A Review of Recent Studies on Cost Effectiveness of GHG Mitigation Measures in the European Agro-Forestry Sector

Francesco Bosello, Carlo Giupponi
and Andrea Povellato

NOTA DI LAVORO 14.2007

JANUARY 2007

NRM – Natural Resources Management

Francesco Bosello, *Fondazione Eni Enrico Mattei*
Carlo Giupponi, *Fondazione Eni Enrico Mattei and Università degli Studi di Milano, Dipartimento di Produzione Vegetale*
Andrea Povellato, *Fondazione Eni Enrico Mattei and Istituto Nazionale di Economia Agraria (INEA), Agripolis*

A Review of Recent Studies on Cost Effectiveness of GHG Mitigation Measures in the European Agro-Forestry Sector

Summary

Over the last twenty years, climate change has become an increasing concern for scientists, public opinions and policy makers. Due to the pervasive nature of its impacts for many important aspects of human life, climate change is likely to influence and be influenced by the most diverse policy or management choices. This is particularly true for those interventions affecting agriculture and forestry: they are strongly dependent on climate phenomena, but also contribute to climate evolution being sources of and sinks for greenhouse gases. This paper offers a survey of the existing literature assessing cost, effectiveness and efficiency of greenhouse gas mitigation strategies, or broader economic reforms, targeted to the agricultural and forestry sectors. The specific focus is on European Countries. Different methodological approaches, research questions addressed and results are examined. The main finding is that agriculture and forestry can potentially provide GHG reduction at a competitive cost. Nevertheless this cost is positive; accordingly, mitigation policies should be carefully designed either to balance costs with expected benefits or to avoid excessive penalisation of the sectors involved. Finally needs are highlighted for improving the existing knowledge and research methodologies.

Keywords: Agriculture, Forestry, Climate Change, Greenhouse Gases, Policy Measures, Cost-Effectiveness, Meacap

JEL Classification: Q54

Research carried out with the financial contribution of the Project MEACAP (Impact of Environmental Agreements on the Common Agricultural Policy), funded by the European Commission under the Sixth Framework Programme (SSPE-CT-2004-503604). The views expressed in this paper do not necessarily reflect the position of the European Commission.

Address for correspondence:

Carlo Giupponi
Dipartimento di Produzione Vegetale
Università degli Studi di Milano
Via Celoria, 2
20133 Milano
Italy
Phone: +39 02503 16596
Fax: +39 0250316575
E-mail: carlo.giupponi@unimi.it

1. Introduction

Climate change is recognised as one of the major sources of concern for the Planet. Even if the scientific community is not unanimous about the entities of phenomena and their most likely future trends, binding international agreements have been signed, in particular the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, entered into force on February 16th, 2005.

The European Union has played a leading role in climate negotiations and agreements within the international community. In response, to those agreements and the continuous process of negotiations at the annual Conferences and Meetings of the Parties (COP/MOP) individual Member States of the EU are designing ad hoc policies and are implementing measures which are expected to determine significant changes in many areas of human activity, including agriculture.

Large scale estimations of anthropogenic contributions to climate change are affected by largest uncertainties, nevertheless, agriculture is commonly identified as an economic sector that contribute most to climate change. According to FAO (2003, p.334) agriculture worldwide contributes about 30 % of total anthropogenic emissions of Greenhouse Gasses (GHG), accounting for 15% of total anthropogenic sources of carbon dioxide (CO_2), 49% of methane (CH_4), and 66% of nitrous oxide (N_2O).

Several agricultural practices are implicated in GHG emissions. Livestock productions and rice cultivation emitting methane and nitrous oxide (deriving also from the use of mineral fertilisers), the emissions of carbon dioxide from the conversion of tropical forest to cropland, are amongst the practices mentioned more often.

Peculiar for the agricultural and forestry sectors is its capability to act also as a sink for GHG. Therefore, the possibility emerges to adapt agricultural practices to reduce these negative impacts and, in many instances, to deliver positive benefits for the environment. The substitution of fossil fuels with biofuels and the sequestration of carbon in cultivated or forested soils, being two examples.

Adequate policies are needed for orienting agro-forestry practices to cope with the overall objectives of GHG mitigation and adaptation identified in the international agreements mentioned above and such policies should be integrated within the broader context of national and international agricultural and forestry policies and agreements.

MEACAP (Impact of Environmental Agreements on the Common Agricultural Policy) is a three-year project (2004-2007) financed by the 6th Framework Programme of the European Research, aiming at screening and evaluating technical and policy measures, for deriving strategies to progress towards a more integrated strategy between the Common Agricultural Policy (CAP) and international environmental agreements. In particular one specific objective of the project is the identification of the most desirable changes in agricultural practices and of the policy measures needed to deliver changes in practice, with focus on efficiency, effectiveness, compatibility with other objectives and constraints.

In general, policy measures in Europe should be identified to integrate the principles of the UNFCCC with the CAP to orient the agriculture and forestry activities to provide a contribution to the reduction of GHG concentrations in the atmosphere. Three are the main possible strategies at this regard: CO_2 sequestration, GHG emission reduction and fossil fuel substitution. Carbon dioxide removed from the atmosphere can be sequestered in biomass, soils and harvested products which can serve as carbon sinks, even if the preservation does not always appear effective. As mentioned above, agriculture is also the main responsible for the CH_4 and N_2O emissions that have a high CO_2 conversion coefficient, so some abatement should be obtained by modifying the production intensity and management practice of farming systems. Farming system changes could be helpful to decrease CO_2 emissions, indirectly, by reducing the use of energy-intensive inputs. Finally, CO_2 concentration can be lowered by using fossil fuel substitutes to produce energy power. With biofuel, CO_2 is essentially recycled in the atmosphere while fossil fuel combustion releases CO_2 that would otherwise be permanently stored in fossil deposits.

A list of GHG mitigation strategies and the most affected GHG by such activities are provided in Table 1 (from Murray, 2004). The list - and the mitigation measures considered in our survey - go beyond the specific measures included in the Kyoto Protocol as far as the Land Use, Land Use Change and Forestry (LULUCF) are also considered. Two considerations should be made regarding the approach of the the present survey. On the one hand, the survey reports some measures that provide GHG reductions indirectly (e.g. fossil fuel substitution) or positive environmental impact as a side effect. On the other hand, the survey tries to understand the effect of the agricultural policy reform process – mainly that endorsed by the Agenda 2000 and the 2003 Mid-Term Review - on the GHG concentration, considering its overall socioeconomic effects and impact on land use.

Table 1 - Key mitigation strategies in agriculture and forestry

		Greenhouse gas affected		
Mitigation strategy	**Strategy nature**	**CO_2**	**CH_4**	**N_2O**
Afforestation	Sequestration	X		
Deforestation (avoided)	Sequestration	X		
Timberland management	Sequestration	X		
Rotation length	Sequestration	X		
Crop tillage alteration	Sequestration	X		
Grassland conversion	Sequestration	X		
Biofuel production	Fossil fuel substitution	X	X	X
Crop mix alteration	Emission reduction, sequestration	X		X
Rice acreage reduction	Emission reduction		X	
Crop fertilizer rate reduction	Emission reduction	X		X
Other crop input alteration	Emission reduction	X		
Irrigated/dry land conversion	Emission reduction	X		X
Livestock management	Emission reduction		X	
Livestock herd size alteration	Emission reduction		X	X
Livestock system change	Emission reduction		X	X
Liquid manure management	Emission reduction		X	X

Source: Murray, 2004

This paper provides an overview of academic studies concerning the evaluation of greenhouse gas mitigation strategies targeting the agricultural and forestry sectors with specific references to the situation in Europe. It highlights the major research issues covered in the literature, the main results related to different policy instruments.

The paper is mainly devoted to comparing the results of evaluation studies rather than to comparing the methodological issues concerning the use of different types of models.

Notwithstanding, some methodological comparisons will be made if they have implications for the results obtained in the evaluation process.

The evaluation outcomes of analyses based on European experiences are not so numerous, a comprehensive analysis is difficult, moreover, available studies have unbalanced distribution among the various Member States and different mitigation strategies. Therefore, in some cases the survey has been extended to non European countries, mainly other developed countries like the USA, Canada and Australia, where the agricultural policy and the socioeconomic context is, to some extent, similar to the European one.

The paper is organised as follows. In section 2, we examine some issues concerning the definition of cost-effectiveness and the type of models used in the evaluation studies, while the other sections are devoted to the three main fields of mitigation measures. Specifically, Section 3 briefly analyses phenomena, trends and future scenarios of agro-forestry activities within the context of climate change in Europe; Section 4 deals with issues in the field of agricultural activities, Section 5 reviews some empirical studies concerning biomass and biofuel, while section 6 discusses studies related to forestry. Finally, section 7 contains some concluding remarks.

2. Methodological Issues

2.1 Cost-effectiveness analysis

From an economic point of view, the criteria for selecting policy instruments should be based on a social cost-benefit analysis with the typical efficiency rule of maximising the present value of utility over time. Also distributional concerns, macroeconomic issues and administrative feasibility should be taken into consideration (Pearce, Howarth, 2000). However, in the context of integration between environmental and economic objectives, the implementation of an economically-optimal level of pollution is often not a policy option due to the difficulty of assessing the benefits from reductions in pollution residuals. Instead, it is common for policymakers to set environmental objectives, so attention then shifts to assessing alternative instruments to achieve the objective (Weersink, *et al.*, 1998).

Setting a policy target on some basis other than a strict comparison of benefits and costs is possible and frequently used by policymakers when the level of uncertainty about the economic estimation of environmental damage is very high. The utility of the economic approach to environmental policy is not in dispute, but the analysis can be shifted to the cost consequences of choosing among different policy options to achieve a certain objective. Environmental standards can be defined on the basis of wellbeing considerations based on ecological or health evidence rather than on strict efficiency criterion.

The economic comparison of alternative policy options (strategies) leads to a cost effectiveness analysis. In the economic jargon this refers to a systematic method for finding the lowest-cost option among a set of different policy measures allowing to reach a given target. But consider that cost effectiveness does not necessarily produce the optimal allocation of resources because, as said, the predetermined objective for the strategy may not be efficient. That is, due to lack of information, its costs and benefits may not be perfectly balanced. In conclusion "all efficient policies are cost-effective, but not all cost-effective policies are efficient" (Tietenberg, 2004, p. 49). Although economic literature is not completely clear on the terminology, a more limited definition of economic efficiency stated that the compliance costs associated with a given environmental benefit should be minimised (OECD, 1989).

