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A quantitative assessment of the implications of including non-CO_2 emissions in the european ETS

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Abstract

Although CO_2 emissions stand for most of greenhouse gas (GHG) emissions, the contribution of mitigation efforts based on non-CO_2 emissions is still a field that needs to be explored more thoroughly. Extending abatement opportunities to non-CO_2 could reduce overall mitigation costs but it could also exert a negative pressure on agricultural output. This paper offers insights about the first effect while provides a preliminary discussion for the second.

We investigate the role of non-CO_2 GHGs in climate change mitigation in Europe using a computable general equilibrium (CGE) model. We develop a specific modelling framework extending the model with non-CO_2 GHGs as an additional mitigation alternative.

These modifications allow us to analyse the implications for the European Union (EU) of including non-CO_2 GHG emissions in its cap and trade system. We distinguish two targets on all GHG emissions for 2020, a reduction by 20% and 30% with respect to 1990 levels. Within each reduction cap, we consider two mitigation opportunities by means of a carbon tax levied on: 1) CO_2 emissions only, and 2) All GHGs emissions (both CO_2 and non-CO_2 GHG). Results show that a multi-gas mitigation policy would slightly decrease policy costs compared to the CO_2 only alternative.

Keywords: CGE, Greenhouse gas emissions, Cap-and-trade system, Agriculture, Non-CO_2 emissions, European Union, Effort Sharing Decision

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1. Introduction

Non-CO_2 greenhouse gas (GHG) emissions such as methane and nitrous oxide play an important role in Earth's climate warming. They have a greater global warming potential (GWP) than CO_2 and are responsible of approximately 30% of the anthropogenic greenhouse effect since preindustrial times (IPCC, 2001). Latest information from the International Energy Agency (IEA) points out that in 2010 non-CO_2 emissions account for around 17% of all GHG European emissions (IEA 2013). Thus, a growing attention has been devoted to these gases. As a matter of fact, these emissions come from sectors not included in the European cap and trade system (the so-called European Trading System ETS). In 2008, the European climate energy package (European Commission, 2008) outlined a differentiated strategy defining commitments for Member States and for sectors not covered by the ETS, namely transport, agriculture and waste. In 2009, the Effort Sharing Decision- ESD (European Union, 2009) established binding annual GHG emission targets for Member States for these emissions/sectors from 2013 until 2020. The current mitigation efforts can be distinguished in two broad groups: 1) Mitigation of GHG emissions currently covered by the ETS from large scale emitters, industry, and energy sectors, and 2) Abatement of emissions subject to national targets from transport, residential, and agricultural sectors. Differently from ETS sectors, targets for the ESD are based on Gross Domestic Product (GDP) per capita. This implies a global EU average emissions reduction target of 10% by 2020 compared to 2005 levels, with single targets ranging from 20% abatement for the richest countries to a 20% increase for the less rich ones. While the ETS has received large attention and has been widely studied from an economic standpoint, the implications of the ESD have not been yet fully explored. Only few exceptions exist: the works of Capros et al. (2011), Höglund-Isaksson et al. (2010) and De Cara and Jayet (2011) which shed some light on the cost-effectiveness of the ESD targets.

This paper aims at a quantitative assessment of the extension of the European ETS to allow for the exchange of permits related to non-CO_2 GHG emissions quotas. Within this context, it is possible to examine emission reduction efforts in line with the EU commitments. In particular, we want to answer the following questions: Which would be the cost of a mitigation policy that includes also non-CO_2 emissions? What would happen in terms of welfare if the European Union were to include non-CO_2 emissions in the ETS? How, a multi-gas ETS might impact the sectoral composition of output?

In fact, future climate policy implementation could produce important effects at different levels. For example, the imposition of a carbon tax in agriculture might have impacts on food consumption and on food security. Another crucial issue to be considered is the geographical distribution of non-CO_2 emissions. Large differences exist in terms of emissions per unit of output (emission intensity) between regions and sectors (Avetisyan, 2010). As we will explain later in the paper, emission intensities play a

crucial role in defining the impact of a carbon tax in a given economy and its sectors. These considerations suggest that a multi-gas approach can, in principle, improve societal welfare by better internalizing the costs of climate change but that it can also have important distributional consequences that need to be addressed in advance.

We find that policies targeting both CO_2 and non-CO_2 GHG emissions reduce the GDP loss and therefore achieve emission targets in a less costly manner. This implies a different distribution of the mitigation costs burden among all economic sectors with a higher impact on agricultural activities.

The rest of the paper has the following outline. Section 2 reviews the related literature. Section 3 shows the most notable features of the model used in this study. Section 4 explains the additions to model an extended carbon tax on non-CO_2 GHG emissions. Finally, policy scenarios and results are detailed in section 5, while Section 6 concludes.

2. Literature Review

In general, early economic literature on climate change focused mainly on CO_2 GHG emissions. As a matter of fact, CO_2 emissions represent a great deal of all GHGs emissions and derive from large emitting sectors such as industry and electricity. The first analyses on non-CO_2 emissions only appeared at the end of the nineties with quantitative studies on the costs of reducing CH_4 and N_2O emissions (Reilly et al., 1999). Since then, a growing number of studies have focused on multi-gas mitigation options and costs.

Bosello et al. (2005) reviewed the existing literature on cost efficiency of GHG mitigation policies in the agricultural sector. The methodological issues on cost effectiveness of climate change policies have been addressed by Povellato et al. (2007). In 2006, the Energy Modeling Forum realized a large model comparison (Weyant et al., 2006). The study devoted special attention to non-CO_2 GHGs and their findings showed that extending mitigation efforts to non-CO_2 emissions allows us to achieve the same policy target but at substantially lower costs.

