NOTA DI LAVORO
100.2013

A Quantitative Assessment of the Implications of Including non-CO2 Emissions in the European ETS

By **Carlo Orecchia**, Fondazione Eni Enrico Mattei (FEEM), and Euro-Mediterranean Center on Climate Change (CMCC), Italy

Ramiro Parrado, Fondazione Eni Enrico Mattei (FEEM), and Euro-Mediterranean Center on Climate Change (CMCC), Italy

Climate Change and Sustainable Development
Series Editor: Carlo Carraro

A Quantitative Assessment of the Implications of Including non-CO2 Emissions in the European ETS

By Carlo Orecchia, Fondazione Eni Enrico Mattei (FEEM), and Euro-Mediterranean Center on Climate Change (CMCC), Italy
Ramiro Parrado, Fondazione Eni Enrico Mattei (FEEM), and Euro-Mediterranean Center on Climate Change (CMCC), Italy

Summary

Although CO2 emissions stand for most of greenhouse gas (GHG) emissions, the contribution of mitigation efforts based on non-CO2 emissions is still a field that needs to be explored more thoroughly. Extending abatement opportunities to non-CO2 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-CO2 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-CO2 GHGs as an additional mitigation alternative. These modifications allow us to analyse the implications for the European Union (EU) of including non-CO2 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) CO2 emissions only, and 2) All GHGs emissions (both CO2 and non-CO2 GHG). Results show that a multi-gas mitigation policy would slightly decrease policy costs compared to the CO2 only alternative.

Keywords: CGE, Greenhouse gas emissions, Cap-and-trade system, Agriculture, Non-CO2 emissions, European Union, Effort Sharing Decision

JEL Classification: Q5, Q58

Address for correspondence:

Carlo Orecchia
Fondazione Eni Enrico Mattei
Isola di San Giorgio Maggiore 8
30124 Venice
Italy
E-mail: carlo.orecchia@feem.it

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

Carlo Orecchia[a,b], Ramiro Parrado[a,b]

[a]*Fondazione Eni Enrico Mattei (FEEM), Isola di San Giorgio Maggiore 8, 30124 Venice, Italy*
[b]*Euro-Mediterranean Center on Climate Change (CMCC), Isola di San Giorgio Maggiore 8, 30124 Venice, Italy*

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

Contents

List of Tables

List of Figures

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.

References

[1] Avetisyan, M., A. Golub, T. Hertel and S. Rose. (2010), "Why a Global Carbon Policy could have a dramatic impact on the pattern of worldwide livestock productio". Draft manuscript, Center for Global Trade Analysis. Purdue University, West Lafayette, IN.

[2] Böhringer C., Rutherford T. and Tol R., (2009), "The EU 20/20/20 targets: an Overview of the EMF22". Energy Economics 31, 268-273.

[3] Böhringer, C., Fisher, C. and K.E. Rosendahl (2010), "The global effects of subglobal climate policies, Resources for the Future". Discussion Paper 10-48.

[4] Bosello, F., Buchner, B., Crimi J., Giupponi C., Piovesan F. and Povellato A. (2005), "Cost efficiency and effectiveness of GHG mitigation policies and measures in the agro-forestry sector: a survey of the economic literature. MEACAP WP2 D6. Feem, Milan, Italy.

[5] Bosello, F., Campagnolo, L., Eboli, F., Parrado, R. and Portale, E. (2011), "Extending Energy Portfolio with Clean Technologies in the ICES Model". 14th Annual Conference on Global Economic Analysis, Venice, 16–18 June. $https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID = 3632$

[6] Bosello, F., Campagnolo L., Carraro C., Eboli F., Parrado R., Portale E. (2013a), "Macroeconomic Impacts of the EU 30% GHG Mitigation Target". Feem NOTE DI LAVORO, 2013.028. Milan, Italy.

[7] Bosello, F., Orecchia C., Parrado R. (2013b), "The additional contribution of non-CO_2 mitigation in climate policy costs and efforts in Europe". Proceedings of the Gtap 16th Annual Conference on Global Economic Analysis. ISSN 2160-2115 (online).