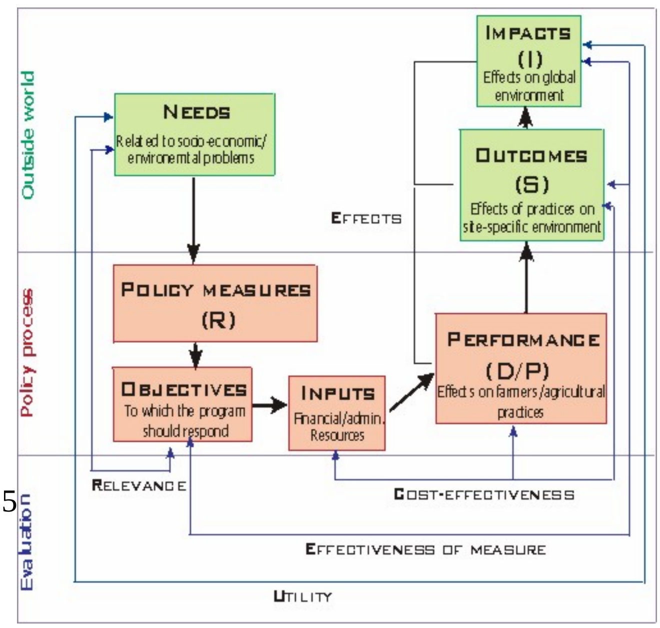
2.2 Policy evaluation framework

The choice of appropriate environmental standards and the cost estimation of the associated policy measures rise a question about the causal links between the measures and their expected positive impacts on the problem concerned. Measurable indicators should provide the data for such analysis (European Environmental Agency, 2001). By comparing the effects with the intended objectives or reference thresholds, one can say something about the effectiveness of the measure, while the comparison of inputs with the results or outcomes, can say something about its cost-effectiveness. The effectiveness of a measure can thus be defined in terms of whether the expected objectives and targets of the policy measure have or have not been achieved. Cost-effectiveness instead derives from the comparison of the effects of a set of measures with the costs of implementing them. Figure 1 illustrates in graphical format a conceptual framework showing how evaluations of the effects and cost-effectiveness of policy measures may fit within a wider policy implementation process. It builds upon the framework defined by the EEA (2001) within the REM Project (Reporting about Environmental Measures).

The conceptual frameworks makes explicit the fact that policy measures should be defined in order to fulfil specific needs related to a wide range of issues (social, economic, environmental). Having such measures explicitly stated objectives, inputs should be provided in terms of resources dedicated to the design and implementation of the measure that has a first tangible result, which is that of the response of the target group (performance). The effect of these changes in behaviour on the specific environment are the outcomes of the measure (i.e. its tangible results) and on a more global scale, the ultimate effect (on the environment and therefore on human health) is identified as the impact of the policy.

According to the conceptualisation provided in Figure 1, the present work focuses on the cost-effectiveness, i.e. on the comparison of the inputs with the performances or outcomes of the measure(s) in question.

Figure 1. Policy evaluation framework and cause-effect links indicators within a framework of cause-effect links for cost-effectiveness evaluation.



In order to facilitate the interpretation of the survey results with the current literature in the field of environmental policy and management, we have integrated the REM approach in Figure 1 with the DPSIR (Driving Force – Pressure – State – Impact – Response) environmental reporting framework (European Environmental Agency, 1999), which has the potential to better formalise the causal links between the measure and its ultimate environmental impact. The DPSIR leads on from performances in terms of human behaviour to the consequences for the biophysical environment (outcomes/impacts). It also emphasises the importance of tracing through the causality of effects, thus linking, the effects of a driving force (e.g. agricultural activities) to a certain pressure (e.g. methane emission) to a change in the state of the natural resource (e.g. depletion of air quality) to a final impact (e.g. global warming). Policy measures are thus formalised in terms of responses, from which we expect specific positive impacts on the problem in question. The terminology adopted in the following pages was as consistent as possible with the combined REM-DPSIR framework described here.

There are two main contexts in which the evaluation of a policy measure can be carried out: ex ante and ex post. Ex ante evaluation provides the estimation of the likely environmental impacts of proposed measures at a certain moment in the future. This work requires the development of future scenarios, typically representing alternative possible strategies, and the simulation of the states of selected indicators by means of modelling techniques. Ex post evaluation provides, instead, an assessment of what has actually happened following the introduction of a measure or set of measures, thus requiring primarily the availability of quantitative data measured by adequate monitoring systems (in the case of physical indicators) and other types of direct or indirect measurements and surveys (e.g. questionnaires, census data, etc.). Results of ex post evaluation are necessary to build and calibrate evidence-based models and to support future ex ante evaluation. In the case of GHG mitigation policies, evaluation is almost entirely limited to ex ante evaluations. This is explained by various reasons, but mainly because the introduction of GHG policies is relatively recent and their final impacts on GHG concentrations in the atmosphere can be expected only in the medium term.

2.3 Policy evaluation methods

The literature highlights three different perspectives of investigation. The first is technical and focuses on the effectiveness of measures. It often emphasises either complementarity and the trade-off between them disregarding the economic efficiency side. The second and the third explicitly introduce the cost dimension. One keeps a particularly sector-oriented perspective, specifying marginal abatement cost function for the agricultural sector (De Cara, Jayet, 2001; Deybe, Fallot, 2003; Gillig, *et al.*, 2004; De Cara, *et al.*, 2005, Hediger, *et al.*, 2005) the other addresses the welfare implication of a given policy (Gallagher, *et al.*, 2003; Saunders, Wreford, 2003; Wier, *et al.*, 2002; Wong, Alavalapati, 2003).

This strand of research is particularly interested in the effects induced by different economic-policy interventions that can be thought to come into play before the adoption of specific technical options to mitigate GHG emissions. Typical issues treated by this stream of literature are firstly the comparison of different policy tools in terms of cost-effectiveness. Typically, pros and cons of command-and-control (e.g. emission or concentration caps) versus market-based instruments (taxes, subsidies and trade permits) are compared (De Cara, *et al.*, 2005; Gottinger, 1998; Ignaciuk, *et al.*, 2004; Pautsch, *et al.*, 2000). Secondly, the evaluation of existing or planned policies in terms of acceptability of costs are compared to their benefits. This approach is principally proposed by the biofuel/bio-energy literature and is related to the massive public support necessary to make biofuels an economically-viable alternative to fossil fuels. The main interest here is thus to assess whether the support offered is appropriate compared to the environmental benefit obtained. (see e.g. Ericsson, *et al.*, 2004; Henke, *et al.*, 2004; Rozakis, Sourie, 2005; Rozakis, *et al.*, 2001; Vollebergh, 1997).

Different research issues often generate also different methodological approaches. “Technically” or “sectorally” oriented studies are indeed mainly conducted with a “bottom-up” approach. The terms “bottom-up” and “top-down” are typically used in energy modelling to identify two approaches: one technical and engineering oriented, the other general and economic oriented (see e.g. Grubb, *et al.*, 1993; Bohringer, 1998; Diesendorf, 1998). They are now commonly used in different fields to characterise studies of high detail, but limited in scope (bottom-up models) and studies with low detail, but wide scope (top-down models). This is also the case in this survey.

Different abatement options, their costs and effectiveness are explicitly modelled. Typically, the farmer is called upon to solve a cost minimisation or profit maximisation mathematical programming problem to decide the best technology mix to comply with a given policy requirement. A given goal (say a carbon sequestration target or a CH_4 emission reduction commitment) can be implemented through different economic instruments whose costs can be assessed and ranked according to their different implications in terms of the adoption of abatement technologies. This approach relies on highly detailed databases at the farm level (De Cara, *et al.*, 2005; Pautsch, *et al.*, 2000; Rozakis, Sourie, 2005) and examines the response to policy of a wide range of technical measures. Nevertheless, this technical orientation often obliges to restrict the investigation at the sectoral and/or plot level leaving aside the broader economic context.

On the other hand, investigating welfare implications of policies, cost/benefit analysis, cost efficiency of alternative economic instruments requires a macro or top-down view. Indeed an exercise in policy evaluation usually needs to take into account at least the inter-sectoral dependencies. Moreover, when a commodity is traded on international markets – and in the case of European agricultural products, foreign competition is going to increase due to the evolution of the CAP endorsed by the first Agenda 2000 reform and further strengthened by the last 2003 Mid-Term Review – international trade relationships also have to be considered. The appropriate scope of the investigation is thus the country or the international level.

The top-down approach highlights the economic relationships among sectors and countries emphasising trade, competitiveness and finally welfare issues associated to broad policy designs. Within this category a partial equilibrium and a general equilibrium perspective can be identified. Partial equilibrium studies concentrate on the agricultural and/or forestry sector; the rest of the economic system remains outside the picture (Ignaciuk, *et al.*, 2004; Saunders, Wreford, 2003). Even though providing a detailed characterisation of agriculture and forestry, a partial equilibrium approach cannot capture the crucial aspect of factor reallocation and demand shifts that a policy in the primary sector induces on all the other sectors and industries. Also the international dimension is highly simplified: international flows of goods and factors are indeed considered, but they are limited to the import/export of agricultural commodities. General equilibrium studies partly overcome these shortcomings. They are based on Computable General Equilibrium (CGE) models (Gottinger, 1998; Rae, Strutt, 2003; Wong, Alavalapati, 2003; Jensen, *et al.*, 2003) which comprehensively describe the economic system, optimising producers and households demand and supply goods and factors. Adjustment processes to excess demand and supply determine equilibrium prices in all markets. Profit maximisation under perfect competition and free market entrance guarantee zero profits and the optimal distribution of resources. All markets being linked, the main feature of GEMs is the ability to capture the intersectoral/international propagation mechanisms and feedback induced by a localised policy shock such as a taxation policy or the imposition of a standard in the agricultural or forestry sectors. Top-down partial, and in particular, general equilibrium models are hugely data demanding. They are based on social accounting matrices (SAM) which collects all the inputs to and outputs from each sector and each country represented. Moreover tariffs, subsidies, savings, government expenditures have to be taken into account. Finally all the behavioural parameters like substitution elasticity characterising demand and production functions and technological factors need to be calibrated or estimated.

These models suffer from some limitations. They are interested in macro-economic relationships, thus a detailed description of the technological side remains outside the scope of the investigation. Indeed technical substitution possibilities and technological improvements are usually considered only to a limited extent. By the same token, also the geographical specificity is rough: pursuing macro-economic relevance, usually the finest detail provided is the country level; it is quite unusual to have regional general equilibrium models. Finally these models are mostly static or consider highly simplified dynamics: this is a shortcoming imposed by the computational burden of their huge structure that interfaces many countries and sectors.

The increasing awareness that agriculture and forestry must be treated as systems integrated to the whole economy, coupled with the need to access a detailed description of the different options available to farmers to reduce emissions, has recently generated some integrated (or hybrid) methodologies. There are studies (Antle, *et al.*, 2003; Gillig, *et al.*, 2004; Rae, Strutt, 2003; Wier, *et al.*, 2002) that couple a socio-economic core with environmental models and/or agricultural sector models. In doing so, in principle, a comprehensive economic description can coexist with a detailed technical and environmental specification of agriculture and forestry. In practice, these exercises are still dominated by the intrinsic uncertainties surrounding the various integrated components and pose the basic problem of managing them together with the inherent set of approximations and assumptions common to any modelling exercise. Such problems still limit the potentials of integrated models to determine reliably relative effects.

Many different methodological approaches are available and have been used to study the complex relationships between agriculture and forestry, GHG emissions and mitigation policies. Each method has its own strengths and weaknesses, accordingly the main message that can be derived from this overview is that one single methodology can hardly deal with all the complexities involved. Rather than finding the best tool, the main issue becomes to select that tool/s that is/are tailored best to the problem under investigation. As an example, assessing the welfare cost and the GHG mitigation potential of a broad policy design like the CAP reform for member countries, probably requires the use of a world CGE model describing international and intersectoral relationships. Differently, a CGE model will be ill-suited to analyse the cost and environmental effectiveness of, say, different manure-management practices in a specific region; a bottom-up model would be more appropriate.