In the following years, a number of studies (McKinsey 2009, USEPA 2006 and Smith et al. 2007) provided marginal abatement cost curves using engineering bottom-up models for the agricultural sectors. A distinguishing feature of these studies is that they have detailed information on abatement technologies but they do not have a broad macroeconomic perspective and do not take into account the mutual influences that might derive from international trade and land competition.

Recently, attention has been devoted to assess the links between land-based climate policies, development, and food security focusing on abatement opportunities and impacts in the agricultural sectors. Golub et al. (2010) analysed the effects of GHGs policy mitigation on the livestock sector using the Gtap-

AEZ-GHG model. They find that a carbon tax, combined with a subsidy in the forestry sector to reduce deforestation, can have a strong impact on the livestock production in developing countries. These results depend on the wide heterogeneity that characterizes the livestock sector in terms of emissions intensities especially between developing and developed countries. In another paper Golub et al. (2012) analyze climate policy impacts on households' income and food consumption in developing countries. They find out that farm prices might rise considerably as a consequence of the multi-gas mitigation policy. This causes a fall in food consumption among unskilled labour, and on the contrast, a consistent increase of the income of the farmers.

Undoubtedly, a considerable number of methods and approaches have been developed to assess the costs of climate policy mitigation. A synthesis of this heterogeneity is provided by Vermont and De Cara (2010). They reviewed the existing literature on the costs of mitigation in agriculture and identified three modelling approaches (see also De Cara and Jayet, 2011).Although they focused on agriculture, their categorization can be extended to a broader generalization and used to conceptualize all main approaches used to assess costs and benefits of climate policies. First, they identified studies on the supply side based on microeconomic models carefully describe the behaviour of specific group of representative farmers with detailed information on the technical and economic constraints they face in the production (De Cara et al., 2005; Hediger, 2006). Second, studies using partial or general equilibrium models which are able to consider the influence of both direct and indirect market responses to different mitigation strategies (Golub et al, 2012). Third, studies relying on engineering models (Höglund-Isaksson et al, 2010) assess mitigation potentials of new technologies within a bottom-up framework with particular emphasis on the carbon price needed to trigger the adoption of these new technologies.

The approach followed in this work pertains to the second category proposed by Vermont and De Cara. The use of a computable general equilibrium (CGE) model to assess the costs of a multi-gas mitigation policy, considering CO_2 and non-CO_2 emissions, is quite new to the literature. This enables us to have a comprehensive and realistic analysis of multi-gas mitigation policy costs and opportunities. It also provides additional information on potential distributional effects in terms of changes in production, trade and consumption.

3. An overview of the model

The analysis throughout the paper is carried out with the Intertemporal Computable Equilibrium System (ICES) model. The present version of ICES incorporates several model and database improvements. Broadly speaking, ICES is a CGE model. Originally developed to study the effects of international trade policies, nowadays CGE models are widely used to assess costs and benefits of climate policies. These

tools have the great advantage of explicitly modelling market interactions between sectors and regions. At the same time, they are usually based on detailed databases that accurately map international trade flows relying upon input output Social Accounting Matrices. Thus, it is possible to analyse how a negative shock on a specific sector and/or region might influence other areas of the economy and other countries and how they react to the initial shock.

More in detail, ICES is a recursive-dynamic CGE using the GTAP 7 database (Narayanan et al. 2008). It shares the core structure of the GTAP-E model developed by Burniaux and Truong (2002) but adds some improvements. First, it is recursive-dynamic meaning that the model solves recursively a sequence of static equilibria linked by endogenous investment decisions determining the growth of capital stock. While the GTAP database provides information for 2004, we calibrate the model to 2010 taking into account GDP and GHGs emissions growth to consider for recent economic trends. The world is divided in 13 regions (see Table 1), with the EU represented by two regions: Western Europe (WEURO) and Eastern Europe (EEURO). Each region distinguishes 18 sectors with production of goods and services (see Table 2).

On the production side, a representative firm minimize costs subject to its production constraint. The supply side tree is depicted in Figure 1. The production of final goods combines a Value Added bundle with domestic and foreign intermediate inputs (which are not perfect substitutes, according to the Armington assumption). In turn, Value Added stems from a CES function that combines four primary factors: land (considering agro-ecological zones), natural resources, labour and the capital/energy bundle (KE). Energy production and consumption considers different energy sectors. In particular, renewable energy sources (Hydro, Solar, Wind) are disentangled from the original Electricity sector, relying upon data from IEA (2010) for energy volumes (see Bosello et al. 2011). Various other sources are used to calibrate production costs for each technology.

Renewable Energy Sources (Hydro, Solar, Wind) are stand-alone sectors providing electricity to the rest of the economic system. The intermittency of solar and wind is accounted for by a low substitution with other energy sources which limit their penetration over time in the energy mix.

On the demand side, a representative household owns the factors of production, namely land, natural resource, labour and capital and earns income from the possession of these factors. Capital and labor are perfectly mobile domestically but immobile internationally.

The household spends his income choosing between three types of expenditure: private consumption, public consumption and savings. These are like three types of goods that are aggregated at the the very top-level using a Cobb-Douglas functional form. The shares of these goods are usually fixed and do not change over time. Public and private consumption consider both domestic and foreign commodities.

Public consumption follows a Cobb-Douglas specification, while private consumption employs a Constant Difference in Elasticities (CDE) functional form. This function takes into account the role of differences in income for expenditure decisions considering different income elasticities for various commodities.

