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Greenhouse Gases: Inventories, Abatement Costs and Markets for Emission Permits in European Agriculture – A Modelling Approach

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Abstract

Greenhouse Gases: Inventories, Abatement Costs and Markets for Emission Permits in European Agriculture – A Modelling Approach

Ignacio Pérez Domínguez

Greenhouse gas emissions from the agricultural sector are not yet fully included in the current international obligations on combating the effects of climate change. This is due to the fact that policy efforts have been mainly focused on carbon dioxide emissions from the energy and industry sectors. Nevertheless, the international community is already putting some pressure on scientific researchers to come up with reliable indicators to estimate emissions from other greenhouse gases. This further development towards *integrative multi-gas strategy approaches* has allowed the inclusion of the agricultural sector in the political agenda, where gases like methane and nitrous oxide present considerably higher shares than in other economic sectors. Modelling alternatives for the estimation of emission factors, definition of policy instruments for greenhouse gas emission abatement as well as measurement of their economic effects are at this stage quite important for the coming multilateral negotiations. With this purpose a modelling framework covering greenhouse gas emissions from agricultural sources is developed in this research study. At the first stage, greenhouse gas emission inventories for European regions are constructed with the help of an agricultural programming model, which is modified by integrating estimation methodologies of emission factors for agricultural emission sources recently published by the Intergovernmental Panel on Climate Change (United Nations). These are then used as base information for simulating at the regional level physical and economic effects of implementing uniform emission standards and tradable emission permits in European agricultural markets. Marginal abatement cost curves are also calculated for a wide range of emission objectives. The analysis shows how important is the combined selection of adequate instruments of emission abatement and feasible emission targets for the design of efficient emission reduction policies.

Keywords: *greenhouse gas emissions, Kyoto Protocol, agricultural modelling, CAP, standards, tradable permits, abatement costs.*

Kurzfassung

Klimarelevante Gase: Emissionsbestände, Vermeidungskosten und Märkte für Emissionszertifikate in der europäischen Landwirtschaft – Ein Modellierungsansatz

Ignacio Pérez Domínguez

Emissionen klimarelevanter Gase aus der Landwirtschaft werden zur Zeit nicht vollständig in den aktuellen internationalen Verpflichtungen bezüglich der Auswirkungen des Klimawechsels berücksichtigt. Der Grund hierfür ist die Tatsache, dass die politischen Bemühungen sich hauptsächlich auf Kohlendioxid beziehen. Diesbezüglich sind sowohl der Energie- als auch der Industriesektor die Hauptverursacher. Trotzdem wird der Druck der internationalen Gemeinschaft auf die Wissenschaft größer, zuverlässige Indikatoren zu entwickeln, die die Emissionsauswirkungen anderer klimarelevanter Gase und Sektoren darstellen können. In der politischen Ausrichtung zielt diese Weiterentwicklung in Richtung einer *integrativen Multigas-Strategie* auch auf den Agrarsektor ab, da hier Gase wie Methan und Distickstoffoxid in höheren Mengen als in anderen ökonomischen Sektoren ausgestoßen werden. Die Quantifizierung der Emissionsfaktoren mit Hilfe von Modellierungsansätzen, die Bestimmung von politischen Instrumenten zur Verminderung klimarelevanter Emissionen, sowie die Abschätzung der daraus resultierenden ökonomischen Effekte, sind sehr wichtige Voraussetzungen für die kommenden multilateralen Verhandlungen. Zielsetzung dieser Studie ist es, einen Modellierungsrahmen zur Darstellung der klimarelevanten Emissionen in der Landwirtschaft zu entwickeln. Zunächst sind die vom internationalen wissenschaftlichen Ausschuss für Klimawandel (IPCC, Vereinte Nationen) kürzlich veröffentlichten Schätzmethoden zur Berechnung landwirtschaftlicher Emissionsfaktoren in ein Agrarsektormodell integriert. Somit werden für verschiedene europäische Regionen die Bestände klimarelevanter Gase ermittelt. Diese dienen dann als Basisinformation für die Simulation auf regionaler Ebene, mit welcher physische und ökonomische Effekte der Implementierung einheitlicher Emissionsstandards und Emissionshandel im Agrarsektor aufgezeigt werden können. Zudem sind Grenzvermeidungskostenkurven für eine große Auswahl von Emissionsbereichen berechnet. Die Analyse zeigt, wie wichtig die kombinierte Auswahl von Instrumenten zur Emissionsminderung und realistische Emissionsziele für die Gestaltung einer effizienten emissionsreduzierenden Politik ist.

Schlüsselworte*: klimarelevante Emissionen, Kyoto Protokoll, Agrarmodellierung, CAP, Emissionsauflagen, handelbare Emissionszertifikate, Vermeidungskosten.*

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Abbreviations

ACC	Abatement Cost Curve
AMAD	Agricultural Market Access Database
ASM	US Agricultural Sector Model
ASMGHG	US Agricultural Sector and Greenhouse Gas Mitigation Model
BSA	Burden Sharing Agreement
BSAA	Burden Sharing Agreement in Agriculture
CAC	Command and Control Instruments
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact (model)
CAPRI-DynaSpat	Common Agricultural Policy Regional Impact Assessment – The Dynamic and Spatial Dimension
CAPSIM	Common Agricultural Policy Simulation Model
CAP-STRAT	Common Agricultural Policy Strategy for Regions, Agriculture and Trade
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CH_4	Methane
CMO	Common Market Organisation
CO_2	Carbon Dioxide
CO_2^{eq}	Carbon Dioxide Equivalent
COCO	‘Completeness and Consistency’ Data Base
COP	Conference of Parties
CORINAIR	Core Inventory of Air Emissions
CRF	Common Reporting Format
CSE	Consumer Subsidy Equivalent
EAA	Economic Accounts of Agriculture
ECCP	European Union Climate Change Program
EEA	European Environmental Agency
EIONET	European Environment Information and Observation Network
EPPA	Emission Prediction and Policy Analysis (model)
ERU	Emission Reduction Unit
ETS	Emission Trading Scheme
EETS	European Emission Trading Scheme
EU-15	European Union Member States (15)
FADN	Farm Accountancy Data Network

FAO	Food and Agriculture Organization
FAOSTAT	Statistical Office of the FAO
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GWP	Global Warming Potential
IET	International Emission Trading
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
KP	Kyoto Protocol
LULUCF	Land Use, Land Use Change and Forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MJ	Mega-Joule (energy measurement)
N	Nitrogen
NO_2^-	Nitrite
NO_3^-	Nitrate
N_2O	Nitrous Oxide
NH_3	Ammonia
NH_4^+	Ammonium
NGHGIs	National Greenhouse Gas Inventories
NPK	Nitrogen, Phosphate and Potassium
OECD	Organisation for Economic Cooperation and Development
PMP	Positive Mathematical Programming
POLES	Outlook on long-term Energy Systems (model)
PPP	Polluter Pays Principle
PSE	Producer Subsidy Equivalent
RAINS	Regional Air Pollution Information and Simulation (model)
TRQ	Tariff Rate Quota
UAA	Utilisable Agricultural Area
UNEP	United Nations Environmental Program
UNFCCC	United Nations Framework Convention on Climate Change
WATSIM	World Agricultural Trade s Simulation Model
WMO	World Meteorological Organisation
WTO	World Trade Organisation

CHAPTER 1 Introduction

> *"It is believed that as long as the quality of input is right, the output is likely to be relevant; if the former is of dubious standing, the latter will have little chance of being relevant" (Rao, 2000, Preface).*

1.1 Introductory issues

The climate change externality is nowadays increasingly seen as a relevant issue which encompasses cause-and-effect relationships in almost all sectors of the economy (inter-sectoral dimension) and world regions (inter-regional dimension). With the ratification of the Kyoto Protocol (KP) to the United Nations Framework Convention on Climate Change (UNFCCC) by Russia on the 4th of November 2004, the implementation of the currently most ambitious time plan towards the reduction of anthropogenic greenhouse gas (GHG) emissions by industrialised countries has been formally initiated. The future environmental and economic effects of this piece of international legislation are, however, uncertain, particularly regarding their distribution along the afore-mentioned dimensions. The current research work addresses this issue and aims to close part of this information gap.

1.2 Objectives of research

The central objectives of this thesis are:

(1) *To estimate European GHG emission inventories with the help of an agricultural programming model.* The main idea behind this is to mimic the structure and construction process of official national GHG emission inventories (NGHGIs) reported by UNFCCC parties within a single economic model. This should involve an endogenous calculation of activity and region specific emission coefficients for agricultural emission sources, based on the common methodology used by countries in their reporting obligations. For this objective, the use of a consolidated agricultural programming model at a European level is foreseen.