[8] Burniaux, J.-M., Truong, T.P., (2002), "GTAP-E - an energy-environmental version of the GTAP mode"l. GTAP Technical Papers, No. 16. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana, USA 47907-1145.

[9] Calzadilla, A., Rehdanz, K., Tol, R. (2008), "The Economic Impact of More Sustainable Water Use in Agriculture: A CGE Analysis". Research Unit Sustainability and Global Change, FNU-169. Hamburg University.

[10] Capros, P., Mantzos, L., Parousos, L., Tasios, N., Klaassen, G., Van Ierland, T., (2011), "Analysis of the EU policy package on climate change and renewables". Energy Policy 39 (3), 1476-1485.

[11] De Cian, E., Sferra, F. and Tavoni M., (2013),"The Influence of Economic Growth, Population, and Fossil Fuel Scarcity on Energy Investments". FEEM Working Paper No. 59.2013. Available at SSRN: http://ssrn.com/abstract=2284045 or http://dx.doi.org/10.2139/ssrn.2284045

[12] De Cara, S., Houzé, M., Jayet, P.-A., (2005), "Methane and nitrous oxide emissions from agriculture in the EU: a spatial assessment of sources and abatement costs". Environmental and Resource Economics 32 (4), 551-583.

[13] De Cara, Jayet, P.-A., (2011), "Marginal abatement costs of greenhouse gas emissions from European agriculture, cost effectiveness, and the EU non-ETS burden sharing agreement". Ecological Economics 70 (2011), 1680-1690.

[14] Deke, O., Hooss, K. G., Kasten, C., Klepper, G., Springer, K. (2002) "Economic Impact of Climate Change: Simulations with a Regionalized Climate-Economy Model". Kiel Institute of World Economics, Kiel, 1065.

[15] Eboli, F., Parrado, R. and R. Roson (2009),"Climate Change Feedback on Economic Growth: Explorations with a Dynamic General Equilibrium Model". FEEM Note di Lavoro 2009.043.

[16] European Commission, (2008) 20 20 by 2020:" Europe's climate change opportunity. Communication COM(2008) 30 final". Commission of the European Communities, Brussels, Belgium.

[17] European Union, (2009), "Decision on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020". Decision of the European Parliament and the Council of the European Union 406/2009/EC, Official Journal of the European Union, Brussels, Belgium, L140, pp. 136-138.

[18] Golub, Alla., Thomas Hertel, Huey-Lin Lee, Steven Rose, Brent Sohngen (2009), "The opportunity cost of land use and the global potential for greenhouse gas mitigation in agriculture and forestry". Resource and Energy Economics 31 pp 299-319.

[19] Golub, Alla., B. Henderson, T. Hertel, S. Rose, M. Avetisyan, B. Sohngen (2010), "Effects of GHG Mitigation Policies on Livestock Sectors". GTAP Working Paper No.62.

[20] Golub A A, Henderson B B, Hertel T W, Gerber P J, Rose S K and Sohngen B (2012),"Global climate policy impacts on livestock, land use, livelihoods, and food security". Proc. Natl Acad. Sci. at press (doi:10.1073/pnas.1108772109).

[21] Höglund-Isaksson, L., Winiwarter, W., Wagner, F., Klimont, Z., Amann, M., (2010), "Potentials and costs for mitigation of non-CO_2 greenhouse gas emissions in the European Union until 2030". Results. Report to the European Commission, DG Climate Action Contract No. 537 07.030700/2009/545854/SER/C5. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

[22] Hediger, W., (2006), "Modeling GHG emissions and carbon sequestration in Swiss agriculture: an integrated economic approach. Greenhouse Gases and Animal Agriculture: An Update". Proceedings of the 2nd International Conference on Greenhouse Gases and Animal Agriculture (Zurich, Switzerland): International Congress Series, 1293, pp. 86-95.

[23] Hertel T.W., Lee H., Rose S., Sohngen B., Hertel T.W.,Rose S.,Tol R. (2008), "Modeling Land-use Related Greenhouse Gas Sources and Sinks and their Mitigation Potential" in "Economic Analysis of Land Use in Global Climate Change Policy". Routledge, Chapter 6.

[24] IPCC. 2001. "Climate Change 2001: The Scientific Basis, Intergovernmental Panel on Climate Change". Edited by J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, C.A. Johnson, and K. Maskell. Cambridge, UK: Cambridge University Press.