4. Modelling non-CO_2 GHG emissions and their mitigation potential

To extend the features of the model, we added sectoral emissions from non-CO_2 GHGs: Methane (CH_4), Nitrous Oxide (N_2O), and 14 Fluorinated gases ($PFCs$, $HFCs$, and SF_6). Identifying emissions drivers as precisely as possible enables us to better evaluate the effects of multi-gas mitigation policies. We take advantage of the existing satellite GTAP dataset derived by Rose et al. (2010). This database distinguishes between three sources of non-CO_2 emissions: those related to input consumption (e.g. fertilizers usage in agriculture), those related to endowment consumption (e.g. land in rice cultivation or capital in livestock production), and those related to output production (e.g. wastewater treatment).

Consequently, in ICES non-CO_2 emissions are linked to the underlying economic activities that are the source. Emissions coming from inputs usage evolve proportionally to the demand for these inputs. Those coming from endowment or primary factor usage are linked to the evolution of their consumption. Finally, emissions related to output are therefore linked to output production.

As an example, nitrous oxide emissions from fertilizers use depend on the demand made by the agricultural sectors (i.e. Rice, Other Crops and Vegetables and fruits) for the sector that produce fertilizers (i.e. chemicals sector). Methane emissions that arise from the rice cultivation are tied to the demand for the land endowment. If the demand for these inputs/endowments increases the related nitrous oxide and methane emissions will increase as well.

More formally, consider an economy that produces one good y using intermediate inputs or primary factors x_1 and x_2. Assuming a Constant Elasticity of Substitution (CES) production function, the producer faces the following minimization problem:

$$\min_{x_1,x_2} p_1x_1 + p_2x_2$$

subject to

$$y = \left(a_1 x_1^{\frac{\sigma-1}{\sigma}} + a_2 x_2^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

where:

p_1 and p_2 are market prices, x_1 and x_2 the input levels, y is the output level, a_1 and a_2 are distribution parameters, and

σ is the elasticity of substitution.

Applying the first-order conditions, we can derive the conditional demand for each input:

$$x_1 = y\left(\frac{a_1}{p_1}\right)^{\sigma}\left(a_2^{\sigma}p_2^{1-\sigma} + a_1^{\sigma}p_1^{1-\sigma}\right) \tag{1}$$

$$x_2 = y\left(\frac{a_2}{p_2}\right)^{\sigma}\left(a_2^{\sigma}p_2^{1-\sigma} + a_1^{\sigma}p_1^{1-\sigma}\right) \tag{2}$$

Thus, we link non-CO_2 GHG emissions that depend on output y as,

$$w_y = \alpha_y y \tag{3}$$

where w_y is the level of emissions related to output production, and α_y is an emissions conversion factor.

In a similar way, we link non-CO_2 GHG emissions that depend on the use of input/primary factor x_i as,

$$w_{x_i} = \alpha_i x_i \tag{4}$$

where w_{x_i} are emissions related to the use of input x_i, α_i is an emissions conversion factor and x_i is the level of intermediate good or primary factor used to produce good y. Equations (3) and (4) determine the evolution of non-CO_2 emissions in the model.

Data on emissions from the GTAP satellite database (Rose et al., 2010) 2004 are presented in Table 3 for all GHG, and in Table 4 for $non - CO_2$ by sector. Table 3 shows interesting differences in terms of GHGs distribution around the world. Among all regions, if we look only at CO_2, the biggest emitter are USA (22.3%) followed by China (19.4 %) and Western Europe (13.9%). The distribution changes when we consider non-CO_2 GHGs. China accounts for the highest share of total non-CO_2 emissions (16.7%) in 2004, followed by Latin America (14.1%), USA (11.5%), Transitional Economies (11.0%) and Sub-saharan Africa (9.5%). Western and Eastern Europe hold a share of 8.2% and 1.5% of the world total, respectively.

Considering the sectoral distribution of non-CO_2 GHGs, we can see that most of the emissions originate from the agricultural sectors. At the world level, agriculture accounts for 59% of total emissions. This share range from 32.2% in Transitional Economies (TE) to 79% in Sub Saharan Africa (SSA). Therefore, we could expect different impacts due to the existing large differences between countries, particularly between developing and developed countries. In Europe, emissions from agriculture account for 55.8% in WEURO, and 41.4% in EEURO.

Information on emissions from the updated 2010 database are presented in Table 5 and Table 6. A few

aspects are worth noting in comparison with 2004. Given its size and economic activity, China becomes the largest CO_2 emitter reaching a world share of 25.6%. Regional and sectoral distribution of non-CO_2 GHG emissions does not change much between 2004 and 2010. China consolidates its leading role as emitter with the highest share of total non-CO_2 emissions (18.6%), followed by Latin America (14.1%), Transitional Economies (10.8%), Sub Saharan Africa (10.0%) and USA (9.7%). Non OECD regions' share of world non-CO_2 emissions increases from 71.8% to 75.4%. Western and Eastern Europe hold a share of 7.0% and 2.0% respectively of the world total. In terms of sectoral distribution, agriculture holds the same share of non-CO_2 emissions (59%).

4.1. Extending the mitigation portfolio to non-CO_2 emissions

Abatement alternatives in CGE models have been traditionally modelled by means of a price on emissions to internalize the external costs of polluting activities. We follow the same approach for non-CO_2 emissions and introduce a carbon tax through specific ad valorem rates depending on the source of emissions: one for the use of inputs, one for the use of endowments and one for the output emissions.