(2) *To estimate regional marginal abatement cost curves for GHG emissions as additional information tool for environmental policy regulation.* Observed differences in regional production systems, and indirectly in regional GHG emissions, might have 'attached' different marginal costs of emission abatement. From this information some questions

could be answered: how can a certain emission reduction objective be optimally achieved?, how costly is it for the agricultural sector to fulfil this abatement goal?, and is it cost-effective for society to adopt a European-wide abatement policy or maybe there are signals for regulation at a regional level?. With this objective the optimal response of regional agricultural production systems to different abatement targets is modelled and marginal abatement costs (MACs) per region are estimated.

(3) *To model the use of tradable emission permits in European agriculture as a feasible instrument of emission abatement.* In the last decade, tradable permits have been increasingly applied by national governments to target environmental emissions. Its use has been justified by its potential economic gains with respect to other instruments (e.g. emission standards). The European emission trading scheme (EETS) is set to start on January 2005 for CO_2 emissions from industry and energy sectors. Some questions that might arise by looking at this example are: is this scheme also transferable to the agricultural sector when taking explicitly into account feasibility issues?, and, if implemented, what are the potential efficiency gains of tradable emission permits with respect to other type of instruments such as, for example, emission standards?. In order to answer these questions, a specific design for a market of emission permits in European agriculture is proposed and its potential income effects simulated by means of modelling tools.

(4) *To run simulation scenarios for different GHG emission mitigation policies considering price effects*. Several mechanisms for emission abatement foreseen in the KP are modelled: *a regional uniform emission standard*, *a burden-sharing agreement for agriculture* (specific clause in the KP for European Member States) and *a trading scheme of emission permits*. In their comparison, the Common Agricultural Policy (CAP) and price feedback from the rest of the world are explicitly covered for the year 2001. This allows the consistent estimation of direct welfare effects derived from the implementation of the afore-mentioned emission mitigation policies (effects on agricultural income, consumers, taxpayers and processing industry). Further indicators, such as land use change, agricultural supply, level of emissions and price development are covered in detail for the stated scenarios.

The conceptual design and justification for this study together with some background information on the current research topic are found in sections 1.3 to 1.5.

1.3 The economics of climate change

'Uncertainty' requires working with parameter estimates, which are subject to significant biases. Human life has been inevitably dependant on the vagaries of climate changes and availability of natural resources. Many bio-physical models have been developed in the last decades trying to explain the rise in the earth's temperature or the concentration of gases in the atmosphere[1]. They differentiate between ‘naturally-induced’ and ‘human-induced or enhanced’ GHG effect. Although many inaccuracies and inconsistencies still appear as a form of 'remaining uncertainty', the balance of evidence suggests that there is a discernible human influence on global climate (IPCC, 1996, p. 5).

The *economics of climate change* tries to analyse the enhanced greenhouse effect from an economic perspective, i.e. the effects on global warming of human economic development (through the emission of particular gases). Since 'uncertainty' is not completely overcome from a scientific perspective, economic models must be developed from a ‘precautionary’ perspective. By reducing climate relevant emissions, a slowing-down or even a reduction in the concentration of global warming gases is more likely to be achieved. With this idea in mind, the KP to the UNFCCC was launched in 1997 (UN, 1997) and every signatory received a quantified restriction on GHG emissions (see section 2.2.3).

In this study, the ‘climate change’ externality is addressed from a economic perspective: modelling of GHG emissions, implementation options of different emission abatement instruments and welfare effects derived from climate policies. Climate change has been included in the current international political agenda as an increasing source of concern to society. It is therefore important to examine the economic effects of future action in this field.

1.4 New ‘greening’ perspectives of the Common Agricultural Policy

Agriculture is a highly regulated sector in Europe. The CAP defined in 1957 the objectives and instruments of a free market of agricultural products within the European Community and established protectionist policies that guaranteed sufficient revenues to European farmers, avoiding competition from products of third countries by granting agricultural prices (Treaty of Rome). This policy caused, among other problems, an increasing environmental degradation in certain regions due to an excess of agricultural supply and intensification of production. The need for reform was first noticed in 1992. The McSharry reform introduced several

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[1] A list of the most used Coupled Atmospheric-Ocean General Circulation Models (AOGCMs) is published by the Intergovernmental Panel of Climate Change (IPCC) under http://www.grida.no/climate/ipcc_tar/wg1/316.htm.

environmental payments as rewarding instruments for environmental benefits (e.g. extensification and afforestation payments). This was the first reform effort to attempt to move away from the traditional product support towards producer support. In 1999, the agreement on the Agenda 2000 Reform was reached and the concept of 'cross-compliance' introduced. The second pillar of the CAP (rural development) was reinforced and Member States were allowed to make direct aid payments conditional on compliance with environmental provisions. This path of reform was further revised in the third and last reform to date of the CAP, the Luxembourg Agreements of June 2003. 'Modulation' of premiums was introduced to shift financial resources from the first to the second pillar and further 'decoupling' of payments from production (subject to cross-compliance measures) was adopted.

This history of reform in European agricultural policy highlights the need for revision of the objectives agreed in Rome: *increases in productivity*, *assurance of a fair standard of living for the agricultural community*, *stabilisation of markets* and *food security* (European Economic Community, 2002, article 33). On the one side, the European agricultural sector has reached a high level of technological progress and food security is no longer a domestic problem. On the other side, health and environmental issues have gained weight in people's preferences. This has been mainly caused by recent incidences such as the Bovine Spongiform Encephalopathy or foot and mouth crises and new scientific findings on the long-term effects of environmental pollution. The future fields of action in the CAP are therefore, among others: *product traceability* (quality control), *water management* (control of water scarcity in southern regions and nitrate and pesticides leaching in sensitive areas), *air pollution* (control of GHG and ammonia emissions), *soil erosion* (control of land abandonment) and *market orientation* (inter-sectoral horizon through economic and physical linkages with forest and industrial sectors).

The current research study concentrates on European agriculture. A partial analysis is justified by the singularities of this sector, which is highly isolated from the rest of the economy through the afore-mentioned 'umbrella' of policy measures. Moreover, some other reasons justify the selection of this sector. Firstly, according to the estimates of the Intergovernmental Panel on Climate Change (IPCC), agricultural activities in Europe contribute to about 10 % of European total GHG emissions (see section 2.2), therefore playing an important role in the concentration of GHGs in the atmosphere. Additionally, the complex agricultural policy network and the relative high availability of data in Europe offer a chance for modelling approaches in this field. Lastly, unlike other environmental externalities, climate change can be regarded within the European boundaries as a global externality, i.e. damages can be assumed to be equally distributed across regions, so that ‘regional abatement costs’ are the principal determinant for emission abatement policies.

1.5 A suitable methodological approach

One of the most important questions to answer when choosing a methodological approach for the analysis of a specific issue is ‘if it matches the current need of research’. Actually, one of the recommendations of the 'Working Group 7 - Agriculture' within the European Climate Change Programme (COM (2000)88) was to connect emission reduction measures with concrete statistical data (Commission of the European Communities, 2000a, p. 15). With this purpose the CAPRI (**C**ommon **A**gricultural **P**olicy **R**egionalised **I**mpact) Modelling System[2] is chosen and adapted. An additional environmental module should cover the estimation of GHG emissions and simulate the use of different instruments of emission abatement. The advantages of estimating GHG emissions within a solid modelling framework are: (1) a centralised pool of data which can be subject to tight consistency restrictions, (2) a common set of functions and similar assumptions for agricultural activities and sources and (3) a consistent calculation of emission parameters able to take account of the physical linkages between agricultural activities across Member State borders. The model is designed to reproduce official emission statistics in a baseline period and deliver simulation results for different impact scenarios. Policy recommendations might be extracted and used within the ongoing international negotiations on climate change.

1.6 Structure of the thesis

As the title indicates, this research work is divided in 3 main parts: *estimation of regional GHG emission inventories in European agriculture*, *simulation of marginal abatement cost curves* and *modelling of a market of tradable emission permits*. Additionally, the economic and environmental effects of several instruments of GHG emission abatement are simulated.

Chapter 2 gives an overview of the global warming issue from an economic perspective and highlights the main climate-relevant externalities in agriculture (sections 2.2 and 2.3). Among other issues, it includes a review of the international legislation on GHG emission control and some of the modelling efforts applied to date to the estimation of agricultural GHG emissions. In section 2.5, the main modelling tool used in this research work, the CAPRI model, is thoroughly described.

Chapter 3 introduces the necessary technicalities for the estimation of regional GHG emission inventories. On the one hand, section 3.2 describes the equations and data flows used for a consistent estimation of agricultural emissions. On the other hand, the technical implementation in the model of the common accounting guidelines for single emission sources is analysed in section 3.3 and endogenously estimated emission factors presented. In section 3.4, selected aggregated results are compared with the official NGHGIs reported by European Member States to the UNFCCC.