Nevertheless the two approaches do not need to be seen in opposition. Sticking to the example of CAP reform: some of the inputs of the CGE model - for instance: the change in crops' productivity, the change in livestock number, the change in forest cover, etc. - can come from bottom-up models taking into direct consideration technological shift and farmers' behaviour. Also the CGE output can be post-processed. For instance, the information about costs at the country level can be plugged into more detailed sub-models to disentangle costs at the regional or even at the farm level.

3. Agro-forestry activities and climate change: phenomena, trends and future scenarios

Before broaching the core of cost-effectiveness evaluations, we summarise below the main physical and technical aspects of the relationships between GHG emissions and the agro-forestry sector, as a basis for understanding the cause-effect chains between measures and expected outcomes. A selection of evidences presented by recent papers in the international literature is presented below aiming at pointing out the main scientific and technical aspects that should be born in mind while analysing the cost-effectiveness of GHG mitigation policy measures. The survey presented here is not intended to be comprehensive nor systematic, instead it presents - by means of examples in the European context - the relevance of issues such as: the complexity of the forestry and agro-ecological systems to be managed, the variability of the phenomena (in time and space), the existence of feedback effects usually very difficult to define, the many different sources of uncertainty affecting the analyses and contributing to discordant scientific evidences and views.

Regarding the overall contributions of the agro-forestry sector, the most recent annual report at the European level (European Environmental Agency, 2005) provides an overview of the present knowledge about GHG emissions in the EU Member States. Agriculture is reported to contribute 10% of the total emissions of the EU-15 area. Contrary to other sectors, methane and nitrous oxide are the most important gases emitted, rather than carbon dioxide. In terms of CO_2-equivalents, methane emissions from breeding animals are slightly more important than nitrous oxide emission from soils, with the most relevant source being cattle-rearing plants (27 % of the total). Nitrous oxide emissions from agricultural soils, deriving from a very complex set of mechanisms related to management practices (chemical fertilisation, microbial nitrogen fixation, cultivation of histosols, etc.) are considered to be the most uncertain. The lowest uncertainty (in the order of 12%) is attributed to methane emissions from enteric fermentations of reared animals (European Environmental Agency, 2005, p. 181), but with overall uncertainty percentages for the whole agricultural sector ranging between 41 and 74%.

A widest literature exists about carbon balance in cultivated soils. Of greater interest for the present work are those studies dealing with balances in larger areas and, in particular those at the EU level. Freibauer et al. (2004) investigated projections of carbon sequestration in the European agricultural soils in the 2008-2012 commitment period, according to possible scenarios of agricultural land uses. An extensive list of possible measures for increasing carbon stocks in agricultural soils is presented including strategies related to the management of manures, fertilisers, reduced tillage, extension and organic farming, etc., although without an explicit economic evaluation of the hypothetical measures. The BAU (business-as-usual) scenario has been compared with a set of different measures of which the most promising were shown to be: the use of organic input on arable land instead of grassland, introduction of perennial plants on set-aside land (possibly for biofuel production), promotion of organic farming, reduced tillage and careful management of watertable in farmed peat land. A catalogue of possible measures to increase the sequestration of C and to reduce the emissions of methane and nitrous oxide can be found in Oenema et al. (2001). Once more, it should be noted that many options able to increase CO_2 sequestration or limiting CH_4 emissions may have negative side effects on N_2O emissions (Brink, *et al.*, 2004); this is very important due to the high CO_2-equivalent rate of that gas.

The sequestration potential of improved cropland management in Belgium was estimated for the year 2010 considering different measures (Dendoncker, *et al.*, 2004). Estimations suggest that, by 2010, Belgium can only expect a reduction in CO2 emissions ranging from 0.47 to 0.90% of the 1990 greenhouse gas emissions by improving agricultural management. However the authors point out that the measures should not be neglected as they will have other positive effects on soil properties: the increase in soil organic carbon will also benefit agricultural productivity and sustainability.

The effects of crop types and soil variability in Europe have been assessed by Vleeshouwers and Verhagen (2002) with a model developed to calculate fluxes of carbon from agricultural soils. They compared ex ante alternative scenarios for the 2008-2012 commitment period deriving from different mitigation measures. Technical and economic feasibility were not considered. Among the findings we note that: a) arable fields are carbon sources, whereas the majority of grasslands are carbon sinks (average fluxes 0.52 and -0.84 tC ha^{-1} y^{-1} respectively); b) higher fluxes were found from arable land in the western part of the Iberian Peninsula, North Germany and Eastern Europe, with losses concentrated in north-eastern Europe; c) carbon gains from measures implementing conversion of arable land to grassland, use of farmyard manure, reduced tillage and incorporation of cereal straw showed average values of 1.44, 1.50, 0.25 and 0.15 tC ha^{-1} y^{-1} respectively (reference to 231 Mha of arable land); d) marginal and contrasting effects could come from the parallel effects of climate change (higher decomposition rate resulting from increasing temperatures not fully compensated by increased yields deriving from increased concentrations of CO_2); e) there are considerable geographical differences within Europe, with negative phenomena concentrated in regions with higher temperatures and wet summers.

Smith (2004) reviews carbon sequestration in croplands considering Europe in the global context, with specific reference to Article 3.4 of the Kyoto Protocol. Europe (from Portugal as far east as the Urals) is estimated to lose 300 Mt C per year from agricultural land (78 for the EU15 area). A combination of measures ranging from zero tillage to bioenergy crops may provide a biological potential for carbon storage in the EU15 cropland in the order of 90-120 Mt C per year. Socioeconomic and other constraints lower the realistically achievable potential to 20% of the biological one. The author stresses the need for measurability and verifiability of the expected theoretical effects of the measures and of the fact that C sequestration in soil has a finite potential and is not permanent. Therefore, strategies related to C sequestration in cropland should be considered as temporary measures to contribute to the short-term targets of the Protocol, while waiting for more effective new energy technologies to be developed in the next 20-30 years.

Six et al. (2004) go deeper into the details of the potentials of no-tillage on a global scale. They evidence the interactions between the local climatic and soil conditions and the effectiveness of the measure, showing that the role of no-tillage should be considered more carefully than in the past, since it can provide positive effects only over defined time periods, in conjunction with adequate nitrogen management, and in specific environmental conditions.

In general, chain-oriented methods seeking to increase carbon, nitrogen, water and energy use efficiency should be given priority, with the aim of increasing resource-use efficiency (Oenema, *et al.*, 2001). Europe will have the potential to significantly increase agricultural production, therefore we should either expect increasing agricultural land surpluses (according also to Rounsevell, *et al.*, 2004) or, with adequate market scenarios, we will experience an increased importance of Europe in the world food supply.

A crucial aspect for ex ante evaluations, as previously stated, is the analysis of the evolution trends of the agricultural sector and the land use changes, to allow for scenario simulations analysing the likely effects of policy measures as compared to the BAU trend. Rounsevell et al. (2004) present a method for developing quantitative, spatially explicit scenarios of agricultural land use in Europe, based on the IPCC SRES (Special Report on Emission Scenarios) storylines of the IPCC (2000) and a simple supply/demand model of agricultural areas. Substantial decreases of agricultural areas are expected if the technological developments proceed at the current rates. Thus, large areas may become surplus to the requirements of food and fibre production. The land no longer used for agricultural purposes is expected to be converted mainly to urban expansion, recreation and forest. All these possible trends are expected to have remarkable side effects on GHG emissions and sequestrations.

It is very interesting to mention one of the very few studies providing an attempt of ex post evaluation of GHG emissions as affected by changes in the agricultural sector, thus providing insight of future problems when the assessment of the outcomes of implemented measures should be performed. Sutton et al. (2004) analysed the potential of GHG monitoring activities in the UK to reduce the estimation uncertainties. They analysed the 2001 outbreak of the Foot and Mouth Disease, which dramatically reduced the number of cattle heads in some regions of the UK. The absolute changes in livestock production activities were dramatic, but nevertheless the monitoring accuracy and the estimated variations provided by regional models were of the same order of magnitude. The temporal and spatial variability of trace gases in the atmosphere adds more problems to the feasibility of ex post assessment, thus concluding that adequate and new strategies for targeted monitoring systems are needed.

Regarding the interaction between different driving forces and the feedback effects, crop productivity as affected by the interaction between socio-economic drivers and climate change is of greater interest. Olesen and Bindi (2002) attempted a general review of the possible consequences of climate change for agricultural productivity in Europe. Once more they evidence the many uncertainties and contrasting trends, but they point out that the expected increase of CO_2 concentration should in general increase resource use efficiency, with a balance between positive and negative effects to the detriment of southern Member States and expected overall positive effects in the north. They stress the need to link adaptation and mitigation policies with agri-environmental schemes of the CAP, mainly because climate change may exacerbate some of the problems of European agriculture already targeted by the CAP, and because there are evident potential synergies and side effects between CAP measures and those related to GHG emission abatement. A recent document of the European Climate Change Programme (2003), states also that the already existing dynamics of the agricultural sector are providing significant reductions in GHG emissions from agriculture, in the order of 6.4% between 1990 and 2000, while the EEA estimated an overall 10% reduction in the 1990-2003 period (European Environmental Agency, 2005).

It is worth mentioning also the work of Ewert et al. (2005), who estimated the possible future changes in crop productivity in Europe, as a consequence of climatic change (temperature, rainfall and CO_2 concentrations) and technological developments. In this case, remarkable increases in crop productivity were estimated (between 25 and 163%) and technological development is expected to play a crucial role, as the most important driver of change.

In general, from the above it is clear that the agro-forestry sector may act as both a sink of CO_2 - besides source of non-anthropogenic CO_2 - and a source of N_2O and CH_4, but the extremely complex set of variables and phenomena characterising the agricultural and forestry ecosystems, makes the analysis of causal links between policy measures and the expected positive impacts on the environment extremely challenging. Moreover, the agro-forestry sector having its own dynamics ruled by specific policies, commodity markets, etc., not only the assessment of the phenomena, but even more so the distinction of the effects of the various driving forces is very difficult.

It is clear from the above, in accordance with Freibauer et al. (2004), Antle et al. (2003) and Vleeshouwers and Verhagen (2002) that even within common mitigation policies, spatially differentiated measures are needed not only at the Member State level, but also with finer geographical details, taking into consideration the specificities of local forestry and agro-ecosystems.

4 Agricultural activities and GHG emissions

4.1 Effectiveness and costs of mitigation strategies

In general the literature following bottom-up approaches supports the idea that policy measures have some potential to induce a cost-effective abatement in the EU agricultural sector. De Cara et al. (2005) develop a linear programming model for the European agricultural sector and derive marginal abatement cost curves in response to different levels of emission taxes. They show that a 20 €/tCO2eq tax - equal to the carbon price threshold retained cost-effective for mitigation strategies by the European Climate Change Programme (2003) - can induce a 4% GHG emission reduction with respect to 2001 levels in the whole EU agriculture equalling 13.8 Mt/CO2eq. Also, it is highlighted that CH4 emissions reduction costs are lower due to the cheap option to substitute animal feeding with respect to N_2O reductions which happens only when high tax levels are imposed (above 50 €/tCO_2eq). On the contrary Deybe and Fallot (2003), using a hybrid world model for the agricultural sector, report much lower estimates of mitigation potential in the EU. They conclude that a 20\$/tCO_2eq tax allows for only 0.2% reduction of non CO_2 gases in 2010.