[25] Narayanan, G.B. and T.L. Walmsley, Eds. (2008), "Global Trade, Assistance, and Production: The GTAP 7 Data Base". Center for Global Trade Analysis, Purdue University.

[26] Povellato A., Bosello F. and Giupponi C. (2007) , "Cost-effectiveness of GHG mitigation measures in the european agro-forestry sector: a literature survey". Environmental Science & Policy 10 (5), 474-490.

[27] Reilly, J.,Prinn, R., Harnisch, J., Fitzmaurice, J., Jacoby, H., Kicklighter, D.W., Melillo, J.M., Stone, P., Sokolov, A., and Ng, C. (1999). "Multi-gas assessment of the Kyoto Protocol". Nature, 401, 549-555.

[28] Rose, S.K., Avetisyan, M., and Hertel, T. W (2010),"Development of the Preliminary Version 7 Non-CO_2 GHG Emissions Dataset". GTAP Research Memorandum No. 17.

[29] Rose SK, et al. (2012), "Land-based mitigation in climate stabilization". Energy Econ 34: 365-380

[30] Weyant JP, de la Chesnaye FC, Blanford GJ. (2006), "Overview of EMF-21: Multigas Mitigation and Climate Policy". The Energy Journal Special Issue on Multi-Greenhouse Gas Mitigation and Climate Policy: 1–32

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
$20all$	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
$30all$	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

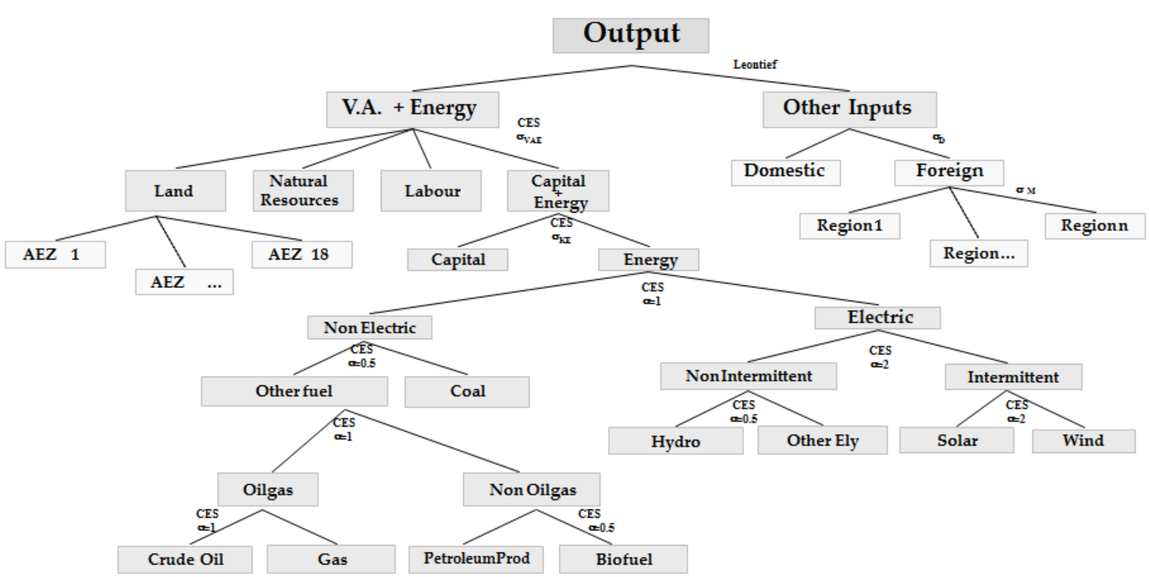
	20co2	**20all**	**30co2**	**30all**
Rice	-0.29	-0.20	-0.71	-0.50
Oth. Crops	-0.21	-0.24	-0.49	-0.56
Veg.&Fruits	-0.06	-0.04	-0.12	-0.08
Livestock	-0.16	-1.18	-0.42	-2.82
Timber	-0.07	-0.04	-0.16	-0.09
Coal	-24.46	-24.04	-41.96	-42.29
Crude Oil	-3.15	-2.72	-7.75	-6.62
Gas	-12.18	-11.96	-26.04	-25.50
Petr. 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



NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI

Fondazione Eni Enrico Mattei Working Paper Series

Our Note di Lavoro are available on the Internet at the following addresses:
http://www.feem.it/getpage.aspx?id=73&sez=Publications&padre=20&tab=1
http://papers.ssrn.com/sol3/JELJOUR_Results.cfm?form_name=journalbrowse&journal_id=266659
http://ideas.repec.org/s/fem/femwpa.html
http://www.econis.eu/LNG=EN/FAM?PPN=505954494
http://ageconsearch.umn.edu/handle/35978
http://www.bepress.com/feem/

NOTE DI LAVORO PUBLISHED IN 2013

CCSD	1.2013	Mikel Bedayo, Ana Mauleon and Vincent Vannetelbosch: Bargaining and Delay in Trading Networks
CCSD	2.2013	Emiliya Lazarova and Dinko Dimitrov: Paths to Stability in Two-sided Matching with Uncertainty
CCSD	3.2013	Luca Di Corato and Natalia Montinari: Flexible Waste Management under Uncertainty
CCSD	4.2013	Sergio Currarini, Elena Fumagalli and Fabrizio Panebianco: Games on Networks: Direct Complements and Indirect Substitutes
ES	5.2013	Mirco Tonin and Michael Vlassopoulos: Social Incentives Matter: Evidence from an Online Real Effort Experiment
CCSD	6.2013	Mare Sarr and Tim Swanson: Corruption and the Curse: The Dictator's Choice
CCSD	7.2013	Michael Hoel and Aart de Zeeuw: Technology Agreements with Heterogeneous Countries
CCSD	8.2013	Robert Pietzcker, Thomas Longden, Wenying Chen, Sha Fu, Elmar Kriegler, Page Kyle and Gunnar Luderer: Long-term Transport Energy Demand and Climate Policy: Alternative Visions on Transport Decarbonization in Energy Economy Models
CCSD	9.2013	Walid Oueslati: Short and Long-term Effects of Environmental Tax Reform
CCSD	10.2013	Lorenza Campagnolo, Carlo Carraro, Marinella Davide, Fabio Eboli, Elisa Lanzi and Ramiro Parrado: Can Climate Policy Enhance Sustainability?
CCSD	11.2013	William A. Brock, Anastasios Xepapadeas and Athanasios N. Yannacopoulos: Robust Control of a Spatially Distributed Commercial Fishery
ERM	12.2013	Simone Tagliapietra: Towards a New Eastern Mediterranean Energy Corridor? Natural Gas Developments Between Market Opportunities and Geopolitical Risks
CCSD	13.2013	Alice Favero and Emanuele Massetti: Trade of Woody Biomass for Electricity Generation under Climate Mitigation Policy
CCSD	14.2013	Alexandros Maziotis, David S. Saal and Emmanuel Thanassoulis: A Methodology to Propose the X-Factor in the Regulated English and Welsh Water And Sewerage Companies
CCSD	15.2013	Alexandros Maziotis, David S. Saal and Emmanuel Thanassoulis: Profit, Productivity, Price and Quality Performance Changes in the English and Welsh Water and Sewerage Companies
CCSD	16.2013	Caterina Cruciani, Silvio Giove, Mehmet Pinar and Matteo Sostero: Constructing the FEEM Sustainability Index: A Choquet-integral Application
CCSD	17.2013	Ling Tang, Qin Bao, ZhongXiang Zhang and Shouyang Wang: Carbon-based Border Tax Adjustments and China's International Trade: Analysis based on a Dynamic Computable General Equilibrium Model
CCSD	18.2013	Giulia Fiorese, Michela Catenacci, Valentina Bosetti and Elena Verdolini: The Power of Biomass: Experts Disclose the Potential for Success of Bioenergy Technologies
CCSD	19.2013	Charles F. Mason: Uranium and Nuclear Power: The Role of Exploration Information in Framing Public Policy
ES	20.2013	Nuno Carlos Leitão: The Impact of Immigration on Portuguese Intra-Industry Trade
CCSD	21.2013	Thierry Bréchet and Henry Tulkens: Climate Policies: a Burden or a Gain?
ERM	22.2013	Andrea Bastianin, Marzio Galeotti and Matteo Manera: Biofuels and Food Prices: Searching for the Causal Link
ERM	23.2013	Andrea Bastianin, Marzio Galeotti and Matteo Manera: Food versus Fuel: Causality and Predictability in Distribution
ERM	24.2013	Anna Alberini, Andrea Bigano and Marco Boeri: Looking for Free-riding: Energy Efficiency Incentives and Italian Homeowners
CCSD	25.2013	Shoibal Chakravarty and Massimo Tavoni: Energy Poverty Alleviation and Climate Change Mitigation: Is There a Trade off?
ERM	26.2013	Manfred Hafner and Simone Tagliapietra: East Africa: The Next Game-Changer for the Global Gas Markets?
CCSD	27.2013	Li Ping, Yang Danhui, Li Pengfei, Ye Zhenyu and Deng Zhou: A Study on Industrial Green Transformation in China
CCSD	28.2013	Francesco Bosello, Lorenza Campagnolo, Carlo Carraro, Fabio Eboli, Ramiro Parrado and Elisa Portale: Macroeconomic Impacts of the EU 30% GHG Mitigation Target
CCSD	29.2013	Stéphane Hallegatte: An Exploration of the Link Between Development, Economic Growth, and Natural Risk
CCSD	30.2013	Klarizze Anne Martin Puzon: Cost-Reducing R&D in the Presence of an Appropriation Alternative: An Application to the Natural Resource Curse
CCSD	31.2013	Johannes Emmerling and Massimo Tavoni: Geoengineering and Abatement: A 'flat' Relationship under Uncertainty