Chapter 4 contains a theoretical review on the use of emission abatement instruments and focuses on tradable emission permits for GHG emission abatement as a feasible option in agriculture. It begins with a historical overview of the implementation of pollution abatement instruments (section 4.2). Command-and-control and market-based instruments are confronted in section 4.3, the use of the latter being justified based on efficiency grounds. The basic economic theory and characteristics of tradable emission permit markets are introduced in section 4.4.

Chapter 5 concentrates on the measurement of the economic costs faced by agricultural producers with the implementation of emission restrictions. In section 5.2, the concept of shadow value in mathematical programming models is introduced. The chapter builds upon this concept as a proxy to estimate marginal costs linked to GHG emission abatement and, in sections 5.3 and 5.4, presents different methodological approaches for the estimation of marginal abatement cost curves (MACCs). In section 5.5, model results are presented for European regions.

Chapter 6 deals with the implementation of a market of emission permits in the European agricultural sector. The European regulation on climate policy, with special focus on the emission trading directive (2003/87/EC), is thoroughly analysed in section 6.2. Based on this legislation, a potential market for emission permits in the European agricultural sector is then designed (section 6.3). In sections 6.4 and 6.5, the analytical implementation of an EETS in the CAPRI model is technically described, and results are analysed.

In chapter 7 three selected emission mitigation policy strategies are simulated for European agriculture including price endogeneity: a regional uniform emission standard, a burden-sharing agreement and a market of emission permits. In section 7.2, simulation scenarios are described, with special consideration of the current KP abatement mechanisms. In section 7.3, several physical, environmental and economic indicators are analysed for these scenarios: emissions, supply, prices, income and, finally, welfare effects for the different economic agents implicated.

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[2] Web Site of the CAPRI Modelling System: http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm. A detailed

For this analysis, the main policy variables affecting agricultural markets are explicitly taken into account, both internal CAP regulations and trade policy instruments. In section 7.4, some conclusions are given.

Chapter 8 introduces a short discussion on the limitations of the present study, the possible environmental effects of emission mitigation policies and the use of technological abatement options in agriculture. In chapter 9, the main conclusions to the study are summarised.

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description is given in section 2.5.

CHAPTER 2 Climate Change and Agriculture

> *"With the possible exception of another world war, a giant asteroid, or an incurable plague, global warming may be the single largest threat to our planet [...]. On the other hand, there are those, some of whom are scientists, who believe that global warming will result in little more than warmer winters and increased plant growth. They point to the flaws in scientists' measurements, the complexity of the climate, and the uncertainty in the climate models used to predict climate change [...].In truth, the future probably fits somewhere between these two scenarios." (John Weier, NASA's Earth Observatory).*

2.1 Introduction

The climate change phenomenon is a highly complex environmental issue that has become a great matter of concern in recent human history. The irreversible and uncertain consequences linked to it have pushed the international community to come up with some solutions in terms of emission reduction commitments and policy instruments. In this chapter, this environmental problem is analysed from the legal and economic perspectives and its importance for the agricultural sector highlighted. In section 2.1, general issues related to the *global warming externality* are addressed, including the important recent developments in international legislation. Section 2.2 gives an overview of the main linkages between agriculture and climate change from a twofold perspective: agriculture might suffer in the future from the consequences of an acute climate change (floods, high temperature variability) but at the same time is an important contributor to it, mainly through intensive farming practices. Section 2.3 includes a thorough literature review on the currently implemented modelling approaches to the estimation of GHG emission indicators for the agricultural sector.

The **C**ommon **A**gricultural **P**olicy **R**egionalised **I**mpact (CAPRI) Modelling System is the basic tool of analysis in this study. It is an *economic partial comparative-static equilibrium model* designed primarily to analyse different policy simulation scenarios for European agriculture. For this research work, an expansion of the model towards the endogenous estimation of GHG emissions has been attempted. The general modelling system is presented in section 2.4 which covers in detail its modular structure, data base issues and exogenous assumptions. In section 2.5, some conclusions are drawn on the advantages and disadvantages of this methodology for the construction of environmental indicators.

2.2 The Global Warming Effect

2.2.1 A historical perspective of climate change

The term climate change refers to changes in the earth's temperature, although 'climate' encompasses many other variables such as precipitation, clouds, etc. *Climate change* includes therefore natural and anthropogenic emissions, and *global warming* usually applies to temperature changes with predominantly anthropogenic influence, i.e. caused by human activity. The first references acknowledging the global warming effect are dated in the last decade of the 19th century, with Arrhenius' contributions. He described the warming or greenhouse effect as the imbalance between in and out infrared radiation in the atmosphere and analysed the possible contribution of fossil fuel combustion and industrial emissions of carbon dioxide to a human-induced greenhouse effect (Rao, 2000, p. 7). Recent studies have tried to measure the contributions of human activity in the last century to global warming (IPCC, 2001a). The hard task is to differentiate temperature variation derived from human activity from that derived from natural catastrophes that have occurred in the past such as, for example, glacial periods.

There is a general consensus that global temperature has risen in the last century by around 0.6 °C (IPCC, 2001b) and it is forecasted to increase until 2100 within a range of 1.4 °C to 5.8 °C, depending on the simulation scenario used[3]. This short-term effect is mainly due to human activity, natural-induced changes not playing an important role. Moreover, global warming is not likely to be equally distributed, the southern parts of the planet facing more severe temperature peaks and also increasing temperature variability within regions and seasons.

Relevant emissions causing the afore-mentioned temperature variations are the so called 'greenhouse gas emissions': *carbon dioxide* (*CO_2*), *methane* (*CH_4*), *nitrous oxide* (*N_2O*) and *fluorinated gases (HFCs, PFCs, SF6)*. These gases are classified by the IPCC according to their

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[3] The IPCC was established by the World Meteorological Organisation (WMO) and the United Nations Environment Program (UNEP). Its main task is to assess technical and economic information found in published technical reviews relevant to understand the scientific linkages of climate change. The IPCC defines six emission scenarios by introducing different variables like economic growth, evolution of global population, technological change. While the worst-case scenario considers rapid economic growth and intensive use of fossil fuels, the most optimistic one concentrates on flexible technological change, economic, social and environmental sustainability.

atmospheric lifetime and radioactive forcing[4], scaling the data to a certain conventional lifetime period (usually 100 years), i.e. the so-called 'global warming potential' (GWP). Emissions are then expressed in relative terms, with CO_2 units as the reference gas (see table (1)). By using this approach, emissions can be compared and homogeneously aggregated.

Table (1) Global Warming Potentials (100-year estimates)

Greenhouse Gas	Symbol	1996 IPCC GWP	2001 IPCC GWP
Carbon Dioxide	CO_2	1	1
Methane	CH_4	21	23
Nitrous Oxide	N_2O	310	296
Trifluoroethane (HFC-23)	CHF_3	11.7	12
Pentafluoroethane (HFC-125)	C_2HF_5	2.8	3.4
Tetrafluoroethane (HFC-134a)	$C_2H_2F_4$	1.3	1.3
Trifluoroethane (HFC-143a)	$C_2H_3F_3$	3.8	4.3
Difluoroethane (HFC-152a)	$C_2H_4F_2$	140	120
Heptafluoropropane (HFC-227ea)	C_3HF_7	2.9	3.5
Hexafluoropropane (HFC-236fa)	$C_3H_2F_6$	6.3	9.4
Perfluoromethane	CF_4	6.5	5.7
Perfluoroethane	C_2F_6	9.2	11.9
Sulfur Hexafluoride	SF_6	23.9	22.2

Source: IPCC's 2nd and 3rd Assessment Reports (IPCC, 1996; IPCC, 2001b).

Table (1) shows different estimated GWPs for single GHGs and also addresses the improvements of science in the estimation of the global warming effect. The IPCC periodically updates these coefficients according to a better understanding of the physical and chemical processes involved.

In the current study, only *methane* and *nitrous oxide* gases will be analysed since they account for most of GHG emissions in the European agricultural sector, carbon dioxide and fluorinated gases (HFCs, CFCs and PFCs) being mainly linked to industrial processes.