Hediger et al. (2005), on the basis of marginal abatement cost curves for the energy and the agricultural sectors in Switzerland, show that the possibility to allocate optimally the abatement effort required by the Kyoto Protocol between the two sectors can reduce the abatement cost per ton of CO2 from the 3.3% to the 16.5% respect to the case in which agriculture is not involved. In the period 1990-2010 agriculture contributes with a yearly GHG reduction of 0.7 to 1.20 Mt/CO2 eq.

Abatement opportunities improve when carbon sequestration is included in the analysis. De Cara and Jayet (2001) examine the response to policy of a wide range of technical measures in the European-aggregate agricultural and forestry sectors. Indeed forest carbon storage is a feasible mitigation option, nevertheless it would become economically efficient beyond a tax threshold of 50 €/tCO2eq. The relation between technical efficiency and marginal abatement costs of CO2 emission has been investigated with a short-run microeconomic simulation model of the Dutch glasshouse industry, also comparing the effects of an emission tax and systems of tradable and non-tradable quota for groups of firms with different rates of technical efficiency (Oude Lansink, 2003). The results show that marginal abatement costs are very responsive to changes in technical efficiency. Furthermore, it is found that firms with a low technical efficiency are faced with a higher profit reduction under different abatement policies than firms with a high technical efficiency

Brink et al. (2004) identify animal productions and the use and production of fertilisers as the main driving forces of agricultural emissions in the Netherlands, for nitrous oxide and methane the former, and for nitrous oxide the latter, substantially confirming a previous study (Brink, *et al.*, 2001). The same authors also identify the possible synergies and trade-offs, including ammonia as a source of air pollution from agricultural sources, within the sets of policy measures available. Potential economic synergies were found in policies for the abatement of methane and nitrous oxide with ammonia reductions as a side effect, whereas negative side effects were found between ammonia abatement and nitrous oxide emissions. The whole study suggests that integrated approaches are therefore needed. The above calls again for a crucial role to be played by integrated models to cope with ex-ante policy assessment and scenario analysis.

To complete the picture, we report on some studies on the US with similar outcomes. Gillig et al. (2004) use a detailed agricultural sector model for the US depicting production, consumption and international trade for 63 US regions, 22 traditional crops, 3 biofuel crops, 29 animal products and more than 60 processed agricultural products. The model considers 4 soil types on which 3 tillage and 3 nitrogen fertilisation technologies can be applied. They show that mitigating CH4 is cheaper than N2O: for example with a carbon equivalent price of 100 $/t, CH4 abatement is 30% higher than that of N2O. Total non-CO2 abatement is equal to nearly 17 million metric tons of carbon equivalent. The importance of carbon sequestration in forests is also highlighted. Excluding forestry, carbon sequestration can reduce the mitigation potential of a 100 $/tCeq. tax by up to 50%. Carbon sequestered amounts to nearly 30 MtCeq. Also carbon sequestration in agricultural soil can be relevant: Pautsch et al. (2000) modelling the adoption of conservation tillage in Iowa, show that a carbon price of 100$/t can "store from 3 to 4 Mt of carbon" in the soil, depending on the subsidy scheme designed. Using the U.S. Agricultural Sector Model, Lewandrowski et al. (2004) find that sequestration activities become economically feasible at different carbon prices with farmers adopting conservation tillage and other cropland management at the lowest carbon price (10 $/tCeq). The conversion of land to forest happens when the price rose to 25 $ and beyond. Another significant result of this last study concerns the economic potential of sequestration much lower than previously estimated technical possibilities made by soil scientists.

With the exception of one study, agriculture and forestry sectors show a good potential for a cost-effective GHG mitigation. In addition, CH4 abatement seems to be cheaper than N2O abatement, and this is confirmed by both European and American studies. Finally, carbon sequestration can play an important role among mitigation strategies as it offers an additional tool to reduce emissions. Nevertheless storing carbon in forests or agricultural soils is more costly than directly abate emissions in agriculture or livestock sectors thus it becomes an economic viable possibility only when abatement costs in those sectors become sufficiently high.

4.2 Evaluating alternative economic tools

In this subsection, we report the results of those studies comparing efficiency advantages of different instruments. Even though speculative, they can offer an order of magnitude for possible cost-saving opportunities.

Gottiger (1998) develops a conceptual CGE model to compare effectiveness and efficiency of emission standards, tradable emission permits and carbon taxes. He shows that using taxes or permits, welfare is roughly two times higher with respect to the case of a command-and-control approach, as stated by the vast majority of the economic literature (Tietenberg, 2004). Interestingly, the exercise demonstrates that mitigation induced by a carbon tax tends to favour land owners who can potentially experience an increase in rewards. This is due to the fact that demand for land as a production factor increases as it becomes either cheaper respect to capital - penalised more heavily by taxation - or more used as a source of carbon sink.

De Cara et al. (2005) estimate the cost reduction potential of an emission tax over a uniform relative quota both designed to meet the 4% GHG emission reduction target in EU agriculture and forestry. The average marginal abatement costs for a uniform relative quota are 3.6 times higher than the marginal abatement cost associated with the emission tax. Only increasing the rate of reduction, the relative difference between the two approaches diminishes.

Positive costs are also demonstrated by studies conducted at a supra national scale. Saunders and Wreford (2003) applying LTEM, a partial equilibrium model for 17 world regions and 19 agricultural (7 crop and 12 livestock products) commodities, analyse the effect of a unilateral policy by the EU to reduce GHG emissions from the dairy industry. The authors conclude that a 35% reduction accomplished by reducing the stocking rate and limiting nitrogen fertiliser entails a 10% loss in the raw milk producer's returns. On the other hand, by allowing the trade of emission permits at a price of 15US$/t$CO_2$, dairy industry losses can be reduced by 13% in the EU and by 3.3% in New Zealand.

Efficiency gains can be obtained not only by moving from command and control to market-based instruments, but also by choosing among different tax schemes. For instance, Ignatiuk et al. (2004), with a partial equilibrium model, examine alternative taxation policies to foster the production of bioelectricity in Poland. They show that fostering bio-electricity production seems much cheaper by means of a conventional electricity tax coupled with a bio-electricity subsidy than with a carbon tax with subsidy. Indeed, an equal revenue carbon tax is less effective by 15% and doubles the welfare cost compared to the conventional electricity tax. This depends on the fact that the conventional electricity tax is a much more direct means to address production in favour of bio-electricity than the carbon tax. In this case, when revenue-rising is not the first goal, the more distortionary instrument is better in terms of welfare than the less distortionary. On the other hand a 10% conventional electricity tax coupled with a 25% subsidy on bioelectricity production can increase the share of bioelectricity to 7.5% (Poland's policy objective for 2010), but it imposes a welfare loss of 4.5%.

Finally Pautsch et al. (2000), in their study for Iowa, show that a single per-acre subsidy paid to all adopters to undertake conservation tillage can be much more expensive than a discriminatory subsidy paying only new adopters based on their effective ability to sequester carbon. Indeed, about 1 MMt of carbon can be acquired for $ 270 per acre from a single subsidy and $ 190 from a discriminatory subsidy. Nevertheless it is recognised that this second scheme may not be viable either politically or due to prohibitively high administrative or enforcement costs. A more recent study, conducted in the grain-producing regions of Montana, shows that the relative inefficiency of per-hectare contracts increases with the degree of spatial heterogeneity of agricultural production systems (Antle, *et al.*, 2003). The high difference of costs between per-hectare and per-ton contracts, in presence of spatial heterogeneity, implies that transaction costs could be afforded by the contracting parties in order to achieve a lower total cost.

A common result in a partial equilibrium framework is that a given target can be accomplished at a lower cost if market-based instruments like taxes, incentives or tradable permits are used instead of command-and-control like emission standards and quotas. The main reason is that a market-based instrument – through equalisation of marginal abatement costs among different pollution sources - concentrates abatement where it is cheaper. On the other hand, from a strictly administrative standpoint, emissions standards and quantity restrictions are easier to operate and are more certain in terms of environmental effectiveness. Therefore they are often preferred by policy makers over first-best instruments.

4.3 The impact of Common Agricultural Policy on GHG concentration

Some studies have focussed the attention on the implications of the CAP reform process on the contribution of the farming sector to GHG emissions. Since the Mac Sharry reform in 1992, the European Union has tried to introduce substantial adjustments to the CAP with the objective of enhancing the competitiveness of EU agriculture, promoting a market-oriented, sustainable agriculture and strengthening rural development. The integration of environmental considerations in the agricultural policy process became more apparent with the Agenda 2000 reform, even if the mainstream approach of the Mac Sharry reform, based on crop subsidies and livestock support measures, was not given up. The new round of the reform in 2003, established on the basis of the Mid Term Review, should lead to more significant impacts on the relationships between agriculture and environment. Decoupling, cross-compliance and modulation should be expected to affect the intensity of agricultural factor usage and even land allocation among different land uses.

As far as Agenda 2000 is considered, the only study concerning GHG emissions was made in Denmark. Wier et al. (2002) used an integrated assessment model (DIAS) coupling a macroeconomic model (ADAM), an agricultural-economic model (ESMERALDA) and an environmental model (NERI) to assess the environmental and economic effect of the EU's Agenda 2000 reform for the Danish agricultural sector. Considering the relative difference between the Agenda 2000 scenario and the Baseline scenario, the costs are borne by the farming sector mainly as lower exports of food (-13%) and production (-7%) and a decrease in employment. The decrease in production volume is not accompanied by a significant emission reduction. CH_4 and N_2O emissions are indeed reduced only by 1% in terms of CO_2 eq., as changes in the crop mix, in fertilisation intensity and in livestock production counterbalance each other in environmental terms.

At present only four studies present some results on the impact of CAP Reform 2003: one concerns the whole EU-15, one refers to six countries, while other two analyses are focussed on Irish agriculture but with interesting comparisons due to different methodological approaches.

Using a spatial economic agricultural model for the EU15 (CAPRI), Pérez and Holm-Muller (2005) conclude that the shrinking effect on agricultural production driven by the reform can induce per-se a 1.8% GHG emission reduction in 2009 with respect to the 2001 level. Crop activities are more affected by the reduction of subsidies, so N_2O emissions decline more (-3.5%) than CH_4 emissions (-0.3%). The highest relative decrease in GHG emissions (-10%) is due to the decline in the use of synthetic fertilisers.

Ronco and Soares (2005) try to identify the overall effect of the implementation of CAP on agricultural emissions, estimating econometrically the evolution of emissions into countries before and after accession to the EU. The study, performed over Spain, Greece, Austria, Portugal, Finland, and Sweden, highlights the importance of regional specificities: CAP seems to have negative relationships with CO_2 emissions in Austria, Finland and Sweden, but an increase in Spain. It seems to be irrelevant for Greece and Portugal. The outcome is driven mainly by a loss of competitiveness, due to the fact that emissions per agricultural added value show an increasing trend. The study suggests that CAP induced a general loss of sectoral efficiency, although additional analysis should be done to confirm a consistent relationship between emissions and CAP.