ERM	32.2013	Marc Joëts: Heterogeneous Beliefs, Regret, and Uncertainty: The Role of Speculation in Energy Price Dynamics
ES	33.2013	Carlo Altomonte and Armando Rungi: Business Groups as Hierarchies of Firms: Determinants of Vertical Integration and Performance
CCSD	34.2013	Joëlle Noailly and Roger Smeets: Directing Technical Change from Fossil-Fuel to Renewable Energy Innovation: An Empirical Application Using Firm-Level Patent Data
CCSD	35.2013	Francesco Bosello, Lorenza Campagnolo and Fabio Eboli: Climate Change and Adaptation: The Case of Nigerian Agriculture
CCSD	36.2013	Andries Richter, Daan van Soest and Johan Grasman: Contagious Cooperation, Temptation, and Ecosystem Collapse
CCSD	37.2013	Alice Favero and Robert Mendelsohn: Evaluating the Global Role of Woody Biomass as a Mitigation Strategy
CCSD	38.2013	Enrica De Cian, Michael Schymura, Elena Verdolini and Sebastian Voigt: Energy Intensity Developments in 40 Major Economies: Structural Change or Technology Improvement?
ES	39.2013	Nuno Carlos Leitão, Bogdan Dima and Dima (Cristea) Stefana: Marginal Intra-industry Trade and Adjustment Costs in Labour Market
CCSD	40.2013	Stergios Athanassoglou: Robust Multidimensional Welfare Comparisons: One Vector of Weights, One Vote
CCSD	41.2013	Vasiliki Manousi and Anastasios Xepapadeas: Mitigation and Solar Radiation Management in Climate Change Policies
CCSD	42.2013	Y. Hossein Farzin and Ronald Wendner: Saving Rate Dynamics in the Neoclassical Growth Model – Hyperbolic Discounting and Observational Equivalence
CCSD	43.2013	Valentina Bosetti and Elena Verdolini: Clean and Dirty International Technology Diffusion
CCSD	44.2013	Grazia Cecere, Susanna Mancinelli and Massimiliano Mazzanti: Waste Prevention and Social Preferences: The Role of Intrinsic and Extrinsic Motivations
ERM	45.2013	Matteo Manera, Marcella Nicolini and Ilaria Vignati: Futures Price Volatility in Commodities Markets: The Role of Short Term vs Long Term Speculation
ERM	46.2013	Lion Hirth and Inka Ziegenhagen: Control Power and Variable Renewables A Glimpse at German Data
CCSD	47.2013	Sergio Currarini and Francesco Feri: Information Sharing Networks in Linear Quadratic Games
CCSD	48.2013	Jobst Heitzig: Bottom-Up Strategic Linking of Carbon Markets: Which Climate Coalitions Would Farsighted Players Form?
CCSD	49.2013	Peter Coles and Ran Shorrer: Optimal Truncation in Matching Markets
CCSD	50.2013	Heinrich H. Nax, Bary S. R. Pradelski and H. Peyton Young: The Evolution of Core Stability in Decentralized Matching Markets
CCSD	51.2013	Manuel Förster, Michel Grabisch and Agnieszka Rusinowsk: Anonymous Social Influence
CCSD	52.2013	Nizar Allouch: The Cost of Segregation in Social Networks