In figure (1) trends on GHG emissions from 1990 to 2001 for the EU-15 are reported by the European Environmental Agency (EEA). Whereas total emissions in the whole period slightly

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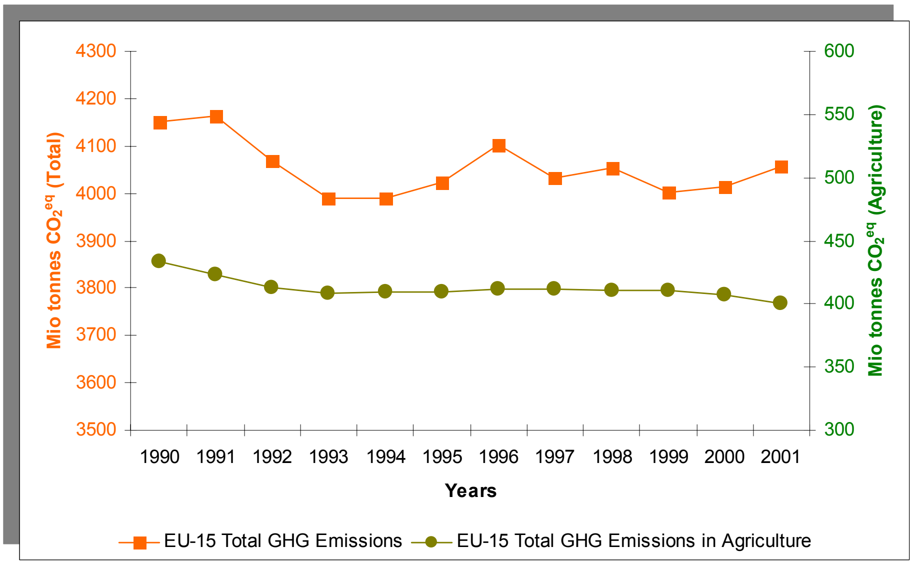
[4] These gases do not remain eternally in the atmosphere, being removed *physically* (through rain), *chemically* (through reaction with radicals OH in the case of methane or photosynthesis of plants for carbon dioxide) and as a

decrease (-2.2 %), emissions under the rubric ‘agriculture’ drop from 434 to 400 Mio CO_2^{eq} (-7.7 %).

Figure (1) Trends on greenhouse gas emissions for the EU-15 (1990-2001)



Source: EEA data service; CH_4, N_2O and CO_2 gases expressed in Mio tonnes of CO_2^{eq}.

This downward trend for the agricultural sector is consistent with the last policy reforms implemented in the EU within this period (‘McSharry’ in 1992 and ‘Agenda 2000’ in 1999): *introduction of obligatory set-aside, environmental payments and reduction in subsidisation*. Compared to emissions from other economic sectors, agriculture shows a share of 10 % on total emissions for year 2001 (see figure (2)).

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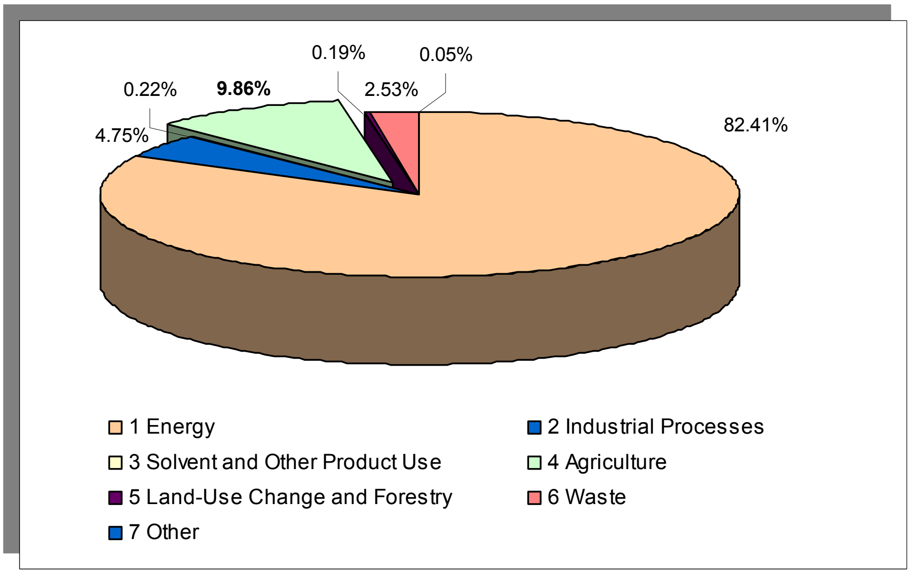
consequence of a *radioactive phenomenon* (destruction of molecules through solar radiation in the case of halocarbons).

Figure (2) Greenhouse gas sectoral emissions for the EU-15



Source: EEA data service; year 2001; CH_4, N_2O and CO_2 gases expressed in CO_2^{eq}.

2.2.2 Legislation: international agreements

In environmental legislation it is possible to differentiate between multilateral, regional and bilateral agreements. Bilateral or regional environmental agreements have usually small and highly localised effects, are signed between two or few parties respectively and apply preferably to non-transboundary pollution problems[5]. From a political economic perspective they offer a higher degree of flexibility since agreements between a limited number of negotiators are easier to achieve than in the multilateral case. The peculiarities of *global warming,* as a typical case of global externality, require a different solution. Emission abatement does not have to be localised in a specific region but requires the cooperation of a relevant number of parties. This is because (1) a significant percentage of emissions and polluters should be covered in order to achieve positive results for the environment, and (2) in large agreements free-riding is considerably reduced[6]. It is for this reason that in the last two decades several legislative efforts at multilateral level have been developed in this field, as summarised in table (2):

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[5] There is a strong relationship between how much a country pollutes and how much pollution is deposited within its national borders, i.e. the negative externality is ‘geographically bounded’.

[6] Free-riders in this case are those countries not taking part in a certain agreement but which benefit from it (e.g. less periods of droughts in the future through reductions in emissions).

Table (2) Multilateral international agreements on climate change

Date of Agreement	Date of entry force	Place of Agreement	Title of Agreement	Parties
22.03.1985	22.09.1988	Vienna	Vienna Convention for the Protection of the Ozone Layer	188 [a]
16.09.1987	01.01.1989	Montreal	Montreal Protocol on Substances that deplete the Ozone Layer	187 [a]
09.05.1992	01.08.1994	New York	United Nations Framework Convention on Climate Change (UNFCCC)	189 [b]
11.12.1997	18.02.2005 [d]	Kyoto	Kyoto Protocol to the United Nations Framework Convention on Climate Change	36 Annex I [c] 93 Non-Annex I [c]

[a] Last modified on: 4th October 2004. Amendments to the Montreal Protocol: 1990 (London, 175 signatories), 1992 (Copenhagen, 164 signatories), 1997 (Montreal, 120 signatories) and 1999 (Beijing, 83 signatories).

[b] Last modified on: 24th May 2004.

[c] Last modified on: 25th November 2004.

[d] Last modified on: 18 November 2004. Russia deposited its instrument of ratification with the United Nations. This marked the start of a 90 days countdown to the entry in force of the KP (16th February 2005).

The *Vienna Convention for the Protection of the Ozone Layer* was the first international attempt to address the consequences of climate change on human health and the environment on a global scale. In 1981, the UN Council set up a working group whose aim was to secure a general treaty to stop ozone depletion, by encouraging research, cooperation among countries and exchange of information (UN, 1985). One of the main scientific findings was that the modification of the vertical distribution of ozone through photochemical reactions caused by several anthropogenic gases could have potential consequences for weather and climate on the earth. The Convention was agreed in 1985 and entered into force in September 1988, *'on the nineteenth day after the date of deposit of the twentieth instrument of ratification'*. Its importance lies in being one of the first applications of the 'precautionary principle' to a global environmental externality, i.e. precautionary measures were agreed by the parties, although dose-response effects in ozone depletion were not yet fully understood: 'prevention first, science second'.

The *Montreal Protocol on Substances that deplete the Ozone Layer* to the Vienna Convention was agreed in 1987 and entered into force in 1989 after being ratified by eleven states or regional integration organisations representing at least two thirds of 1986 estimated global consumption of the controlled substances (UN, 1992a). The Montreal Protocol is considered one of the most successful environmental protection agreements in the world[7]. The Protocol sets out a mandatory timetable for the phasing out of single ozone depleting substances (article 2A to 2I) and acknowledges that the provision of additional financial resources is required to meet the needs of developing countries (article 5). Trade of these substances with non-parties is also banned within a tight schedule (article 4). This timetable has been under constant revision, with phase-out dates accelerated in accordance with scientific understanding and technological advances (see appendix 1). Recent scientific findings indicate that the Protocol measures are starting to achieve the expected results, with a slowing of the rate of ozone depleting substances entering the atmosphere. Assuming that all countries continue to meet the Protocol's timetable, ozone depletion is expected to stabilise in the short-term and start to recover by about 2050 (The Economist, 1997).