Other two studies provide some evidence about the impact of the Fischler reform affecting the agriculture sector in Ireland in terms of GHG emissions. Both studies estimate an emission reduction but the different model approach has led to different results. Donnellan and Hanrahan (2003) calculate the GHG consequence using the FAPRI_Ireland partial equilibrium agricultural sector model which integrates forestry as an alternative land use. Full decoupling of CAP subsidies produces the largest reduction in GHG emissions, compared to the Baseline represented by Agenda 2000 which would have led to a less significant reduction. The Baseline projection suggests that there will be a decline of GHG emissions (approximately -9% by 2012 relative to the average of 2000-02) as a consequence of a reduction in overall agricultural activity. Under the 2003 CAP reform scenario, by 2012 the emission reduction would be almost 50% greater than the one projected to occur in the Baseline, if full decoupling was chosen, reaching an overall -13.2%. Under a minimal decoupling option the emissions would be reduced by a lesser extent, since cattle and sheep numbers are maintained at levels closer to the projected Baseline level. Carbon sequestration through farm forestry could potentially increase the net contribution of agriculture to GHG emissions in Ireland, but further analysis will be necessary.

The second study reaches similar results - full decoupling has a better performance than intermediate decoupling, and farm forestry could significantly contribute to emissions reduction - but the figures seem less relevant (Jensen, *et al.*, 2003). Using a computable general equilibrium model of the Irish economy with a disaggregated agri-food sector (IMAGE) Jensen et al. calculate a -11% decrease in GHG emissions due to different forecasts in sheep numbers. The study highlights the importance of policy details in determining the level of reductions, considering that "if agricultural land is allowed to be transferred to forestry, a double dividend can be obtained because land is no longer in emission-producing activities and it is instead used in emission sequestration".

Even though not explicitly concerned with CAP reforms we finally report the study by Rae and Strutt (2003), which investigates the partially similar situation of a potential agricultural trade-liberalisation reform in OECD countries. They couple the GTAP CGE model with a crop and livestock nitrogen balance model to disentangle, in addition to economic effects, the implications for pollution from livestock. Due to the reduced protection, all European countries experience an environmental-improving reduction in nitrogen balances. These are particularly high in Ireland and EFTA countries showing an 18% decrease from the pre-reform level.

Even though the literature is quite limited, the CAP Mid-Term review - differently from the Agenda 2000 reform - shows some GHG mitigation potential. This effect is partially induced by a possible decline in agricultural production due to the higher exposure of European market to international competition, taking into account the important role played by technological development and adaptation which are very difficult to be forecasted. On the other hand the new environmental requirements should be more effective. Even though agricultural activities and thus N_2O reductions are more directly affected, important CH_4 reductions can come from the livestock sector.

5. Biomasses for energy production

With the 1997 White Paper, the European Union (1992) declared its aim to promote the use of renewable energy. In accordance with Directive 2001/77/EC, all Member States have adopted national targets for the share of electricity production from renewable energy sources aiming to increase the use of electricity from renewable sources from the current 6% to 12% in 2010. Further initiatives were established with other two directives. The so-called Biofuel Directive (2003/30) defines indicative targets for the biofuel share of all transport fuels at 2% by 2005 and 5.75% by 2010 for the EU, while the second directive (2003/96 on the taxation of energy products and electricity) allows for tax reductions for energy from biomass. Support to biomass as an energy source is motivated by the general policy goals of secure energy supplies, low health/environmental impacts and secure incomes and jobs in the agricultural sectors. In response to these goals, a number of Member States implemented national schemes of tax exemption or subsidies that offer a particular opportunity to analyse on a practical level the cost effectiveness of a strategy with important implications for GHG mitigation in agriculture.

More recently EU has moved on with two strategic documents aimed to give further strength to the former policy initiatives in the context of an increasing energy consumption and a steady high level of the crude oil price. The Biomass Action Plan (European Commission, 1992) should guarantee the achievement of the Union's target of a 12% renewable energy share in 2010. According to the impact assessment (European Commission, 1992) the direct additional cost would be in the range of € 2.1 billions up to € 2.1 billions per year, depending on the price level of fossil fuel. Transport biofuel would account for the highest proportion of the additional costs, although its contribution to the increasing usage of renewable energy sources (RES) is estimated in third position after biomass use for electricity generation and biomass use for heat generation. With the second document dedicated to a strategy for biofuel (European Commission, 1992) the Commission tries to carry forward the biofuel component of the Biomass Action Plan. An increase of biofuel consumption will increase the budgetary burden, if Member States continue to rely on tax exemption. The rise of fiscal cost for Member States draws attention to the cost effectiveness of the proposed measures by some MS in the last years. The literature, although mainly based on low crude oil price scenario, seems to highlight that the potential for biofuel production is less effective that alternative usage of biomass as RES, not only in terms of additional costs but also considering the energy efficiency ratio and the overall environmental effects. The main conclusion of the related literature is that existing fiscal incentives and management policies supporting energy biomass are not totally justified at least on the basis of its alleged environmental superiority over fossil-fuel based energy.

The most important analysis on the perspective for biofuel was conducted in Germany. Following the results of a meta-analysis over 15 studies assessing the cost-effectiveness of tax exemption for biofuels in Germany (Henke, *et al.*, 2004), without subsidies, bio-ethanol would not be competitive respect to gasoline given that its production cost is 0.45-0.90 €/l of gasoline eq. compared to that of 0.20 €/l of gasoline. Moreover, net energy balance for the substitution of gasoline by bio-ethanol based on wheat seems negative (as reported by 7 studies over 8). It appears unambiguously positive only for the substitution by bio-ethanol based on sugar beet. Both biofuel production chains show positive GHG reduction potential (higher for sugar-beet bio-ethanol). Nevertheless, the abatement accomplished through biofuel production, under the most promising perspective will cost 270 €/t CO_2, according to the linear programming model used by the authors. Whereas the review of different studies shows a range from 300 to 1,000 €/t CO_2 of the cost for various kind of biofuel sources. The conclusion is that the present support to biofuel in Germany is not an economically viable option for climate policy. An alternative more cost-effective option to reduce GHG emissions using agricultural land would be for instance a direct use of the energy in biomass, e.g. the cultivation of fast-growing woods to produce electricity which entails an abatement cost lower than 50 €/tCO_2. The study emphasises that all these estimations were based on a crude oil price of 20 $ per barrel and higher oil prices have a decisive impact on abatement costs of the bio-ethanol strategy.

Another study examines the relationship between environmental externalities and social optimality in the waste-to-energy biomass market in the Netherlands and in the biofuels market in France (Vollebergh, 1997). Following a life-cycle assessment and cost-benefit approach the author concludes that in both cases, even though the environmental performances of bio-energy production are higher than those associated with fossil-fuel energy, private production costs are so high as to completely offset its externality-reducing properties. In particular, waste-to-energy electricity production cost in the Netherlands is estimated to be 2.5 times higher compared to fossil-fuel based energy, whereas the biofuels in France are 2 to almost 4 times more expensive than fossil fuels in a social evaluation proper. Accordingly, existent policies and subsidies to bio-energy cannot be defended by the difference they make in terms of GHG abatement, although these results might be no more reliable due to the technical change occurred from the nineties up to now.

Inefficiency in the public support to liquid biofuels in France, is highlighted by Rozakis et al. (2001) also on the purely economic grounds of competitiveness with fossil fuels. A partial equilibrium linear programming model for the agricultural sector and biofuel industry based on data from 450 farms and 9 activities per farm is developed. The study shows that when public expenditure (revenue rising) is the first priority, the optimal tax exemption for methyl ester from vegetable oil-rape seed, used as a substitute for diesel, and the optimal exemption for ethyl-tertio-buthyl-ether from ethanol of wheat and sugar beet, used as a substitute for gasoline, should be equal to 2FF/l and 3FF/l, respectively, instead of a tax exemption of 2.30FF/l and 3.30FF/l occurred in 2000. On the other hand, a priority on the reduction in GHG emissions would require an increase of ester volume produced at the expense of ethanol production implying an optimal tax exemption of 2.30FF/l for both chains. In a subsequent research (Rozakis, Sourie, 2005) the investigation was extended to consider the crucial role of market forces in determining convenience of biofuels and the appropriateness of public incentives. Uncertainty in price oscillations of oil and of soybean cake (the reference product for the market value of co-products of the biofuel production) was introduced. The main result was that even in the presence of uncertainty, tax exemptions in France could be reduced by 10%-20% with no risk for the viability of any existing chain. Using the same mathematical programming approach and a large French farm data set but different hypothesis on the farmer's objective, Kazakci and Rozakis (2005) show that farmers' decisions are not exclusively explained by the expected profit maximisation underlined LP model. The min-max regret solutions tend to improve the representative capacity of the model leading the energy crop supply curves to be upward sloped alike the classic LP supply curves. In other terms, biofuel costs calculated using min-max regret objective functions are 5% lower than their LP corresponding models.

Dalgaard et al. (2001) analysed organic and conventional farming in Denmark and found that conventional crop production provided the highest energy production, whereas the organic one showed the highest energy efficiency, although without an explicit economic evaluations of the two options. They concluded that a generalised conversion of agricultural production systems to the organic one would produce a decrease in the energy consumptions per production unit, but also an overall reduction of production at the national level.

The comparison between different biofuels highlights that wood biofuels are less area-efficient than biofuel coming from agricultural biomass, because of lower yields per unit area, and they are therefore less effective whenever land area is a limiting factor. On the other hand, wood biofuels give better GHG balances as a function of the produced amount of energy (CO2 sequestered/produced GJ), and would thus be more effective whenever area constraints are absent (Lettens, *et al.*, 2003; Nevens, *et al.*, 2004). This result seems to be connected to additional carbon sequestration in soils, living biomass and harvested products for wood biofuels.

At present the strategy of fossil fuels substitution seems to be too expensive with respect to the alternatives for CO_2 emission reduction (Faaij, 2004; Garcia-Quijano, *et al.*, 2005). To be competitive with fossil fuels, biofuels need to be sustained by policy measures (taxes, subsidies, etc.) since the prices of biofuels are always higher than their energy equivalent in fossil fuel, and are thus not an attractive alternative to arable production (Nevens, *et al.*, 2004; Parris, 2004; Vollebergh, 1997; Raven, 2004). Taking into account different mitigation incentive levels in the US context, biofuels start to be competitive in comparison with other mitigation options (soil sequestration, ethanol, afforestation) over $30 per ton for switchgrass and $40-70 per ton for willow and hybrid poplar, respectively, and dominate on other agricultural strategies at over $70 per ton (Schneider, McCarl, 2003). This result confirms that biofuels are not competitive at zero price for carbon. Always in the US context, Gallagher et al. (2003) finds a net reduction in market-based welfare when the renewable fuel standards or the national ban on the additive MTBE are implemented. Nevertheless the economic cost may be more than offset by environmental improvement, due to air improvement, decreasing cancer risk and GHG emission reduction. Looking to the producers' situation, ethanol option should be a source of improving profits for corn producers and processors

A Swedish study on the national wood fuel market confirms that wood fuels must be supported by policy measures and that they anyway compete on the market with other biofuels rather than with highly taxed fossil fuels (Hilhing, 1999). The price of forest fuels has declined as a consequence of the introduction of a carbon dioxide tax. The tax-induced large-scale development has led to technological and other improvements which lower the price (Bohlin, 1998).