Carbon tax rates are calculated for each emitting input/endowment/output as the corresponding ratio between tax revenues and the total tax base. Then, this ad valorem tax is added up to the supply price and determines the market price that households and firms face in the market. Tax revenues accrue to the representative consumer of each region and increase regional income. Thus, for the use of input i in sector j in region r, the carbon tax rate trc_{ijr} is defined as

$$trc_{ijr} = \left(\frac{w_{ijr} ctax_r}{pm_{jr} y_{jr}} \right) \tag{5}$$

where w_{ijr} are non-CO_2 emissions related to the use of input i by sector j; $ctax_r$ is the nominal value of the tax (i.e. dollar per ton of carbon); $pm_{jr} y_{jr}$ gives the value of output (i.e. the total tax base) produced by sector j.

Such modellisation of the carbon tax implies that a change in the ad valorem tax rate can derive not only by a change of the tax levied on associated emissions but also on the emissions intensity of the input/endowment/output used (i.e. total emissions related to the use of the input divided by the economic value associated to that input).

In the model, the ad valorem tax is defined as a ratio

$$\frac{pf_{ijr}}{pm_{jr}} = t_{ijr} \tag{6}$$

With pf being the price paid by firm per unit of input and pm the market price of the input.

Thus, with the new carbon tax rate, we have

$$pf_{ijr} = pm_{jr} \times (t_{ijr} + trc_{ijr}) \tag{7}$$

Recalling (5), we can write

$$trc_{ijr} = \phi_{ijr} ctax_r \tag{8}$$

where $\phi_{ijr} = \frac{w_{ijr}}{pm_{jr} y_{jr}}$

Therefore, it's not only the amount of the tax on non-CO_2 emissions (ctax) that determines the impact of the tax on the economy but also the emission intensity per dollar of input ϕ:

$$\frac{pf_{ijr}}{pm_{jr}} = t_{ijr} + \phi_{ijr} ctax_r \tag{9}$$

Information on sectoral emission intensities for dollar of output for both CO_2 and non-CO_2 GHGs are presented in Table 7. The most CO_2 intensive sectors in both EU regions are Other Electricity (i.e. electricity produced using fossil fuel sources) and Petroleum Products. Even though CO_2 emission intensities vary in a similar order of magnitude in both regions, values are higher in EEURO.

Moreover, non-CO_2 emission intensities vary greatly both between sectors and across regions. Excluding the Rice sector which is very small both in terms of output value and level of emissions, it turns out that Livestock, Coal, and Other Crops are the most non-CO_2 intensive sectors in WEURO while in EEURO, the most non-CO_2 intensive sectors are Gas, Coal, and Livestock. Also, we observe higher emission intensity values in EEURO compared to those in WEURO. Thus, we should expect a greater impact of a tax on non-CO_2 GHG emissions in those sectors and in EEURO region.

4.2. Modelling emission trading

Introducing the possibility of levying a tax on non-CO_2 GHG emissions allows us to extend the mitigation portfolio to all sectors emitting these GHG. In addition, the possibility to put a price (tax) on emissions allows us to extend the model's formulation to consider as well a system of emission trading exchange. For this purpose, we modify the structure of the existing emission trading module and extend the constraint on emissions also for non-CO_2 GHGs. In addition, we modified the model in such a way that it is possible to set a cap on GHG emissions and allow for the exchange of emission permits of either CO_2, non-CO_2 emissions, or both at the same time. With this set-up we can assess the additional cost (benefit) of extending the exchange of permits to non-CO_2 GHG.

We allow exchange of all GHG emissions permits among selected countries which choose to participate to a coordinated mitigation effort. For this case it is possible to set regional quotas as well as the total

ETS market quota to establish the carbon price of the traded emission permits.

5. Policy scenarios and results

We formulate a reference scenario (baseline) and a set of four policy scenarios. In particular, the baseline scenario is the result of the evolution of both endogenous and exogenous variables (see Table 8). For exogenous drivers we use population projections from the United Nations (UNPD, 2010) for population and labour stock growth. We calibrate labour productivity as well as the total Factor productivity TFP and energy efficiency trends to replicate GDP growth rates and fossil fuels price trends developed in the context of the RoSe project[1] (see Kriegler et al., 2013).

In all scenarios, EU commits to reduce emissions (see Table 9) on its own. This is done by fixing a cap on all GHGs considering two reduction targets of 20% and of 30% with respect to 1990 values. Within each reduction target we distinguish two mitigation opportunities with a carbon tax imposed on emissions of: CO_2 only (i.e. $20CO_2$ and $30CO_2$) and both CO_2 and non-CO_2 GHGs (i.e. $20all$ and $30all$). In all cases, we limit GHG emissions imposing quotas within an ETS. These quotas are traded in the market of permits and determine a unique carbon price.

Since EEURO already reduced GHGs emissions by 31.4% in 2010 compared to 1990 values, we impose for 2020 a target of +1.4% equal to the baseline emissions growth. EU overall commits to reduce its emissions of 20% and 30%. The total emissions constraint applied to WEURO is augmented by the amount of so-called "hot air"[2] from the EEURO region.

The policy results in this section have been calculated as differences with respect to the baseline scenario. Results show that in terms of GDP (see Table 10), the cost of mitigation is slightly lower when we consider all GHG emissions. In the $20CO_2$ case, the two European regions, WEURO and EEURO, reduce their GDP with respect to the baseline scenario by -0.28% and -0.88% respectively. In the $20all$ case, the indirect cost of the policy in terms of GDP loss is -0.25% and -0.87%. The price of carbon is lower when all GHG emissions are considered reducing the price of carbon from $ 18.8 per ton of CO_2 to $ 16.3, per ton of CO_2 (see Table 11).

In the case of $30CO_2$, WEURO and EEURO reduce their GDP with respect to the baseline scenario by -0.71% and -2.07% respectively. For the $30all$ case, the indirect costs of the policy in terms of GDP loss are -0.62% and -2.05%. Again, the price of carbon is lower when all GHG emissions are considered reducing the overall burden of the mitigation policy from $ 49.1 to $ 41.4 per ton of CO_2eq.