In 1994 the *United Nations Framework Convention on Climate Change (UNFCCC)* entered into force, after being ratified by fifty states or regional economic integration organisations (UN, 1992b). It is the only treaty related to the control of global warming gases after the Vienna Convention. In contrast to the latter which concentrates on ultraviolet radiation from ozone depletion, the UNFCCC refers only to the effects of anthropogenic emissions on temperature change. It comprises as well a complex set of articles which define commitments and reporting obligations for its parties. This information is summarised in figure (3):

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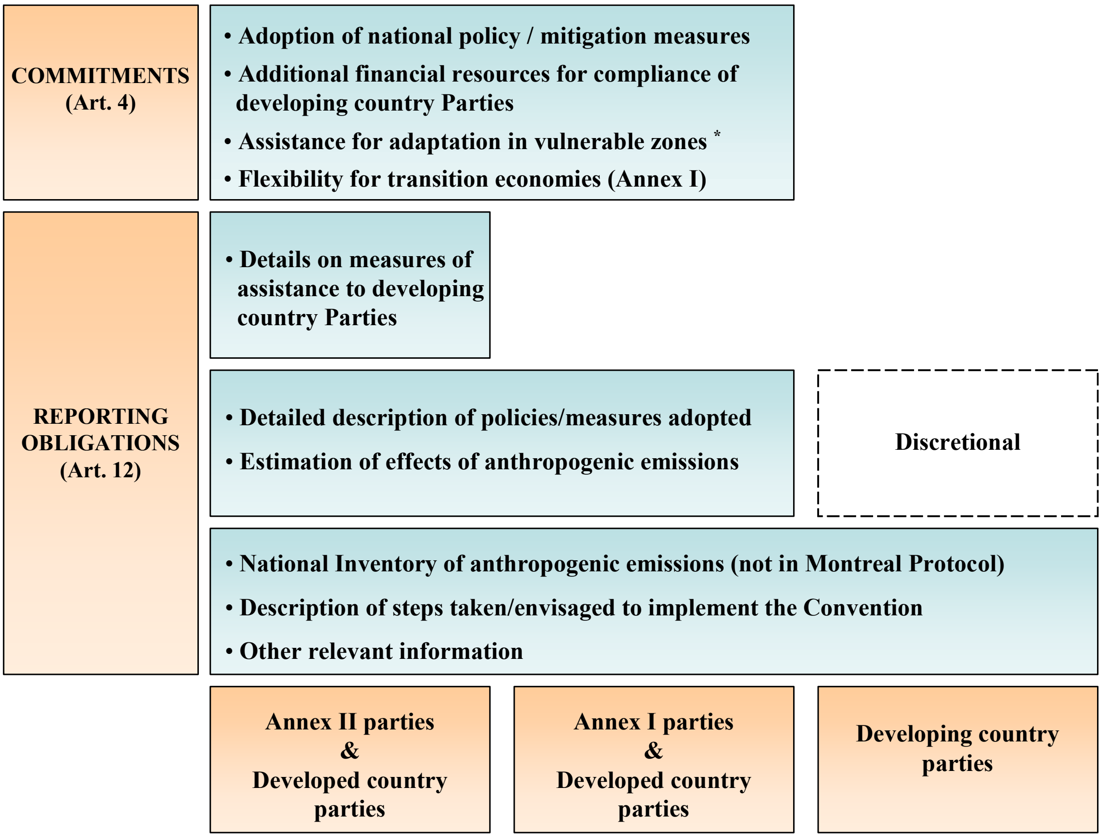
[7] With the signature of Afghanistan on the 17.06.2004.188 parties have ratified, accepted or approved the Vienna Convention and 187 the Montreal Protocol (Equatorial Guinea has not yet joined the latter).

Figure (3) Commitments and reporting obligations of the UNFCCC



Source: based on the UNFCCC legislative text (UN, 1992b).

[*] Refers to countries particularly vulnerable to the adverse effects of climate change

In article 4 of the UNFCCC, the general commitments on reporting of anthropogenic emissions and cooperation among developed countries in the formulation of measures to ‘control, reduce or prevent climate change’ are described. It also foresees the complementarity of this text with the previous legislation, by only affecting GHGs not controlled by the Montreal Protocol. A detailed description of policy measures and necessary steps related to the implementation of the convention is foreseen in article 12. A sharp distinction is made between developed countries (Annex II countries), countries in transition to a market economy (Annex I countries not in Annex II) and developing countries in terms of their commitments and reporting obligations (see appendix 2 and appendix 3).

Article 7 defines the Conference of Parties (COP) as the supreme body of the Convention which shall keep under regular review the adoption of instruments and legal texts of the Convention, and promote its effective implementation. A list of all the COPs and the main issues achieved in each one of them within a historical perspective is given in table (3).

Table (3) Conference of parties of the UNFCCC

COP	Location	Date	Main issues
COP-1	Berlin, Germany	March/April 1995	Agreement on the inadequacy of the UNFCCC to meet its goals: need to quantify emission reductions within set time periods. Agreement on pilot phase of activities implemented jointly (AIJ) between Annex I and non-Annex I countries
COP-2	Geneva, Switzerland	July 1996	Lack of unanimous agreement on the IPCC Second Assessment Report, failure to agree on voting procedures
COP-3	Kyoto, Japan	December 1997	Signature of the **Kyoto Protocol**: legally binding commitment on 58 industrialized countries plus the European Community to limit or reduce the emissions of six greenhouse gases
COP-4	Buenos Aires, Argentina	November 1998	Emergence of a 2-year Plan of Action to strengthen the implementation of the UNFCCC and prepare the entry into force of the Kyoto Protocol. Agreement on substantial progress towards joint activities.
COP-5	Bonn, Germany	November 1999	Preparation of UNFCCC guidelines on reporting and review. Preparation of the COP-6, which should focus on modalities of the Kyoto mechanisms
COP-6	The Hague, Netherlands	November 2000	No agreement, conference postponed. Discussion mainly centered on the treatment of carbon sinks and Kyoto mechamisms, implementation of enforcement penalties and implication of developing countries.
COP-6/2	Bonn, Germany	July 2001	Historical political deal clarifying most of the uncertainties about whether the Kyoto Protocol would work. Parties were able to agree on the process of ratification and implementation of the Kyoto Protocol and initiate internal negotiations in the respective national Parlaments.
COP-7	Marrakesh, Morocco	October/ November 2001	Agreement on the rules governing the implementation of the Kyoto mechanisms, a comprehensive compliance procedure and detailed rules on the accounting, reporting and review of emissions.
COP-8	New Delhi, India	October/ November 2002	Progress on national communications and financial obligations for developing countries. Agreement on the rules for clean development mechanism registries, and legal and institutional relationships between Protocol and Convention bodies.
COP-9	Milan, Italy	December 2003	Agreement on the remaining rules of the Kyoto Protocol mechanisms. Protocol ready to entry into force.
COP-10	Buenos Aires, Argentina	December 2004	10th anniversary of the entry into force of the Framework Convention on Climate Change. Adoption of the Buenos Aires Programme of Work on Adaptation and Response Measures

Source: own analysis based on the legal texts.

2.2.3 The Kyoto Protocol: recent developments

The KP was signed on the 11th of December 1997 at the COP-3 in Kyoto, Japan. In its article 3, countries included in the Annex I of the UNFCCC (see appendix 2) agreed to a 5 % reduction objective of their aggregate anthropogenic GHG emissions with respect to the 1990 base emission levels in the first commitment period 2008-20012[8]. Reduction commitments range from a -8 % cut for the EU-15, with a redistribution of this target across Member States

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[8] Gases affected are listed in the Annex A of the Protocol (see appendix 4) and individual targets for Annex I countries in the Annex B (see appendix 5).

according to the so-called ‘burden sharing agreement’ (BSA), to a 10 % increase for Iceland. For this purpose, Annex I countries have to adopt a national system for the estimation of emissions and reduction of all GHGs not controlled by the Montreal Protocol (article 5). Reporting of annual national GHG emission inventories is an important feature so that emissions by sources and removals by sinks associated with those activities are reported in a transparent and verifiable way.

The KP introduced several innovative mechanisms to help Annex I countries meet their targets at a lower cost. These are known as *Joint Implementation* (JI), *Clean Development Mechanism* (CDM), and *International Emission Trading* (IET). Through the JI mechanism investors and partners from Annex I countries are allowed to transfer to or acquire from any other such party emission credits, the so-called Emission Reduction Units (ERUs), resulting from projects aiming at reducing anthropogenic emissions (article 6 of the KP). These projects have to be supplemental to domestic action for the purposes of meeting commitments under Article 3. The CDM was created as a successor to the previously described instrument and consists of bilateral agreements between developed and developing countries to complete GHG mitigation projects in the latter. The purpose of the CDM is to help parties not included in the Annex I achieve a sustainable development and, at the same time, to assist Annex I countries with their reduction commitments through the acquisition of Certified Emission Reductions (CERs) coming from such project activities (article 12 of the KP). This instrument should enhance the cooperation between developed and developing countries in climate policy. Finally, IET is also foreseen by the Protocol as a flexible mechanism for countries included in the Annex B to fulfil their commitments (article 17 of the KP). According to this instrument, industrial countries receive emission permits equivalent to their emission reduction objectives in the first commitment period and are allowed to trade them. Markets for permits will be analysed in more detail in chapter 6.