ES	53.2013	Fulvio Fontini, Katrin Millock and Michele Moretto: Investments in Quality, Collective Reputation and Information Acquisition
ES	54.2013	Roberta Distante, Ivan Petrella and Emiliano Santoro: Asymmetry Reversals and the Business Cycle
CCSD	55.2013	Thomas Michielsen: Environmental Catastrophes under Time-Inconsistent Preferences
ERM	56.2013	Arjan Ruijs and Herman Vollebergh: Lessons from 15 Years of Experience with the Dutch Tax Allowance for Energy Investments for Firms
ES	57.2013	Luciano Mauro and Francesco Pigliaru: Decentralization, Social Capital and Regional Convergence
CCSD	58.2013	Alexandros Maziotis, Elisa Calliari and Jaroslav Mysiak: Robust Institutions for Sustainable Water Markets: A Survey of the Literature and the Way Forward
CCSD	59.2013	Enrica De Cian, Fabio Sferra and Massimo Tavoni: The Influence of Economic Growth, Population, and Fossil Fuel Scarcity on Energy Investments
CCSD	60.2013	Fabio Sferra and Massimo Tavoni: Endogenous Participation in a Partial Climate Agreement with Open Entry: A Numerical Assessment
ES	61.2013	Daniel Atzori: The Political Economy of Oil and the Crisis of the Arab State System
ERM	62.2013	Julien Chevallier and Benoît Sévi: A Fear Index to Predict Oil Futures Returns
CCSD	63.2013	Dominik Karos: Bargaining and Power
CCSD	64.2013	Carlo Fezzi, Ian J. Bateman, and Silvia Ferrini: Estimating the Value of Travel Time to Recreational Sites Using Revealed Preferences
ES	65.2013	Luca Di Corato, Michele Moretto and Sergio Vergalli: Long-run Investment under Uncertain Demand
ES	66.2013	Michele Moretto, Paolo Panteghini and Sergio Vergalli: Tax Competition, Investment Irreversibility and the Provision of Public Goods
CCSD	67.2013	Dennis Guignet and Anna Alberini: Can Property Values Capture Changes in Environmental Health Risks? Evidence from a Stated Preference Study in Italy and the UK
ES	68.2013	William Brock, Anastasios Xepapadeas and Athanasios Yannacopoulos: Adjustment Costs and Long Run Spatial Agglomerations
ES	69.2013	Sasan Bakhtiari, Antonio Minniti and Alireza Naghavi: Multiproduct Multinationals and the Quality of Innovation
CCSD	70.2013	Rafael González-Val and Fernando Pueyo: Trade Liberalisation and Global-scale Forest Transition
CCSD	71.2013	Elena Claire Ricci: Smart-Grids and Climate Change. Consumer adoption of smart energy behaviour: a system dynamics approach to evaluate the mitigation potential
CCSD	72.2013	Valentina Bosetti and Marco Maffezzoli: Taxing Carbon under Market Incompleteness
CCSD	73.2013	Francesco Silvestri, Stefano Ghinoi and Vincenzo Barone: Nautical Tourism, Carrying Capacity and Environmental Externality in the Lagoon of Marano and Grado