[1] http://www.rose-project.org/

[2] Hot air occurs when baseline emissions are lower than the emission target. Within an ETS, the emission surplus in one region can be transferred to other regions that participate at no cost (see also De Cara and Jayet 2011)

GDP losses and the price of carbon are slightly lower than those found in other previous studies focusing on EU (Böhringer et al. 2009, Capros et al. 2011, Bosello et al. 2013a). As a matter of fact, the stringency of the target on all GHGs is lower than that calculated only on CO_2 emissions in EU. In 2010, EU has already reduced its GHG emissions of 15% (-10% WEURO and -31.4% in EEURO). This implies the imposition of a generous target for EEURO (+ 1.4% emissions growth) which has lower abatement costs compared to WEURO and is allowed to sell the permits to WEURO. This lowers the global marginal cost of abatement and implies transfers from WEURO to EEURO. As expected, regions with higher abatement costs buy emission permits from countries with lower mitigation costs or indulgent targets.

Turning our attention to emissions reductions, our results capture two important effects (see Table 12). First, even though we set the price only on CO_2 emissions, there are some reductions in non-CO_2 GHGs in the agricultural and livestock sectors in scenarios $20CO_2$ and $30CO_2$. Ancillary effects are very important as they show that there are synergies between mitigation efforts that need to be taken into account when designing policies. Second, another important aspect is that of substitution of mitigation between CO_2 and non-CO_2. In other words, taxing all GHGs allows both regions to substitute abatement efforts focusing more on CO_2 than on non-CO_2 emissions.

The substitution of mitigation efforts of CO_2 emissions with non-CO_2 in the all GHG mitigation scenarios implies a different distribution of the mitigation costs among economic sectors (see Table 13). This determines a shift of the policy burden from fossil fuel intensive sectors to agricultural sectors. Thus, a greater output reduction in fossil fuel energy sectors is observed when we tax only CO_2 emissions. These sectors bear most of the burden of the reduction needed to achieve the target. Extending the tax to all GHGs, reduces the price of carbon and allows a more efficient burden-sharing of the emissions abatement among all sectors of the economy. Particularly, in this case we observe a more prominent role of the agricultural sectors. Output reduction of Other crops sector goes from -0.21% to -0.24% in WEURO and from -0.35% to -0.47% in EEURO in 2020 for the 20% reduction scenario.

Among the agricultural sectors, the most negatively affected is livestock, with an output reduction of 1.18% and 2.82% in WEURO and 1.08% and 2.27% in EEURO for the $20all$ and $30all$ scenarios, respectively. This also implies increased net imports and reduced exports for both European regions.

Wind and solar power production grow considerably thanks to the mitigation policies. In addition, lower increases are observed in the all GHGs tax case due to the smaller price of carbon which induces slightly lower incentives to generate electricity from renewables. However, the changes in terms of renewable deployment shares both in the electricity mix and primary energy is not significant when we extend the mitigation alternative to all GHGs.

Differences in the sectoral distribution of output between the CO_2 only and all GHG become more prominent when we consider the more ambitious target of 30% reduction.

6. Conclusions

We modified the ICES model framework to include multi-gas emissions of GHG to evaluate the implications of extending the ETS to non-CO_2 GHG emissions. Results from our policy analysis suggest that non-CO_2 emissions could only slightly decrease policy costs while they would negatively affect agricultural activities and slow down the process towards a zero carbon economy. Policy makers should bear this in mind when considering the alternatives to tax or set a price on non-CO_2 emissions.

Ancillary benefits of mitigating efforts are worth exploring. Even though mitigation efforts could focus on only CO_2 emissions, there are also reductions of non-CO_2 emissions as well. This could provide additional flexibility for policy design. Substitution of mitigation efforts based on the reduction of CO_2 emissions with non-CO_2 in the all GHG mitigation option implies a different distribution of the cost of the mitigation among the economic sectors. It determines a shift of the burden from fossil fuel intensive sectors to agricultural sectors. However, this affects agricultural output, inducing a reduction of production from agricultural sectors.

Interestingly, the impacts of extending the mitigation alternatives to non-CO_2 GHG on renewable energies deployment are not very significant, in terms of the share in the electricity mix and primary energy. Nevertheless, reductions in wind and solar production might not be a cost-efficient way to make the European economy more climate-friendly and might, on the contrary, slow the path towards a low carbon economy.

Although the issues raised above suggest that non-CO_2 emissions could constitute an alternative for mitigation policies, agricultural activities would have to reduce their output as a consequence. More research is needed to provide a better understanding of such effects as well as the potential ancillary benefits.

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Appendix

Table 1: Regional aggregation

OECD	**NON-OECD**
USA (United States of America)	TE (Transitional Economies)
WEURO (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands Portugal, Spain, Sweden, UK + Norway and Switzerland)	MENA (Middle East and North Africa)
EEURO (Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Malta, Romania, Slovak Republic, Slovenia)	SSA (Sub-Saharan Africa)
KOSAU (Korea, South Africa, Australia)	SASIA (South Asia)
CAJANZ (Canada, Japan, New Zealand)	INDIA
	CHINA
	EASIA (East Asia)
	LACA (Latin America)

Table 2: Sectoral aggregation

Sectors		
Agriculture/Land Use	***Energy***	***Others***
Rice	Coal	Heavy Industry
Other Crops	Crude Oil	Light Industry
Vegetables & Fruits	Natural Gas	Services
Livestock	Petroleum Products	
Timber	Hydro	
	Solar	
	Wind	
	Other Electricity	
	Biofuels	