The KP negotiations left a considerable number of issues to be completed in the post-Kyoto negotiation process. While the compliance system and mechanisms of abatement were basically agreed, their operational details were not defined and further work was required on emissions and sinks from land use, land use change and forestry (LULUCF activities). Several of these issues have been successfully addressed in the following COPs and meetings of the subsidiary bodies (articles 9 and 10 of the UNFCCC). With respect to agriculture, in June 2004 the subsidiary body for scientific and technological advice (SBSTA) of the UNFCC achieved important advances in the elaboration of common reporting format (CRF) tables for LULUCF modalities (Bonn, Germany). An increasing recognition in the international community of the importance of agricultural and forestry activities, and non-CO_2 gases towards an effective climate policy was reflected in the conclusions.

The KP entered officially into force on the 16th of February 2005. In March 2005, 144 countries responsible for around 61.6 % of global CO_2 emissions have *acceded to, ratified, approved or accepted* the KP[9]. The conditions required by the protocol to entry into force were fulfilled with the signature of the Russian Federation on the 18th of November 2004: *55 countries emitting at least 55 % of world 1990* CO_2 *emissions*. The prospects for an effective implementation of the KP are good but still lack the ratification of the USA, which emits 36 % of global CO_2 emissions.

2.2.4 Economic aspects of climate change

The launching of the Kyoto economic instruments is an implicit recognition of the importance of economics in environmental policy-making. According to Rao *simultaneous operations of a multitude of economic agents and the dynamics of bio-economic systems are some of the factors that must be considered in any realistic appraisal of the economic parameters (...) in the presence of environmental unknowns* (Rao, 2000). In other words, many of the traditional assumptions regarding private-sector economics in ascertaining costs and benefits do not hold under environmental constraints because the value of the environment is not taken into account. In the following lines, the main concepts relevant to climate change economics are briefly explained: *scarcity*, *adaptation*, *uncertainty* and *time horizon*.

- In economics resource *scarcity* is defined as the positive difference between the desire and the demand for a good. This means that a good is scarce if people would consume more of it if it were free (in the presence of markets) or if it were available (in the absence of markets). In a closed system like the earth, under the current circumstances, 'normal climate conditions' are not a free resource any more. None of the environmental adjustments needed to combat the global warming effect are free of costs, although these may not be entirely monetary in the market sense. Climate protection policies, e.g. markets for GHG emission permits, try to define property rights and liability systems and put a price on this environmental scarcity.

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[9] Stand of the KP thermometer: http://unfccc.int/essential_background/kyoto_protocol/status_of_ratification/items/3134.php (March 2005).

- *Adaptation*. Climate change in a global context also incorporates vulnerability issues, the demand side of the problem (IPCC, 2001a). Assuming that climate change is unavoidable to a certain extent, adaptation to it in the long term puts an economic burden on the international community. The net present value of damages that arise from the emission of a gas, such as productivity losses or human health problems (also partially uncertain), would also have to be covered by the revenues achieved in today's climate policy. As in any other environmental issue there are gainers and losers and most likely an unequal distribution of damages will result. It is at this stage where *adaptation* meets *mitigation*.

- *Uncertainty* is the failure to know something that might be relevant for an economic decision. The climate change externality has a risk component since its real consequences are not perfectly known. Whereas the KP sets a time path in the medium-term for the achievement of an environmental good in the long-term, it is uncertain that this effort will achieve the expected results in terms of a 'sufficient' reduction in the atmospheric GHG concentration. The level of uncertainty can only be reduced through a better understanding of the weather phenomena and its long-term effects.

- *Time horizon.* The radiation time of well-mixed gases is incorporated in the global warming potential concept and must be considered in the environmental assessment of a mitigation project's lifetime. Moreover, discounting issues have an important effect on a project's valuation.

2.3 Main climate-relevant externalities in agriculture

'Agriculture and climate are mutually dependent'. Agriculture is an important source of environmental benefits and can play an important role in climate change regulation (e.g. through carbon sequestration). Moreover, agricultural activities can be a contributor to and a recipient of the effects of a changing climate (Rosenzweig, Hillel, 1998). Both these beneficial and negative effects, the latter from a production or consumption perspective of an environmental good, are unfortunately not captured by the market and result in market failure (Schimmelpfennig et al., 1996).

On the one hand, agriculture is an important source of environmental benefits. The use of best management practices and integrated farming systems protect soil fertility and stability, increase carbon sequestration and reduce the incidence and severity of natural disasters such as floods and landslides. These positive benefits should be seen as a 'potential' for targeted climate change mitigation policies and might justify public assistance to producers such as technical and financial aid. On the other hand, agricultural production is also a direct and indirect contributor of GHG emissions, mainly methane and nitrous oxide, through concentrated livestock production, pesticide and fertiliser use, deforestation, drainage of wetlands and soil erosion from cropland. Moreover, from the 'vulnerability' perspective (regarding agriculture as a sector dependent on the environmental good 'climate') long-term effects of climate change are likely to have a negative effect on agricultural production. Fluctuations in weather patterns could have extreme impacts on agricultural production, slashing crop yields and forcing farmers to adopt new agricultural practices in response to altered conditions. Whereas a temperature rising will expand the area of cereals cultivation in the colder regions of the globe and an increase of CO_2 concentration will have a positive effect on yields, drier conditions will reduce the growing season and enhance water requirements. Overall, climate change may lead to water stress, lower yields and the need for new varieties and cultivation methods (IPCC, 2001a).

There is, however, a complex debate around the scientific evidence of climate change (Centre for the Study of Carbon Dioxide and Global Change, USA; School of International Service, American University, USA; Argentinian Foundation for a Scientific Ecology, Argentina). These institutions, among others, refute today's scientific basis for climate change and the significant effect of human behaviour on it. In fact, they stress that scientific knowledge about climate change is limited and data are poor and not of sufficient quantity and quality to support a rigorous scientific debate. It is therefore important to pay attention to this controversy and ensure within the current climate change international negotiations more and better data for the future. Policy-makers will decide, upon this information, if evidence for such a change exists and what should be done about it. With this purpose, the development of models to estimate confidently the impacts of agriculture on climate change and vice-versa is critically important. They provide the information needed for the design of sector-specific mitigation policies and at the same time help agricultural producers to develop their own long-term responses to climate change within a certain policy context.

2.4 Modelling climate change indicators for agriculture

In the last two decades, the combination of economics and bio-physics has proven to be a feasible approach in the analysis of environmental policies. Several economic models have been recently developed in order to estimate climate change indicators in the agricultural sector.

An interesting economic model applied to the measurement of GHG emissions through the integration of bio-physical parameters is the US Agricultural Sector Model (ASM). It was designed as a regionalised model whose main objective was to simulate the effects of various changes in agricultural resource use or availability (Chang, McCarl, 1992). It is characterized by a welfare maximization objective function, where regional consumer and producer rents for the main crop and livestock activities, production costs, fixed resources (land, water and labour) and premiums are included. In the ASM, available technologies are represented through production budgets (fixed input-output combinations) and crop rotations are explicitly modelled. For simulation purposes, regional area allocation is constrained by 'crop-mix equations' which couple factor-production possibilities with historical cropping records. The ASMGHG (US Agricultural Sector and Greenhouse Gas Mitigation Model) expands this model and analyses GHG emission mitigation options by incorporating several agricultural management options (Schneider, 2000). Emissions and sinks by source are estimated for the US agricultural sector and simulation scenarios for different mitigation options and carbon prices constructed.

A second economic model used to assess the impacts of agri-environmental policy on GHG emissions is the AROPAj model (Jayet et al., 2000). This model was developed by the Institut National de la Recherche Agronomique France (INRA) to evaluate the economic impacts of agricultural and environmental policies first in France and afterwards extended to the EU. It comprises a classical linear programming supply model where agricultural income is maximised at the regional level subject to agronomic requirements and policy restrictions. It covers crop, animal and feeding activities and is based on representative farm types from the Farm Accountancy Data Network (FADN). In recent years, GHG emissions and sinks by source have been calculated by following both the IPCC methodology and some technical references (econometric estimation based on published parameters).

2.5 The CAPRI Modelling System

For the purposes of this study the CAPRI model is chosen as the main instrument of analysis. It is a spatial economic model that makes use of non-linear mathematical programming tools to maximise regional agricultural income with explicit consideration of the CAP instruments of support in a wide context (price interactions with other regions of the world are taken into account). Moreover, it makes use of bio-physical data to construct environmental indicators. Its main characteristics are explained in detail in this section.

2.5.1 History of the model

The CAPRI model was first developed in the context of the 4th EU Framework Program (FAIR3-CT96-1849) within the period 1997-1999 and coordinated by the Institute for

Agricultural Policy of the Bonn University. It comprised a network of four main partners and further sub-partners in order to cover all EU-15 Member States. In 1999, the system was first tested on an ‘Agenda 2000 reform’ simulation run and the concept and main results presented.