Additional effects of the implementation of biofuel strategies are provided on traditional agricultural markets and environmental matters. The agricultural commodity prices rise as mitigation incentives increase because of higher land rental costs (land competition) and increased costs of intensive inputs (fertiliser and fossil fuels). The land competition led to environmental effects due to the greater pressure to intensify traditional crop production on the remaining land (Gillig, *et al.*, 2004; Schneider, McCarl, 2003; Parris, 2004). A study, conducted using a biomass-flow model generating four scenarios for Austria in 2020 (Haberl, *et al.*, 2003), tries to estimate the possible impact of policies to encourage the use of biomass as an energy source or an industrial raw material. Looking at the results of the simulations the authors conclude it is necessary to exercise caution when developing policies to substitute biomass for fossil energy in order to reduce CO_2 emissions. The potential of biomass energy should not over-estimated and many measures to increase the availability of biomass could lead to a reduction of the functioning of forest ecosystems as carbon sinks, offsetting any CO_2 reduction from fossil fuel substitution.

6. Forestry activities as a mitigation option for the GHG emission reduction

Forestry has been the subject of analysis concerning its role on the mitigation strategies since climate change became an important issue in the research field during the 1980s. Better data and sounder methods of analysis led to the first evaluation attempts to analyse the cost-effectiveness of mitigation options at the beginning of the 1990s. Two recent meta-analyses collected several studies carried out around the world to critically review the carbon sequestration cost studies. Richards and Stokes (2004) synthesise the contribution of various studies in terms of carbon-sequestering costs by means of forestry activities, while Van Kooten et. al (2004), using the data from 55 studies, employed a meta-regression analysis to estimate the relationship between carbon-uptake costs and various factors affecting such calculations. Another recent review (Prisley, Mortimer, 2004a) covers the methodological aspects of evaluation models in the field of forest carbon accounting. Due to important policy implications, the application of such models should be based on the guidelines for model development and the standards for model documentation.

The comparisons between different strategies highlight that carbon sequestration strategies (afforestation, sequestration in soils) seem to become attractive at lower incentives levels (subsidies, taxes) compared to biomass strategies for energy or materials (Gielen, *et al.*, 2002; Schneider, McCarl, 2003). On the other hand bioenergy is reported as a preferred option instead of afforestation in the long term (Gielen, *et al.*, 2002), and it has a more permanent impact on mitigation efforts in the long run (Murray, 2004). The short-rotation energy forest or energy crops are more area-efficient than the new multifunctional forests as far as emission reduction capacity is concerned. The energy plantations fit better when land occupation and environmental impacts per functional area are considered, because of their higher emission reduction capacity (Garcia-Quijano, *et al.*, 2005).

The costs of forest management projects appear to be similar to those of conservation (van Kooten, *et al.*, 2004). Increasing the stock in the wood products might be a way to reduce the costs of forestry strategies; the estimates for product sinks suggest that costs might be lowered by perhaps 75% but the stock in wood products doesn't qualify for the Kyoto Protocol as deforestation reduction (van Kooten, *et al.*, 2004). Wood products may play a role as substitutes for other materials in the mitigation of GHG emissions, avoiding emissions. As regards waste handling it is important for the impact result, but further analysis should be developed on their cost competitiveness (Petersen, Solberg, 2005).

The regions where the mitigation projects are developed could influence its costs. There seems to be no evidence of the lower cost of such strategies in the tropics (Garcia-Quijano, *et al.*, 2005; van Kooten, *et al.*, 2004). However, even if the conservation of tropical forests by avoiding deforestation should be a cost-effective mitigation option, it does not qualify for the Kyoto Protocol (Garcia-Quijano, *et al.*, 2005; van Kooten, *et al.*, 2004).

The size of incentives necessary to generate GHG mitigation in the agriculture and forest sectors ranges from $5 to $80 per tonne of CO_2 : agricultural soil carbon sequestration and forest management are fairly low-cost options, ($5 per tonne); afforestation and biofuels become the dominant mitigation options at GHG prices above $15–30 per tonne; mitigation of CH_4 and N_2O from agriculture has a fairly small but steady scope for mitigation in general (Murray, 2004).

Alternative land use can produce a mitigation effect on land areas addressed to other uses. An integrated agricultural system, consisting of short rotation coppices biofuel strips separating fields, could be a mitigation option that could be adopted in mandatory set-aside areas. The net reduction of CO_2 is equivalent to an externality benefit of about 300 €/ha, an amount equivalent to the current set-aside payments in Denmark (Kuemmel, *et al.*, 1998).

The evaluation of the forestry mitigation strategies is influenced by C sequestration estimation methods and by the costs and benefits considered in the economic analysis and applied discounting rates. The results have shown to be strongly influenced by the carbon pool types considered in the analysis (van Kooten, *et al.*, 2004). The models applied for forest carbon accounting should be evaluated in order to provide a correct application in policy decisions taking into account some model characteristics. (Prisley, Mortimer, 2004b). The estimates of the mitigation strategies in the forest sector lead to different results due to the different assumption and key factors considered. Different definitions for a “ton of carbon”, different yield levels and formats, distinct approaches for comparing the most important components of carbon sequestration costs–land opportunity cost give rise to different estimations of the costs of forest sequestration (Richards, Stokes, 2004). Several factors affect the estimates of the cost of forest carbon sequestration: forest species and practices; opportunity costs of land; the disposition of biomass, forest and agricultural product prices; methods used to account for carbon flows over time; the discount rate employed; and the policy instruments used (Stavins, Richards, 2005).

When the opportunity costs of land are considered the costs of carbon uptake significantly increase: average cost estimates raised by a factor of under three to over five times (van Kooten, *et al.*, 2004) and the inclusion of opportunity costs of land can influence the profitability of different measures when compared to each other. If optimal environmental benefits are contingent on maximum biomass yields as a carbon offset, incentives should focus on encouraging the conversion of the most productive croplands (Updegraff, *et al.*, 2004). The result is reversed whenever the opportunity costs of land are taken into account. Arable land (most often used for afforestation) becomes the least profitable, followed by pasture land, whereas non-cultivated land is more profitable, because of the higher opportunity costs of arable land (Tassone, *et al.*, 2004).

As regards discounting rates, an increase of the reported costs is expected. (increasing discounting rates.) The comparison of different studies gives contradictory results. It seems that whether or not carbon is discounted is less important than other factors in determining costs of carbon sequestration projects (van Kooten, *et al.*, 2004).

The inclusion of environmental and social benefits can change the profitability results of a mitigation program (Updegraff, *et al.*, 2004). Taking into consideration other environmental and recreational benefits, the multifunctional forest becomes the most attractive eligible option in Flanders (Garcia-Quijano, *et al.*, 2005); preliminary results on the secondary effects of afforestation suggest that these effects may be significant, leading to a positive evaluation of the effectiveness of this strategy (Richards, Stokes, 2004). To maximise different benefits different technical measures should be applied (Updegraff, *et al.*, 2004). As a consequence of the implementation of specific policies, subsidies for afforestation in agricultural land (e.g. EEC Regulation 2080/92) shorten the optimal rotation age when only timber benefits are considered; the inclusion of C uptake benefits lengthens the rotation age increasing with rising C prices (Tassone, *et al.*, 2004).

The estimates of costs and efficiency of a mitigation strategy are also conditioned by the policy measure used to achieve the emission reduction. Some policies do not affect the emissions in the forestry sector while a CO_2-target policy that entails a combination of an overall cap on carbon dioxide emissions from the stationary energy system and a target of stabilising carbon dioxide emissions from the transportation sector is conditioned by the forest sector: the development of the forest industry does not affect total emissions, thus the cost of achieving the CO_2 target is affected (Nyström, Cornland, 2003). Gielen et al. (2002) highlight how afforestation seems to have an important role in a policy scenario with limited participation and limited ambitions, while an ambitious global policy is connected to an increase in the use of biomass for energy. The introduction of a permit trade could result in additional emission reduction (20-50%). Different forest policies are associated with different responses: a land use shift is normally observed but it can be transitory (conversion back to former land use); a change in forest type can result in a change of biodiversity and habitat conditions; the age class distribution and succession stages can be affected; the most effective price-rising policies entail a growth in the total cubic volume of private inventory (carbon continues to rise) (Alig, *et al.*, 1998).

Information about the way the subsidies are entertained is an important tool to better address policies. A study in Sweden highlights that the subsidies (for willow plantation) are mainly received by large farms in terms of arable land area because they are better informed about the economy and subsides available and more capable to assess and diversify the risks connected to new crops. The farms are less oriented to fodder, cattle or milk production (Rosenqvist, *et al.*, 2000).

Further analysis should be developed on the issues not fully considered in the studies presented. Among others, the studies mentioned are: reversibility of LULUCF activities that induce the release of carbon sequestered by the activities; leakage of emissions outside the project due to the application of the strategy; impacts of the strategies on the agriculture and forestry sectors and on public finance and tax system; additional benefits (environmental, social) connected to carbon emission reduction strategies; transaction costs associated with getting the mitigation option in action; interaction between policy mechanisms; opportunity costs (Alig, *et al.*, 1998; Gielen, *et al.*, 2002; Richards, Stokes, 2004; Stavins, Richards, 2005; Updegraff, *et al.*, 2004; Murray, 2004). Finally, the quality of cost estimates is affected by the date of the study and peer review: the increasing quality over time entails the implementation of better accounting methods for all costs and carbon. (van Kooten, *et al.*, 2004)

7. Discussion and conclusions

Many authors who have attempted to estimate the effects of measures on farm profitability have found it to be a difficult task. Uncertainty and diversity of methods and results seem to be the only elements in common in the scientific literature and in the official reports.

The literature concerned with the cost-effectiveness of policy measures for the mitigation of GHG emissions in agriculture and forestry is wide. The issue is treated under different viewpoints and approaches: a bottom-up engineering approach focussing on abatement technologies and costs, a top-down partial or general equilibrium economic approach emphasising economic sectoral and international policy feedback assessing welfare costs, and hybrid approaches trying to couple the two perspectives. Research questions are also very different: main themes range from assessing the environmental effectiveness of a particular policy, to comparing efficiency associated with different policy tools, to the appropriateness in term of costs and benefits of some existing policies. All this makes it difficult to compare results of different studies; also studies sharing the same methodology and trying to answer the same question usually end up with quite different outcomes depending on the hypotheses driving the underlying modelling exercise, the geographical and the sectoral focus. Nevertheless some results are robust at least under the qualitative point of view.

All the studies highlight that the agricultural and forestry sector can potentially provide GHG abatement at competitive costs. Policy measures targeted to those sectors can thus be justified in terms of effectiveness and efficiency. This conclusion seems particularly robust as it is endorsed both by the technically-oriented and by the economically-oriented veins of literature. In the particular case of EU countries, the CAP reforms can contribute to GHG reduction. This contribution seems quite small for the Agenda 2000 reform, but can be larger for the new reform process established under the Mid-term Review. This can be due partly to a shrinking in agricultural sectors induced by the increased competition in agricultural markets, but also to improved environmental-friendly activities. Among these the most quoted are, conservation tillage, organic farming, extension of crop plan and energy switching, moving from a fossil-fuel to a biomass base.