Table 3: Regional emissions in 2004, MtCeq

	CO2	%	N2O	%	CH4	%	Fgas	%	Non CO2	%	All GHGs	%
USA	1744.1	22.3	106.4	13.1	146.7	9.1	42.4	29.8	295.4	11.5	2039.5	19.6
WEURO	1085.9	13.9	95.2	11.7	93.1	5.8	22.1	15.5	210.4	8.2	1296.3	12.5
EEURO	171.7	2.2	15.4	1.9	20.6	1.3	1.4	1.0	37.4	1.5	209.2	2.0
KOSAU	378.0	4.8	18.7	2.3	55.2	3.4	10.2	7.2	84.2	3.3	462.2	4.4
CAJANZ	584.1	7.5	25.8	3.2	39.4	2.4	16.6	11.7	81.8	3.2	665.9	6.4
TE	785.4	10.0	53.8	6.6	218.5	13.5	9.1	6.4	281.4	11.0	1066.8	10.3
MENA	471.5	6.0	34.4	4.2	95.7	5.9	2.7	1.9	132.8	5.2	604.3	5.8
SSA	46.9	0.6	85.9	10.6	156.6	9.7	0.7	0.5	243.3	9.5	290.2	2.8
SASIA	47.0	0.6	23.9	2.9	49.6	3.1	0.3	0.2	73.7	2.9	120.8	1.2
CHINA	1516.1	19.4	184.3	22.7	219.7	13.6	25.8	18.1	429.8	16.7	1945.9	18.7
INDIA	317.5	4.1	18.4	2.3	135.6	8.4	2.7	1.9	156.7	6.1	474.2	4.6
EASIA	283.7	3.6	32.1	3.9	145.7	9.0	2.2	1.5	180.0	7.0	463.7	4.5
LACA	402.7	5.1	118.5	14.6	237.7	14.7	6.1	4.3	362.3	14.1	765.0	7.4
Total	7834.7	100.0	813.0	100.0	1614.0	100.0	142.4	100.0	2569.3	100.0	10404.0	100.0

Table 4: 2004 Non-CO_2 emissions by sector and region, MtCeq

	USA	WEURO	EEURO	KOSAU	CAJANZ	TE	MENA	SSA	SASIA	CHINA	INDIA	EASIA	LACA	World
Rice	2.8	0.8	0.0	2.5	2.2	1.0	3.0	13.6	16.0	72.2	26.2	59.4	7.9	207.7
Oth.Crops	43.7	27.5	5.2	2.4	6.5	13.0	6.0	16.2	4.3	30.5	7.6	4.1	39.7	206.7
Veg.&Fruits	14.1	8.9	2.7	2.9	3.0	14.2	5.8	10.9	1.2	70.5	2.3	3.7	11.7	152.0
Livestock	65.6	80.3	13.4	35.4	25.6	57.7	31.7	151.5	36.2	129.6	70.9	47.5	203.5	948.8
Timber	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Coal	15.0	4.7	6.1	7.6	0.5	18.1	0.1	0.3	0.3	36.5	5.1	7.7	2.0	104.1
Crude Oil	6.6	0.4	0.0	0.2	3.9	22.0	29.4	11.3	0.1	0.2	0.4	5.2	13.2	93.1
Natural Gas	21.4	5.8	2.8	1.6	5.4	33.6	5.0	1.1	0.4	0.1	0.2	3.9	3.2	84.4
Petr. Prod.	1.4	3.1	0.8	0.9	0.8	18.6	11.5	0.7	0.3	1.7	2.7	6.8	12.1	61.6
Biofuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oth.Ely	5.3	2.2	0.9	0.6	0.7	2.2	0.7	0.1	0.1	2.4	0.7	0.3	1.0	17.3
Heavy Ind.	45.2	38.5	5.5	13.2	17.7	9.0	3.5	0.8	0.2	34.4	3.4	2.6	7.9	181.9
Light Ind.	0.1	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.9
Services	74.1	37.8	14.0	16.7	15.5	77.7	36.0	36.7	14.6	51.7	36.9	38.6	59.7	510.1
Total	295.4	210.5	51.7	84.2	81.8	267.2	132.7	243.3	73.7	429.8	156.7	179.9	362.0	2568.9

Table 5: Regional emissions in 2010, MtCeq

	CO2	%	N2O	%	CH4	%	Fgas	%	Non CO2	%	All GHGs	%
USA	1463.3	17.0	111.9	11.4	145.4	7.5	44.1	25.8	301.3	9.7	1764.6	15.1
WEURO	953.8	11.1	99.8	10.2	95.1	4.9	22.5	13.2	217.4	7.0	1171.2	10.0
EEURO	228.8	2.7	23.0	2.3	35.2	1.8	2.3	1.4	60.5	2.0	289.3	2.5
KOSAU	418.6	4.9	21.7	2.2	63.7	3.3	12.3	7.2	97.7	3.2	516.3	4.4
CAJANZ	524.8	6.1	27.7	2.8	39.5	2.0	17.4	10.2	84.6	2.7	609.3	5.2
TE	885.0	10.3	59.4	6.1	262.4	13.5	12.0	7.0	333.7	10.8	1218.7	10.4
MENA	574.3	6.7	44.9	4.6	119.4	6.1	3.8	2.2	168.1	5.4	742.3	6.3
SSA	56.9	0.7	111.8	11.4	196.7	10.1	1.1	0.6	309.6	10.0	366.5	3.1
SASIA	61.5	0.7	31.0	3.2	68.4	3.5	0.4	0.2	99.9	3.2	161.4	1.4
CHINA	2202.4	25.6	241.5	24.7	294.4	15.2	40.0	23.4	575.9	18.6	2778.3	23.7
INDIA	428.4	5.0	23.5	2.4	181.0	9.3	4.1	2.4	208.6	6.7	637.0	5.4
EASIA	366.6	4.3	37.3	3.8	157.1	8.1	3.3	1.9	197.7	6.4	564.3	4.8
LACA	446.8	5.2	145.2	14.8	284.2	14.6	7.7	4.5	437.0	14.1	883.9	7.6
Total	8611.1	100.0	978.7	100.0	1942.4	100.0	171.0	100.0	3092.1	100.0	11703.2	100.0