After a short phase of consolidation, the model was further developed within a new framework project titled CAP-STRAT, **C**ommon **A**gricultural **P**olicy **Strat**egy for Regions, Agriculture and Trade (QLTR-2000-00394), which was developed during the period 2000-2004. In this period, several objectives were achieved: a complete update of the data base, the implementation of important methodological improvements in the market component of the CAPRI model, a thorough validation of the complete system and the construction and analysis of several policy scenarios[10].

A third phase of model development has been initiated for the period 2004-2007 within the 6th EU Framework Program (STREP 501981). The Specific Targeted Research Project CAPRI-DynaSpat (**C**ommon **A**gricultural **P**olicy **R**egional **I**mpact Assessment – The **Dyna**mic and **Spa**tial Dimension) aims at ex-ante policy assessment of the CAP by maintenance and application of the existing model and its improvement in several directions[11].

2.5.2 General system layout

This model was designed from the beginning as a complex projection and simulation tool for the agricultural sector based on:

- *An activity-based breakdown of regional agricultural production* (about 50 activities) *and farm and market balances* (60 products and 35 inputs).
- *A physical consistency framework* covering balances for agricultural area, young animals, feed requirements for animals and nutrient requirements for crops (requirement functions are modelled as constraints in the regional supply models).
- *Economic accounting principles* according to the definition of the Economic Accounts for Agriculture (EAA). All outputs and inputs included in the national agricultural accounting systems for the Member States are included and revenues and costs are broken down consistently by regions and by production activities.

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[10] Note: the current study has been financed by the CAP-STRAT project.

[11] Relevant information on the description and different development phases of the model can be found on the main CAPRI web site: http://www.agp.uni-bonn.de/agpo/rsrch/capri/capri_e.htm. The final report of the CAPRI project can be found under http://www.agp.uni-bonn.de/agpo/rsrch/capri/finrep.pdf.

- *A detailed policy description*. The regional supply models capture all relevant payment schemes with their respective ceilings as well as set-aside obligations and sales quotas. The market component includes tariff rate quotas, intervention purchases and subsidised exports. The policy of non-EU regions is based on data from the OECD (Junker et al., 2003).

- *Behavioural functions and allocation mechanisms strictly in line with micro-economic theory*. Functional forms are chosen to be globally well-behaved, allowing for a consistent welfare analysis.

In CAPRI supply and market modules are distinguished. They are iteratively coupled to allow for a feasible computation of the model.

2.5.3 The supply module

In the supply module, regional agricultural supply of annual crops and animal outputs is modelled by an aggregated profit function approach under a limited number of constraints: land, policy restrictions such as sales quotas and set-aside obligations and feeding restrictions based on requirement functions. The underlying methodology assumes a two-stage decision process. In the *first stage*, producers determine optimal variable input coefficients per hectare or head (nutrient needs for crops and animals, seed, plant protection, energy, pharmaceutical inputs, etc.) for given yields, which are determined exogenously by trend analysis (data from EUROSTAT). Nutrient requirements enter the supply models as constraints and all other variable inputs, together with their prices, define the accounting cost matrix[12]. In the *second stage*, the profit-maximising mix of crop and animal activities is determined simultaneously with cost-minimising feed and fertiliser in the supply models. Availability of grass and arable land and the presence of quotas impose a restriction on acreage or production possibilities[13]. Moreover, crop production is influenced by set-aside obligations and animal requirements (e.g. gross energy and crude protein) are covered by a cost-minimised feeding combination. Fertiliser needs of crops have to be met by either organic nutrients found in manure (output from animals) or in purchased fertiliser (traded good). This part of the model is explained in more detail in chapter 3.

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[12] The process mimics the calculation of gross margins in farm management.

[13] Agricultural land is considered a fixed resource in the model and divided in arable land and grassland. It is distributed according to cropping shares, crop rotations not being explicitly considered a restriction in the model.

2.5.4 The market module

The market module breaks down the world into 12 country aggregates or trading partners[14], each one featuring systems of supply, human consumption, feed and processing functions. The parameters of these functions are derived from elasticities borrowed from other studies and modelling systems and calibrated to projected quantities and prices in the simulation year. Regularity is ensured through the choice of the functional form (a normalised quadratic function for feed and supply and a generalised Leontief expenditure function for human consumption) and some further restrictions (homogeneity of degree zero in prices, symmetry and correct curvature). Accordingly, the demand system allows for the calculation of welfare changes for consumers, processing industry and public sector (see analysis in chapter 7). Policy instruments in the market module include bilateral tariffs and producer or consumer subsidy equivalent price wedges (PSE/CSE). Tariff rate quotas (TRQs), intervention sales and subsidised exports under the World Trade Organisation (WTO) commitment restrictions are explicitly modelled for the EU-15 (Junker et al., 2003).

In the market module, special attention is given to the processing of dairy products in the EU. First, balancing equations for fat and protein ensure that these make use of the exact amount of fat and protein contained in the raw milk. The production of processed dairy products is based on a normalised quadratic function driven by the regional differences between the market price and the value of its fat and protein content. Then, for consistency, prices of raw milk are decomposed into their fat and protein content valued with fat and protein prices.

The market module comprises of a bilateral world trade model based on the Armington assumption (Armington, 1969). According to Armington's theory, the composition of demand from domestic sales and different import origins depends on price relationships according to bilateral trade streams. This allows the model to reflect trade preferences for certain regions (e.g. Parma or Manchego cheese) that cannot be observed in a net-trade model. A two stage Armington system is adopted: on the *top level,* total demand is divided into imports and domestic sales and, on the *lower level*, different import shares from different origins are determined. The resulting layout of a market for a country/aggregate is shown in figure (4).

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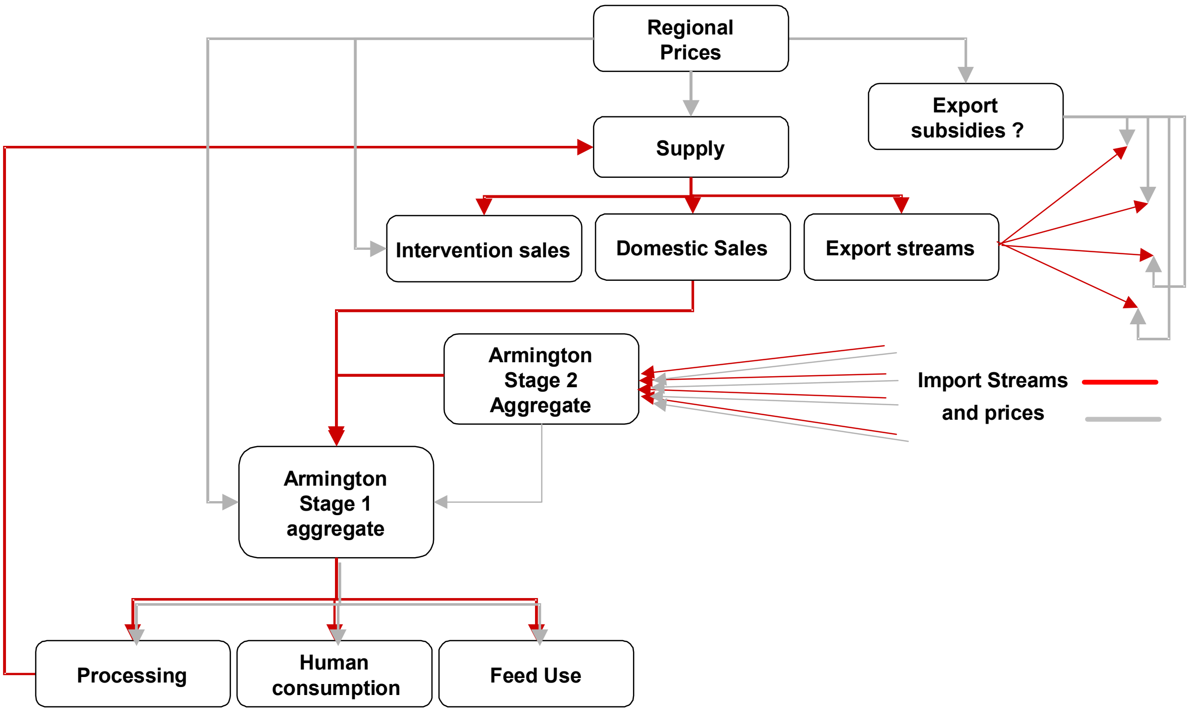
[14] EU-15, East European Candidate Countries, Mediterranean countries, U.S., Canada, Australia & New Zealand, Free trade developing countries, High tariff traders (as Japan), India, China, ACP countries, Rest of the World.