CCSD	74.2013	Herman R.J. Vollebergh and Edwin van der Werf: The Role of Standards in Eco-innovation: Lessons for Policymakers
ES	75.2013	Gérard Mondello: Ambiguous Beliefs on Damages and Civil Liability Theories
CCSD	76.2013	Roberto Antonietti and Alberto Marzucchi: Green Investment Strategies and Export Performance: A Firm-level Investigation
CCSD	77.2013	A.K.S. Chand, Sergio Currarini and Giovanni Ursino: Cheap Talk with Correlated Signals
CCSD	78.2013	Ebru A. Gencer: An Overview of Urban Vulnerability to Natural Disasters and Climate Change in Central America & the Caribbean Region
CCSD	79.2013	Libo Wu, Changhe Li, Haoqi Qian and ZhongXiang Zhang: Understanding the Consumption Behaviors on Electric Vehicles in China - A Stated Preference Analysis
ES	80.2013	Andries Richter and Johan Grasman: The Transmission of Sustainable Harvesting Norms When Agents Are Conditionally Cooperative
CCSD	81.2013	Jonathan Colmer: Climate Variability, Child Labour and Schooling: Evidence on the Intensive and Extensive Margin
ERM	82.2013	Anna Alberini, Will Gans and Charles Towe: Free Riding, Upsizing, and Energy Efficiency Incentives in Maryland Homes
CCSD	83.2013	Inge van den Bijgaart, Reyer Gerlagh, Luuk Korsten and Matti Liski: A Simple Formula for the Social Cost of Carbon
CCSD	84.2013	Elena Claire Ricci: An Integrated Assessment of Super & Smart Grids
CCSD	85.2013	Laura Diaz Anadon, Gregory Nemet and Elena Verdolini: The Future Costs of Nuclear Power Using Multiple Expert Elicitations: Effects of RD&D and Elicitation Design
CCSD	86.2013	Carlo Carraro, Massimo Tavoni, Thomas Longden and Giacomo Marangoni: The Optimal Energy Mix in Power Generation and the Contribution from Natural Gas in Reducing Carbon Emissions to 2030 and Beyond
ES	87.2013	Ho Fai Chan, Bruno S. Frey, Jana Gallus and Benno Torgler: External Influence as an Indicator of Scholarly Importance
CCSD	88.2013	Marianna Gilli, Susanna Mancinelli and Massimiliano Mazzanti: Innovation Complementarity and Environmental Productivity Effects: Reality or Delusion? Evidence from the EU
CCSD	89.2013	Adrien Vogt-Schilb and Stéphane Hallegatte: Marginal Abatement Cost Curves and the Optimal Timing of Mitigation Measures
ERM	90.2013	Lion Hirth: The Optimal Share of Variable Renewables. How the Variability of Wind and Solar Power Affects their Welfare-optimal Deployment
CCSD	91.2013	Massimiliano Mazzanti and Antonio Musolesi: Nonlinearity, Heterogeneity and Unobserved Effects in the CO2-income Relation for Advanced Countries
CCSD	92.2013	ZhongXiang Zhang: Energy and Environmental Issues and Policy in China
CCSD	93.2013	Giacomo Marangoni and Massimo Tavoni: The Clean Energy R&D Strategy for 2°C
CCSD	94.2013	Carlo Fezzi and Ian Bateman: The Impact of Climate Change on Agriculture: Nonlinear Effects and Aggregation Bias in Ricardian Models of Farm Land Values
CCSD	95.2013	Paolo D. Farah and Riccardo Tremolada: A Comparison Between Shale Gas in China and Unconventional Fuel Development in the United States: Health, Water and Environmental Risks
CCSD	96.2013	Florens Flues, Dirk Rübbelke and Stefan Vögele: Energy Efficiency and Industrial Output: The Case of the Iron and Steel Industry
CCSD	97.2013	Gregor Schwerhoff: Leadership and International Climate Cooperation
CCSD	98.2013	Francisco Alvarez and Francisco J. André: Auctioning vs. Grandfathering in Cap-and-Trade Systems with Market Power and Incomplete Information
CCSD	99.2013	Mattia Amadio, Jaroslav Mysiak, Silvano Pecora and Alberto Agnett: Looking Forward from the Past: Assessing the Potential Flood Hazard and Damage in Polesine Region by Revisiting the 1950 Flood Event
CCSD	100.2013	Carlo Orecchia and Ramiro Parrado: A Quantitative Assessment of the Implications of Including non-CO2 Emissions in the European ETS