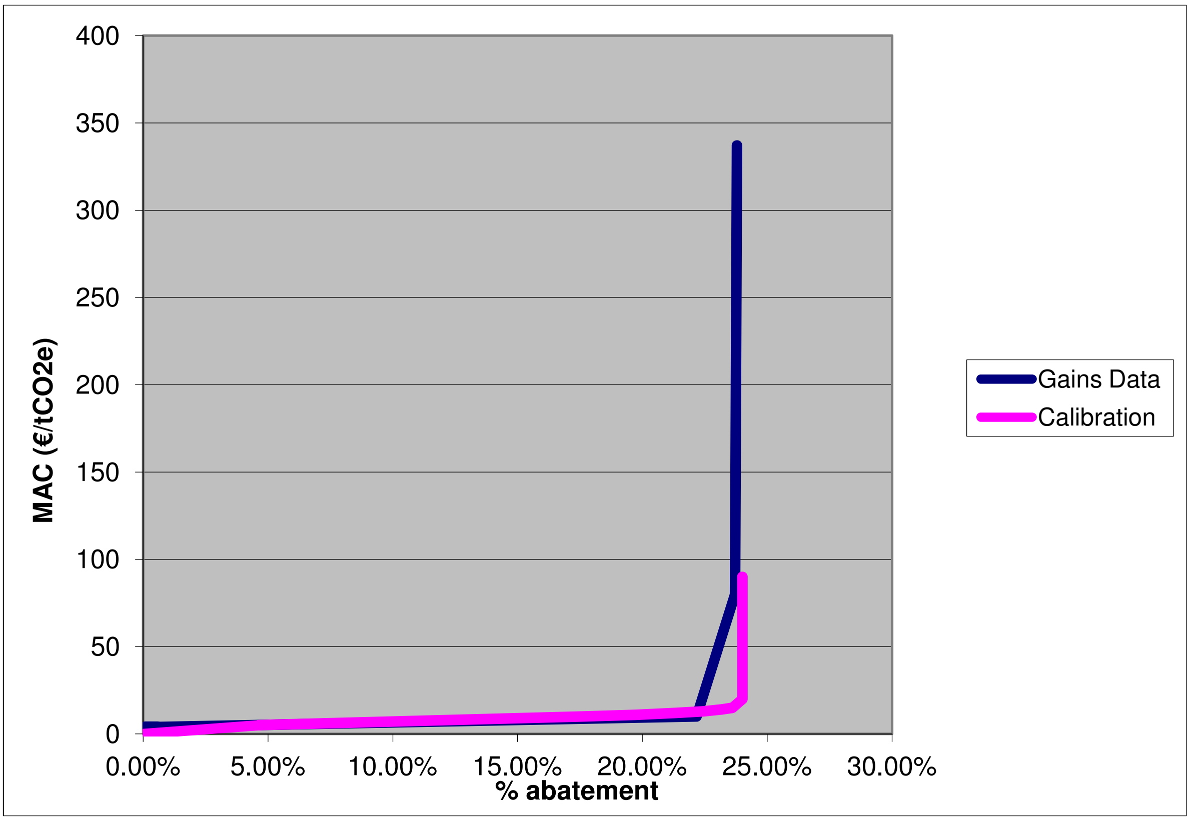


Figure 3: Calibrated MAC curve for fertiliser N2O emissions.

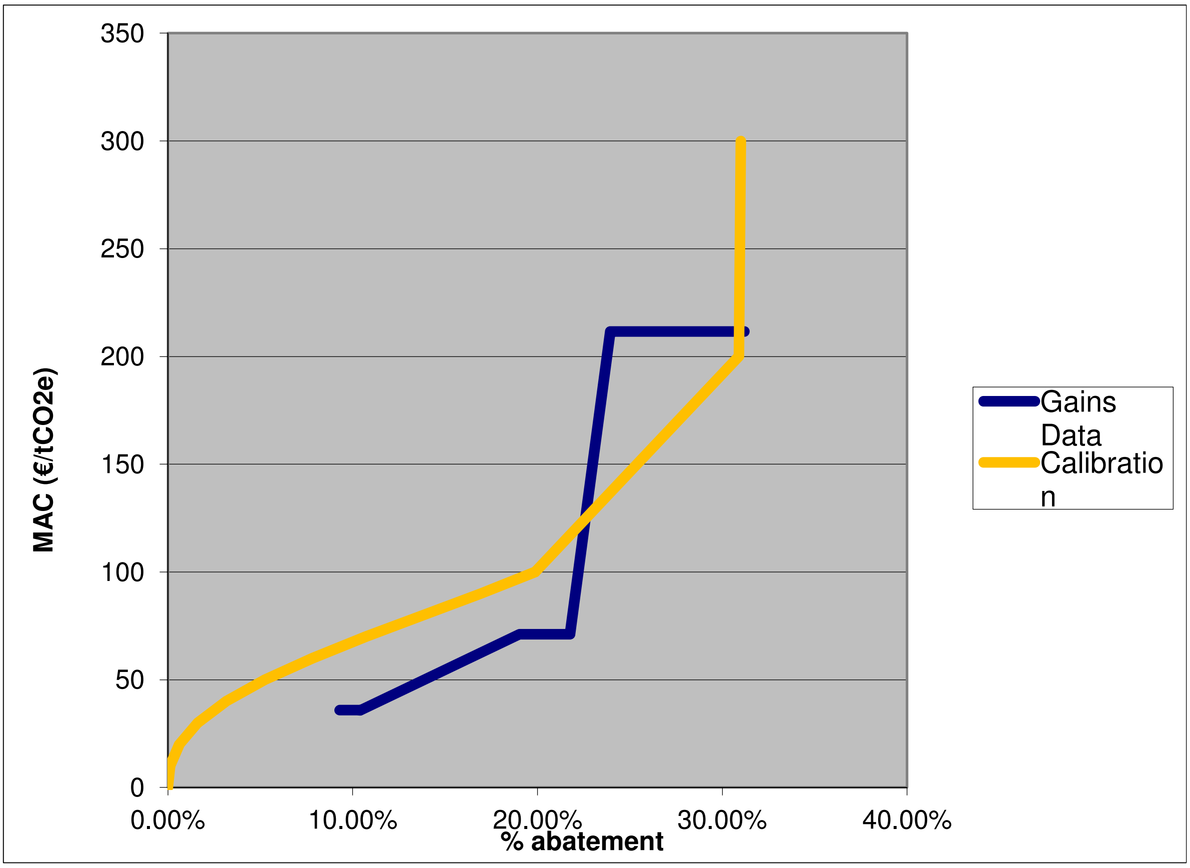


Figure 4: Emissions of major agricultural industries in policy scenario