Table 6: 2010 Non-CO_2 emissions by sector and region, MtCeq

	USA	WEURO	EEURO	KOSAU	CAJANZ	TE	MENA	SSA	SASIA	CHINA	INDIA	EASIA	LACA	World
Rice	3.0	0.9	0.0	2.6	2.2	1.0	3.1	13.7	17.2	73.4	26.4	58.6	8.4	210.5
Other Crops	47.9	30.8	5.8	2.8	7.6	15.0	7.8	20.0	4.8	34.9	9.1	4.6	49.9	241.0
Veg.&Fruits	15.2	9.6	3.0	3.3	3.3	16.0	7.1	13.5	1.4	85.5	2.7	3.9	14.0	178.6
Livestock	69.6	84.8	16.0	42.3	27.8	74.2	42.1	194.9	53.3	188.8	96.2	55.7	244.9	1190.5
Timber	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Coal	11.5	3.7	6.3	7.7	0.4	20.1	0.1	0.4	0.4	52.1	7.3	9.7	1.8	121.4
Crude Oil	5.3	0.3	0.0	0.2	3.4	24.5	32.7	11.8	0.1	0.3	0.6	4.2	14.1	97.6
Natural Gas	18.6	4.9	3.4	1.8	4.2	40.4	5.8	1.1	0.5	0.1	0.3	4.0	3.4	88.5
Petr. Prod.	1.2	2.7	0.8	1.0	0.7	21.1	13.4	0.8	0.4	2.4	3.5	7.5	13.3	69.0
Biofuels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Solar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wind	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydro	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oth.Ely	5.2	2.0	0.9	0.7	0.7	2.7	0.8	0.1	0.2	3.8	1.1	0.4	1.2	19.9
Heavy Ind	46.9	39.0	6.8	15.8	18.5	12.5	4.9	1.2	0.3	53.1	5.2	3.8	9.9	217.7
Light Ind	0.1	0.3	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.9
Services	76.8	38.4	17.4	19.4	15.8	106.1	50.2	52.1	21.3	81.4	56.3	45.0	75.8	655.8
Total	301.3	217.4	60.5	97.7	84.6	333.7	168.1	309.6	99.9	575.9	208.6	197.6	436.7	3091.5

Table 7: CO_2 and non-CO_2 emission intensities (kiloton of CO_2/dollars)

	CO_2	**non-CO_2**
Rice	0.16	2.36
Oth. Crops	0.14	0.76
Veg.&Fruits	0.10	0.35
Livestock	0.07	2.04
Timber	0.07	0.00
Coal	0.01	1.76
Crude Oil	0.13	0.02
Gas	0.52	0.50
Petr. Prod.	2.07	0.04
Biofuels	0.01	0.00
Solar	0.00	0.00
Wind	0.00	0.00
Hydro	0.00	0.00
Oth.Ely	3.21	0.03
Heavy Ind.	0.06	0.02
Light Ind.	0.04	0.00
Services	0.06	0.01

(a) WEURO

	CO_2	**non-CO_2**
Rice	0.13	0.65
Oth. Crops	0.16	0.52
Veg.&Fruits	0.17	0.55
Livestock	0.18	1.91
Timber	0.10	0.00
Coal	0.22	3.23
Crude Oil	0.62	0.06
Gas	2.32	4.72
Petr. Prod.	3.83	0.10
Biofuels	0.01	0.00
Solar	0.00	0.00
Wind	0.00	0.00
Hydro	0.00	0.00
Oth.Ely	7.06	0.07
Heavy Ind.	0.14	0.03
Light Ind.	0.08	0.00
Services	0.14	0.08

(b) EEURO

Table 8: Main variables used for baseline calibration (growth rates 2010-2020)

Region	**GDP**	**Population**	**Energy efficiency**	**Emissions of all GHG**
USA	28.5	8.6	32.7	10.9
WEURO	22.7	2.9	40.6	1.3
EEURO	25.0	-0.8	63.8	1.4
KOSAU	30.7	5.8	25.0	13.1
CAJANZ	19.6	1.1	25.4	-1.1
TE	65.0	3.0	40.6	38.2
MENA	51.5	17.5	38.3	28.1
SSA	81.6	28.5	38.3	64.8
SASIA	77.9	16.7	35.8	51.9
CHINA	66.3	3.5	36.8	37.5
INDIA	84.6	13.3	35.8	55.6
EASIA	83.3	28.1	40.6	48.4
LACA	50.4	10.4	31.5	29.0
World prices of fossil fuel sources *(% wrt 2010)*:				
Coal	4.4			
Oil	30.5			
Gas	2.5			

Table 9: The definition of the scenarios.