Mitigation costs for the European economic system as a whole seem quite low, but remain positive. They can be relevant for the agricultural and forestry sectors when considered individually. This calls for a precise quantification of the social (private and environmental) costs and benefits of mitigation policies in order to avoid the imposition of an excessive burden on those sectors. For this reason, the support to energy from biomass either for transportation or for electricity generation purposes seems non-optimal in terms of both its social and economic cost. This finding is supported by the studies applied to different European economies, and it accordingly appears quite robust. Nevertheless it is worth noting that the improved environmental performance is just one of the aims pursued by encouraging the transition to bio-energy. Therefore inefficiencies may be lower if the additional aims of energy security and farm income and employment support are considered.

On different grounds, welfare-improving opportunities seem to be offered by a more extensive use of taxes or tradable emission permits with respect to fixed quotas. This is an unambiguous theoretical result, and it seems to confirm the idea that the exclusion of agricultural and forestry sectors from NAPs, and of carbon sinks from the Linking Directive (Bosello, *et al.*, 2005) can engender efficiency losses. Nevertheless this claim must be tempered by realism: transaction and monitoring costs can be so high as to possibly offset any efficiency gain.

A crucial aspect for the future of research in the field is the role to be played by the IPCC Guidance (2003). It is clear that there is a substantial dichotomy between the evidence of the recent scientific literature and the approach proposed by the IPCC: the former analysing heterogeneity of phenomena, uncertainty, spatial variability and raising doubts, the latter proposing fixed coefficients that can be adopted in various generic contexts of the globe. The two approaches could theoretically merge only if the assumptions behind the Guidance are found to be generally valid, but problems could arise in many instances. An example is shown by the evidence presented by Antle et al. (2003) about the preference that should be given to policies based upon payments per tonne of soil C sequestered and verification of the environmental outcomes in the field, instead of payment per hectares, usually implying only indirect evaluations based upon performance indicators. Such policies could be theoretically sound according to the IPCC approach and to some simulation models available for ex ante evaluations, but no evidence can be found for various reasons mentioned in the scientific literature: spatial and temporal variability, for instance. The effects could engender public and private transaction costs for the implementation of theoretically cost-effective policy measures, which could end up by providing an episodic benefit for the policy aims and for the potential beneficiaries.

Notwithstanding the vast literature treated, the present work highlights that a systematic and scientifically-sound comparative analysis of the cost-effectiveness of alternative policy and technical measures appears to be still an open issue for future research. Significant methodological progresses in particular are needed in particular respect the treatment of:

a) the intrinsic spatial and temporal variability of phenomena;

b) the limited availability of systematic knowledge on cause-effect chains and feedback effects of the various measures;

c) the difficulties in managing the various scales (from field measurements to national communications), in particular in terms of possibilities of model validation;

d) the difficulties in monitoring and verifying the long-term phenomena involved, in particular for what concerns carbon accumulations in soils.

References

Alig R. J., Adams D. M., McCarl B. A. (1998) "Ecological and economic impacts of forest policies: interactions across forestry and agriculture" *Ecological economics*, vol. 27, n., pp. 63-78.

Antle J., Capalbo S., Mooney S., Elliott E., Paustian K. (2003) "Spatial heterogeneity, contract design, and the efficiency of carbon sequestration policies for agriculture" *Journal of environmental economics and management*, vol. 46, n., pp. 231-50.

Bohlin F. (1998) "The Swedish carbon dioxide tax: effects on biofuel use and carbon dioxide emissions" *Biomass and bioenergy* vol. 15, n. 4-5, pp. 283-91.

Bohringer C. (1998) "The synthesis of bottom-up and top-down in energy policy modeling" *Energy Economics*, vol., n. 20, pp. 233-48.

Bosello F. , Buchner B., Crimi J., Giupponi C., Povellato A. (2005) *The Kyoto Protocol and the effect of existing and planned measures in the agricultural and forestry sector in the EU25. Meacap Project Deliverable #5*, Fondazione Eni Enrico Mattei.

Brink C., Kroeze C., Klimont Z. (2001) "Ammonia abatement and its impact on emissions of nitrous oxide and methane in Europe" *Atmospheric environment*, vol. 35, n., pp. 6299–312.

Brink C., van Ierland E., Hordijk L., Kroeze C. (2004) "Cost-effective emission abatement in agriculture in the presence of interrelations: cases for the Netherlands and Europe" *Ecological economics*, vol., n.

Dalgaard T., Halberg N., Porter J. R. (2001) "A model for fossil energy use in Danish agriculture used to compare organic and conventional farming" *Agriculture, Ecosystems and Environment*, vol. 87, n., pp. 51-65.

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 Abatment Costs" *Environmental & Resources Economics*, vol. 32, n., pp. 551-83.

De Cara S., Jayet P. A. (2001) "Agriculture and climate change in the European Union: greenhouse gas emissions and abatement costs" *AAEA annual meeting*, August 4th - 8th, 2001 ed.: Chicago.

Dendoncker N., Van Wesemael B., Rounsevell M. D., Roelandt C., Lettens S. (2004) "Belgium’s CO2 mitigation potential under improved cropland management" *Agriculture, ecosystems and environment*, vol. 103, n., pp. 101-16.

Deybe D., Fallot A. (2003) "Non-CO2 greenhouse gas emissions from agriculture: analysing

the room for manoeuvre for mitigation, in case of carbon pricing" *25th International Conference of Agricultural Economists*, August 16th - 22th, 2003 ed.: Durban <South Africa>.
Diesendorf M. (1998) "Australian economic models of greenhouse abatement" *Environmental Science & Policy*, vol., n. 1, pp. 1-12.
Donnellan T., Hanrahan K. (2003) "Greenhouse Gas Emissions from Irish Agriculture" in *The Luxembourg CAP Reform Agreement: Implications for EU and Irish Agriculture*. TEAGASC ed, FAPRI-Ireland Partnership.
Ericsson K., Huttunen S., Nilsson L. J., Svenningsson P. (2004) "Bioenergy policy and market development in Finland and Sweden" *Energy policy*, vol. 32, n., pp. 1707-21.
European Climate Change Programme E.C.C.P. (2003) *Can we meet our Kyoto targets? Second ECCP progress report*, Brussels, Belgium, European Commission DG ENV.
European Commission E.C. (1992) "Council Regulation (EEC) No 2080/92 of 30 June 1992 instituting a Community aid scheme for forestry measures in agriculture", vol., n.
European Environmental Agency E.E.A. (1999) *Environmental indicators: Typology and overview*, Copehagen, EEA Technical Report No 25/1999.
European Environmental Agency E.E.A. (2001) *Reporting on environmental measures. Are we being effective?*, Copehagen, EEA Environmental Issues Report No 25/2001.
European Environmental Agency E.E.A. (2005) *Annual European Community greenhouse gas inventory 1990–2003 and inventory report 2005*, Copehagen, EEA Technical Report No 4/2005.
Ewert F., Rounsevell M. D. A., Reginster I. R., Metzger M., Leemans R. (2005) "Future scenarios of European agricultural land use. Part I: estimating changes in crop productivity" *Agriculture, ecosystems and environment*, vol. 107, n., pp. 101-16.
Faaij A. P. (2004) "Bio-energy in Europe: changing technology choices" *Energy policy*, vol., n.
Food and Agriculture Organization F.A.O. (2003) *World agriculture: towards 2015/2030. An FAO perspective.*, Rome, FAO.
Freibauer A., Rounsevell M. D., Smith P., Verhagen J. (2004) "Carbon sequestration in the agricultural soils of Europe" *Geoderma*, vol. 122, n., pp. 1-23.
Gallagher P. W., Shapouri H., Price J., Schamel G., Brubaker H. (2003) "Some long-run effects of growing markets and renewable fuel standards on additives markets and the US ethanol industry" *Journal of policy modeling*, vol. 25, n.
Garcia-Quijano J. F., Deckmyn G., Moons E., Proost S., Ceulemans R., Muys B. (2005) "An integrated decision support framework for the prediction and evaluation of efficiency, environmental impact and total social cost of domestic and international forestry projects for greenhouse gas mitigation: description and case studies" *Forest Ecology and Management*, vol. 207, n., pp. 245-62.
Gielen D. J., Fujino J., Hashimoto S., Moriguchi Y. (2002) "Biomass strategies for climate policies?" *Climate policy*, vol. 2, n., pp. 319-33.
Gillig D., McCarl B. A., Sands R. D. (2004) "Integrating agricultural and forestry GHG mitigation response into general economy frameworks: Developing a family of response functions" *Mitigation and adaptation strategies for global change*, vol. 9, n. 3, pp. 241-59.
Gottinger H. W. (1998) "Greenhouse gas economics and computable general equilibrium" *Journal of policy modeling*, vol. 20, n., pp. 537-80.
Grubb M., Edmunds J., Brink P., Morrison M. (1993) "The costs of limiting fossil-fuel CO2 emissions: a survey and analysis" *Annual Review of Energy and the Environment*, vol. 18, n., pp. 397-478.
Haberl H., Erb K. H., Krausmann F., Adensam H., Schulz N. B. (2003) "Land-use change and

socio-economic metabolism in Austria. Part II: land-use scenarios for 2020" *Land use policy*, vol. 20, n., pp. 21-39.

Hediger W., Hartmann M., Peter S., Lehmann B (2005) "Costs and Policy Implications of Greenhouse Gas Reduction in Swiss Agriculture" *XIth International Congress of the European Association of Agricultural Economists "The Future of Rural Europe in the Global Agri-Food System"*: Copenhagen, Denmark.

Henke J. M., Klepper G., Schmitz N. (2004) "Tax exemption for biofuels in Germany: is bio-ethanol really an option for climate policy?" *Energy*, vol. 30, n. 14, pp. 1-19.

Hilhing B. (1999) "The Swedish wood fuel market" *Renewable energy*, vol. 16, n., pp. 1031-36.

Ignaciuk A., Vöhringer F., Ruijs A., van Ierland E. C. (2004) "Competition between biomass and food production in the presence of energy policies: a partial equilibrium analysis" *Energy policy*, vol., n.

Intergovenramental Panel on Climate Change I.P.C.C. (2000) "IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories ." IPCC.

Intergovenramental Panel on Climate Change I.P.C.C. (2003) "IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry". IPCC.

Jensen J., O'Toole R., A. Matthews (2003) "Controlling Greenhouse Gas Emissions from the Agricultural Sector in Ireland: A CGE Modeling approach" *6th Annual Conference on Global Economic Analysis*: The Hague.

Kazakci A., Rozakis S. (2005) "Energy crop supply in France: A min-max regret approach" *XIth International Congress of the European Association of Agricultural Economists "The Future of Rural Europe in the Global Agri-Food System"*: Copenhagen, Denmark.

Kuemmel B., Langer V., Magid J., De Neergaard A., Porte J. R. (1998) "Energetic, economic and ecological balances of a combined food and energy system" *Biomass and bioenergy*, vol. 15, n., pp. 407-16.

Lettens S., Muys B., Ceulemans R., Moons E., J. García J., Coppin P. (2003) "Energy Budget and Greenhouse Gas Balance Evaluation of Sustainable Coppice Systems for Electricity Production" *Biomass and bioenergy*, vol. 24, n., pp. 179-97.

Lewandrowski J., Peters M. , Jones C., House R. , Sperow M. , Eve M. , Paustian K. (2004) "Economics of Sequestering Carbon in the U.S. Agricultural Sector". USDA/ERS.

Murray B. C. (2004) "Overview of agricultural and forestry GHG offsets on the US landscape" *Choices*, vol. 19, n. 3, pp. 13-18.

Nevens F., Garcia Cidad V., Reheul D., Mathijs E. (2004) "Energy crops in Flemish agriculture: possibilities and limits" in *Biomass and agriculture: sustainability, markets and policies*. Paris <France>, OECD, pp. 139-47.

Nyström I., Cornland D. W. (2003) "Strategic choices: Swedish climate intervention policies and the forest industry’s role in reducing CO2 emissions" *Energy Policy*, vol. 31, n., pp. 937-50.

OECD (1989) *Economic instruments for environmental protection*, Paris, OECD.

Oenema O., Velthof G., Kuikman P. (2001) "Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture" *Nutrient Cycling in Agroecosystems*, vol. 60, n., pp. 301-15.

Olesen J. E., Bindi M. (2002) "Consequences of climate change for European agricultural productivity, land use and policy" *European journal of agronomy*, vol. 16, n., pp. 239-62.

Oude Lansink A. (2003) "Technical efficiency and CO2 abatement policies in the Dutch glasshouse industry" *Agricultural Economics*, vol. 28, n., pp. 99-108.

Parris K. (2004) "Agriculture, biomass, sustainability and policy: an overview" in *Biomass* *and agriculture: sustainability, markets and policies*. OECD ed. Paris <France>, OECD, pp. 27-36.

Pautsch G. R., Kurkalova L. A., Babcock B. A., Kling K. L. (2000) "The efficiency of sequestering carbon in agricultural soils" *CARD working paper*, vol. 246, n., pp. 1-25.

Pearce D.W. , Howarth A. (2000) *Technical Report on Methodology: Cost Benefit Analysis and Policy Responses. RIVM report*, RIVM.

Pérez I., Holm-Müller K. (2005) "Economic incentives and technological options to global warming emission abatement in european agriculture" *89th EAAE Seminar: " Modelling agricultural policies: state of the art and new challenges"*, February 3th - 5th, 2005 ed.: Parma <Italy>.

Petersen A. K., Solberg B. (2005) "Environmental and economic impacts of substitution between wood products and alternative materials: a review of micro-level analyses from Norway and Sweden" *Forest Policy and Economics*, vol. 7, n. 3, pp. 249-59.

Prisley S. P., Mortimer M. J. (2004a) "A synthesis of literature on evaluation of models for policy applications, with implications for forest carbon accounting" *Forest ecology and management*, vol. 198, n., pp. 89-103.

Prisley S. P., Mortimer M. J. (2004b) "A synthesis of literature on evaluation of models for policy applications, with implications for forest carbon accounting" *Forest ecology and management*, vol. 198, n. 1-3, pp. 89-103.

Rae A. N., Strutt A. (2003) "Agricultural trade reform and environmental pollution from livestock in OECD Countries" *6th annual conference on global economic analysis*, June 12th-14th, 2003 ed.: The Hague <The Netherlands>.

Raven R. P. (2004) "Implementation of manure digestion and co-combustion in the Dutch electricity regime: a multi-level analysis of market implementation in the Netherlands" *Energy policy*, vol. 32, n., pp. 29-39.

Richards K.R., Stokes C. (2004) "A review of forest carbon sequestration cost studies: A dozen years of research" *Climatic change*, vol. 63, n., pp. 1-48.

Ronco R. , Soares F.B. (2005) *The Common Agricultural Policy and the Greenhouse Gas Emissions. ICER Working Paper, 17(2005).*

Rosenqvist H., Roos A., Ling E., Hektor B. (2000) "Willow growers in Sweden" *Biomass and bioenergy*, vol. 18, n., pp. 137-45.

Rounsevell M. D., Ewert F., Reginster I., Leemans R., Carter T. R. (2004) "Future scenarios of European agricultural land use. II: projecting changes in cropland and grassland" *Agriculture, ecosystems and environment*, vol. 107, n. 2-3, pp. 117-35

Rozakis S., Sourie J. C. (2005) "Micro-economic modelling of biofuel system in France to determine tax exemption policy under uncertainty" *Energy policy*, vol. 33, n., pp. 171-82.

Rozakis S., Sourie J. C., Vanderpooten D. (2001) "Integrated micro-economic modelling and multi-criteria methodology to support public decision-making: the case of liquid bio-fuels in France" *Biomass and bioenergy*, vol. 20, n., pp. 385-98.

Saunders C., Wreford A. (2003) "Mitigation of greenhouse gas emissions: the impacts on a developed country highly dependent on agriculture" *25th International Conference of Agricultural Economists*, August 16th - 22th 2003 ed.: Durban <South Africa>.

Schneider U. A., McCarl B. A. (2003) "Economic potential of biomass based fuels for greenhouse gas emission mitigation" *Environmental and resource economics*, vol. 24, n., pp. 291-312.

Six J., Ogle S. M., Breidt J., Conant R. T., Mosier A. R., Paustian K. (2004) "The potential to mitigate global warming with no-tillage management is only realized when practised in the long term" *Global change biology*, vol. 10, n., pp. 155-60.

Smith P. (2004) "Carbon sequestration in croplands: the potential in Europe and the global

context" *European journal of agronomy*, vol. 20, n. 3, pp. 229-36.
Stavins R. N. , Richards K. R. (2005) "The cost of U.S. forest-based carbon sequestration. " *Pew Center reports*, vol., n. 19, pp. 1-52.
Sutton M.A., Dragosits U., Dore A.J., McDonald A.G., Y.S. Tang., van Dijk N., Bantock T., Hargreaves K.J., Skiba U., Simmons I., Fowler D., Williams J., Brown L., Hobbs P., Misselbrook T (2004) "The potential of NH_3, N_2O and CH_4 measurements following the 2001 outbreak of Foot and Mouth Disease in Great Britain to reduce the uncertainties in agricultural emissions abatement" *Environmental science and policy*, vol. 7, n. 3, pp. 177-94.
Tassone V. C., Wesseler J., Nesci F. S. (2004) "Diverging incentives for afforestation from carbon sequestration: an economic analysis of the EU afforestation program in the south of Italy" *Forest policy and economics*, vol. 6, n., pp. 567-78.
Tietenberg T. (2004) *Environmental Economics and Policy*, Pearson Addison Wesley.
Updegraff K., Baughman M. J., Taff S. J. (2004) "Environmental benefits of cropland conversion to hybrid poplar:economic and policy considerations" *Biomass and bioenergy*, vol. 27, n., pp. 411-28.
van Kooten G. C., Eagle A. J. , Manley J., Smolak T. (2004) "How costly are carbon offsets? A meta-analysis of carbon forest sinks" *Environmental science & policy*, vol. 7, n. 4, pp. 239–51.
Vleeshouwers L. M., Verhagen A. (2002) "Carbon emission and sequestration by agricultural land use: a model study for Europe" *Global change biology*, vol. 8, n., pp. 519-30.
Vollebergh H. (1997) "Environmental externalities and social optimality in biomass markets" *Energy policy*, vol. 25, n., pp. 605-21.
Weersink A., Livernois J., Shogren J. F., Shortle J.S. (1998) "Economic Instruments and Environmental Policy in Agriculture" *Canadian Public Policy*, vol. XXIV, n. 3.
Wier M., Andersen J. M., Jensen J. D., Jensen T. C. (2002) "The EU's Agenda 2000 reform for the agricultural sector: environmental and economic effects in Denmark" *Ecological Economics*, vol. 41, n., pp. 345-59.
Wong G. Y., Alavalapati Y. R (2003) "The land-use effects of a forest carbon policy in the U.S" *Forest policy and economics*, vol. 5, n., pp. 249-63.

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/Feem/Pub/Publications/WPapers/default.htm
http://www.ssrn.com/link/feem.html
http://www.repec.org
http://agecon.lib.umn.edu
http://www.bepress.com/feem/

NOTE DI LAVORO PUBLISHED IN 2007

NRM	1.2007	*Rinaldo Brau, Alessandro Lanza, and Francesco Pigliaru*: How Fast are Small Tourist Countries Growing? The 1980-2003 Evidence
PRCG	2.2007	*C.V. Fiorio, M. Florio, S. Salini and P. Ferrari:* Consumers' Attitudes on Services of General Interest in the EU: Accessibility, Price and Quality 2000-2004
PRCG	3.2007	*Cesare Dosi and Michele Moretto*: Concession Bidding Rules and Investment Time Flexibility
IEM	4.2007	*Chiara Longo, Matteo Manera, Anil Markandya and Elisa Scarpa*: Evaluating the Empirical Performance of Alternative Econometric Models for Oil Price Forecasting
PRCG	5.2007	*Bernardo Bortolotti, William Megginson and Scott B.* Smart: The Rise of Accelerated Seasoned Equity Underwritings
CCMP	6.2007	*Valentina Bosetti and Massimo Tavoni*: Uncertain R&D, Backstop Technology and GHGs Stabilization
CCMP	7.2007	*Robert Küster, Ingo Ellersdorfer, Ulrich Fahl* (lxxxi): A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications
CCMP	8.2007	*Mònica Serrano* (lxxxi): The Production and Consumption Accounting Principles as a Guideline for Designing Environmental Tax Policy
CCMP	9.2007	*Erwin L. Corong* (lxxxi): Economic and Poverty Impacts of a Voluntary Carbon Reduction for a Small Liberalized Developing Economy: The Case of the Philippines
CCMP	10.2007	*Valentina Bosetti, Emanuele Massetti, and Massimo Tavoni*: The WITCH Model. Structure, Baseline, Solutions
SIEV	11.2007	*Margherita Turvani, Aline Chiabai, Anna Alberini and Stefania Tonin*: Public Policies for Contaminated Site Cleanup: The Opinions of the Italian Public
CCMP	12.2007	*M. Berrittella, A. Certa, M. Enea and P. Zito*: An Analytic Hierarchy Process for The Evaluation of Transport Policies to Reduce Climate Change Impacts
NRM	13.2007	*Francesco Bosello, Barbara Buchner, Jacopo Crimi, Carlo Giupponi and Andrea Povellato*: The Kyoto Protocol and the Effect of Existing and Planned Measures in the Agricultural and Forestry Sector in the EU25
NRM	14.2007	*Francesco Bosello, Carlo Giupponi and Andrea Povellato*: A Review of Recent Studies on Cost Effectiveness of GHG Mitigation Measures in the European Agro-Forestry Sector

(lxxxi) This paper was presented at the EAERE-FEEM-VIU Summer School on "Computable General Equilibrium Modeling in Environmental and Resource Economics", held in Venice from June 25th to July 1st, 2006 and supported by the Marie Curie Series of Conferences "European Summer School in Resource and Environmental Economics".

2007 SERIES

CCMP	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anil Markandya)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KTHC	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Matteo Manera)
CSRM	*Corporate Social Responsibility and Sustainable Management* (Editor: Giulio Sapelli)
PRCG	*Privatisation Regulation Corporate Governance* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*