Name	**Description**
BL	Baseline
20CO_2	All GHG emissions reduction of 20% wrt 1990 values → Tax only on CO_2 emissions
20*all*	All GHG emissions reduction of 20% wrt 1990 values → Tax on all GHG emissions
30CO_2	All GHG emissions reduction of 30% wrt 1990 values → Tax only on CO_2 emissions
30*all*	All GHG emissions reduction of 30% wrt 1990 values → Tax on all GHG emissions

Table 10: Policy costs in 2020 (GDP loss wrt BAU)

	20co2	**20all**	**30co2**	**30all**
USA	0.0	0.0	0.1	0.1
WEURO	**-0.28**	**-0.25**	**-0.71**	**-0.62**
EEURO	**-0.88**	**-0.87**	**-2.07**	**-2.05**
KOSAU	0.0	0.0	0.1	0.1
CAJANZ	0.0	0.0	0.1	0.1
TE	-0.2	-0.2	-0.4	-0.3
MENA	0.0	0.0	-0.1	0.0
SSA	0.0	0.0	0.0	0.0
SASIA	0.0	0.0	0.1	0.1
CHINA	0.0	0.0	0.1	0.1
INDIA	0.1	0.1	0.1	0.1
EASIA	0.0	0.1	0.1	0.1
LACA	0.0	0.0	0.1	0.1

Table 11: Carbon price: $ per ton of CO_2

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
20co2	1.1	2.2	3.6	5.1	6.9	8.8	11.0	13.3	16.0	18.8
20all	1.0	2.0	3.2	4.6	6.1	7.8	9.7	11.7	13.9	16.3
30co2	2.3	5.0	8.1	11.8	16.1	21.0	26.7	33.2	40.6	49.1
30all	2.1	4.5	7.3	10.5	14.2	18.4	23.1	28.5	34.6	41.4

Table 12: Emissions reductions: % differences wrt BAU in 2020, CO_2 and non-CO_2

	20co2	**20all**	**30co2**	**30all**
USA	0.1	0.1	0.2	0.2
WEURO	**-9.8**	**-9.0**	**-19.7**	**-17.9**
EEURO	**-21.1**	**-20.1**	**-35.9**	**-34.3**
KOSAU	0.2	0.2	0.4	0.4
CAJANZ	0.1	0.1	0.3	0.3
TE	0.2	0.2	0.4	0.4
MENA	0.1	0.1	0.2	0.2
SSA	0.1	0.1	0.1	0.1
SASIA	0.1	0.1	0.2	0.2
CHINA	0.1	0.1	0.3	0.3
INDIA	0.1	0.1	0.3	0.3
EASIA	0.1	0.1	0.2	0.3
LACA	0.1	0.1	0.3	0.3

(a) CO_2

	20co2	**20all**	**30co2**	**30all**
USA	0.0	0.1	0.0	0.1
WEURO	**-1.1**	**-3.8**	**-2.2**	**-7.8**
EEURO	**-4.7**	**-9.3**	**-8.2**	**-16.2**
KOSAU	-0.2	0.0	-0.4	0.2
CAJANZ	0.0	0.1	0.1	0.2
TE	-0.3	-0.2	-0.5	-0.3
MENA	0.0	0.1	-0.1	0.1
SSA	0.0	0.1	0.0	0.2
SASIA	0.0	0.1	0.1	0.2
CHINA	0.0	0.1	0.1	0.2
INDIA	0.1	0.1	0.1	0.2
EASIA	0.0	0.1	0.1	0.2
LACA	0.0	0.1	0.0	0.2

(b) non-CO_2

Table 13: Sectoral output: % differences wrt BAU in 2020, WEURO and EEURO

	20co2	20all	30co2	30all
Rice	-0.29	-0.20	-0.71	-0.50
Oth. Crops	-0.21	-0.24	-0.49	-0.56
Veg.&Fruits	-0.06	-0.04	-0.12	-0.08
Livestock	-0.16	-1.18	-0.42	-2.82
Timber	-0.07	-0.04	-0.16	-0.09
Coal	-24.46	-24.04	-41.96	-42.29
Crude Oil	-3.15	-2.72	-7.75	-6.62
Gas	-12.18	-11.96	-26.04	-25.50
Petr. Prod.	-3.79	-3.33	-9.38	-8.12
Biofuels	-0.58	-0.51	-1.60	-1.39
Solar	10.15	9.26	23.44	21.06
Wind	5.69	5.21	13.45	12.11
Hydro	5.13	5.10	8.51	8.39
Oth.Ely	-2.11%	-1.87%	-4.48%	-3.98%
Heavy Ind.	-0.36	-0.33	-0.79	-0.72
Light Ind.	-0.15	-0.33	-0.40	-0.83
Services	-0.16	-0.12	-0.42	-0.32

(a) WEURO

	20co2	20all	30co2	30all
Rice	-1.31	-1.30	-3.10	-3.06
Oth. Crops	-0.35	-0.47	-0.85	-1.10
Veg.&Fruits	-0.52	-0.51	-1.30	-1.27
Livestock	-0.52	-1.08	-1.01	-2.27
Timber	-0.48	-0.40	-1.30	-1.07
Coal	-30.73	-32.27	-49.23	-52.57
Crude Oil	-10.00	-9.32	-22.78	-21.17
Gas	-18.46	-23.84	-37.58	-46.47
Petr. Prod.	-8.64	-7.82	-19.57	-17.59
Biofuels	-0.93	-0.95	-2.61	-2.64
Solar	17.72	17.06	37.85	36.33
Wind	15.57	14.88	33.68	31.91
Hydro	4.13	4.10	6.51	6.39
Oth.Ely	-7.41%	-6.97%	-14.01%	-13.16%
Heavy Ind.	-1.77	-1.64	-4.71	-4.30
Light Ind.	-0.35	-0.42	-0.57	-0.78
Services	-0.46	-0.44	-0.78	-0.80

(b) EEURO

Figure 1: ICES Production tree