Figure (4) Graphic presentation of a spatial market system for one region



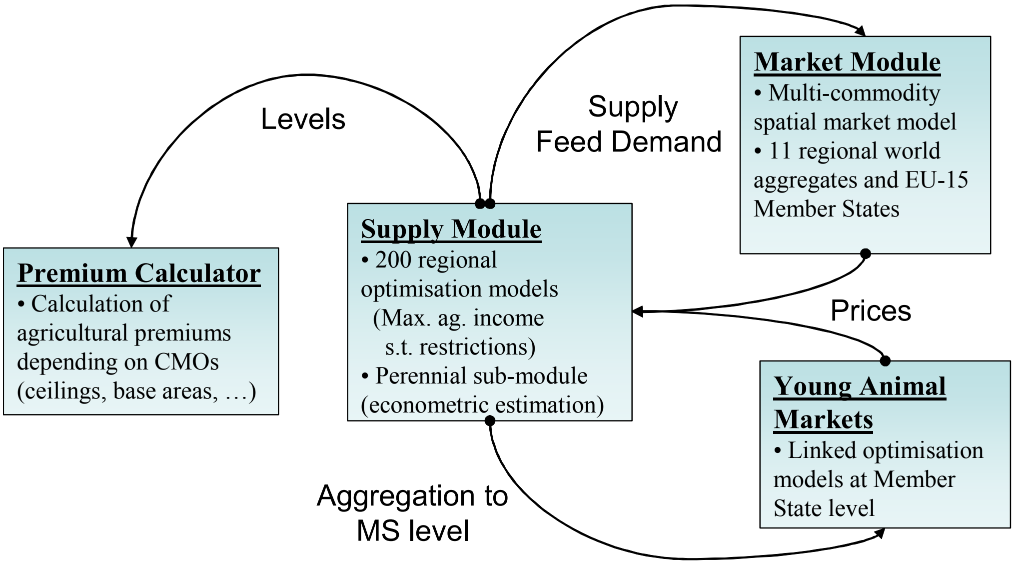
Source: description of the CAPRI model in Britz et al., 2003.

According to the Armington assumption, markets for different agricultural products in different regions are linked to the observed import streams and import prices in the base year[15]. Accordingly, no uniform world market price is found in the system.

2.5.5 Link between the supply and market modules

As previously mentioned, the equilibrium in CAPRI is obtained by letting the supply and market modules iterate with each other. In the first iteration, the regional aggregate programming models (one for each Nuts 2 region) are solved with exogenous prices. Regional agricultural income is therefore maximised subject to several restrictions (land, fertiliser need, set-aside, etc). After being solved, the regional results of these models (crop areas, herd sizes, input/output coefficients, etc.) are aggregated to Member State level models, which are then calibrated using Positive Mathematical Programming (PMP) estimation techniques. Young animal prices are determined by linking these calibrated Member State models into a non-spatial EU trade model with market balances for young animals, as shown in figure (5). In the second iteration, supply and feed demand functions of the market module are first calibrated to the results from the supply module on feed use and production obtained in the previous iteration. The market module is then solved at this stage (constrained equation system) and the resulting producer prices at Member State level transmitted to the supply models for the following iteration. At the same time, in between iterations, premiums for activities are adjusted if ceilings defined in the Common Market Organisations (CMOs) are overshot.

Figure (5) Link of modules in CAPRI



Source: Britz et al., 2003.

A cost function covering the effect of all factors not explicitly handled by any restriction or included in the accounting costs (e.g. risk aversion) ensures calibration of activity levels in the base year and plausible reactions of the system. It is also important to notice that the supply approach just described is not well suited to model perennial crops (vineyards, fruit and olive trees). These activities have a longer planning horizon than one year and require long-term investment decisions which are not suitable to be solved within the presented programming framework. Equally, some other crops such as flowers or vegetables require a completely different marketing and production chain. For both types of activities, a simultaneous econometric estimation of yields, activity levels and market balance positions is embedded in the analysis, with additional constraints ensuring closed market balances (El Kamel et al., 1999).

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[15] This property can be of great advantage when having regional differentiated products, as already mentioned, but does not solve the problem of the ‘zero observation’, i.e. unobserved trade flows in the base year situation cannot be generated in the simulation. This problem is of course also present in net trade models.

2.5.6 Data base issues

The CAPRI modelling system is, as far as possible, fed by statistical sources available at European level which are mostly centralised and regularly updated. Farm and market balances, economic indicators, acreages, herd sizes and national input-output coefficients are almost entirely taken from EUROSTAT. In order to use this information directly in the model, the CAPRI and CAPSIM[16] teams developed out of EUROSTAT data a complete and consistent data base (COCO) at Member State level (Britz et al., 2002). COCO was primarily designed to fill gaps or to correct inconsistencies found in statistical data and, additionally, to easily integrate data from non-EUROSTAT sources in the model. However, given the task of having to construct consistent time series on yields, market balances, EAA positions and prices for all EU Member States, a heavy weight was put on a transparent and uniform econometric solution so that manual corrections were avoided.

In the regionalisation of the model, aggregation errors are minimised by choosing homogenous regions for which data are available. The only uniform data sources at EU level are the REGIO and FADN data bases, from EUROSTAT and the European Commission respectively. Both sources are used to construct a regionalised data base. Given the regional composition of these sources, Nuts 2 and farm typologies are chosen as the minimum level of regionalisation (the latter only used for selected studies[17]). Whereas natural conditions such as slope, soil types and temperature are quite heterogeneous at this level, the main economic indicators and management variables are available. REGIO is used to define acreages, herd sizes and yields at Nuts 2 level. Data at national level (cropped hectares, slaughtered heads, herd sizes and production quantities) are taken directly from COCO. REGIO data are then systematically corrected to allow for a consistent disaggregation. FADN data provide parameters for input-demand functions, which estimate the input allocation and income indicators for activities at a regional level. These data flows are shown in the following figure:

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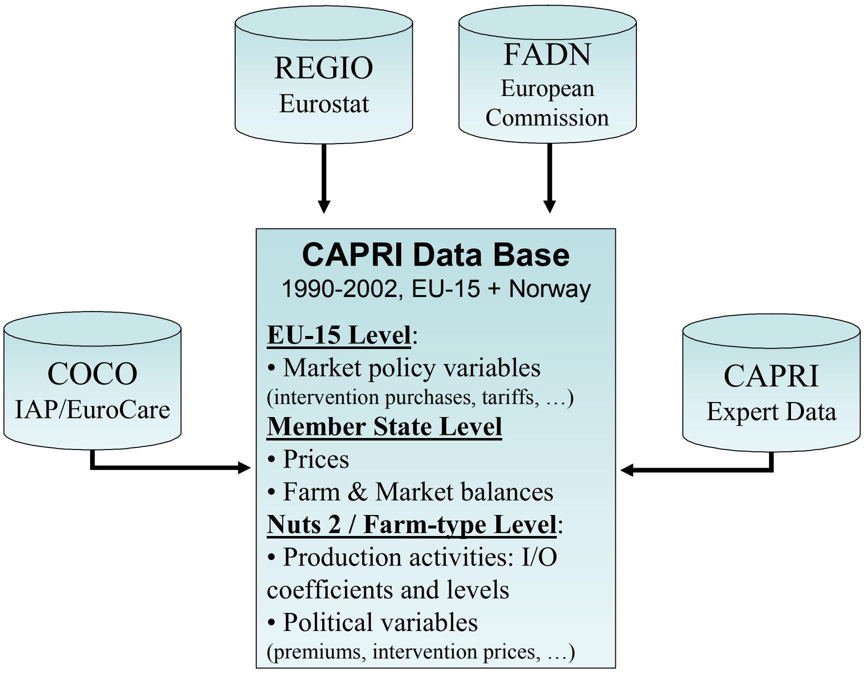
[16] The ‘Common Agricultural Policy Simulation Model’ (CAPSIM) has been developed by Dr. Heinz-Peter Witzke, EuroCare, Bonn (http://www.eurocare-bonn.de/profrec/capsim/capsim_e.htm).

[17] Nuts 2 regions in CAPRI are further regionalised in ‘farm-type regions’. The aggregation error due to heterogeneity inside of the regions is partially addressed by consistently aggregating for each Nuts 2 region individual farm data from FADN into six categories: the five most important farm types in the region plus a residual mixed type closing the data base.

Figure (6) Data flows in CAPRI



Source: CAPRI Modelling System.

2.5.7 Exogenous assumptions and additional sources

Within the supply module, the following assumptions are made:

- *Exogenous development of yields.* Trends have been used to determine yield development in future scenarios, including information from years 1980 to 2002. These are harmonised with yield estimations included in the latest DG-AGRI market outlooks.

- *Rate of input saving technical progress.* Variable inputs besides nutrient requirement needs for crops and animals as well as replacement rates of animals are shifted proportionally with yields. Nutrient needs of crops are yield dependent but driven by specific functions (as well as by nutrient requirements for animals). The rate of input-saving technical progress is assumed to be -0.2 % p.a.

For the market module several assumptions mainly related to the selection of additional data sources are also needed:

- *Inflation* is set to 1.9 % p.a. and nominal Gross Domestic Product (GDP) growth for the EU to 2.7 % p.a. (Commission of the European Communities, 2002).

- *Data on bilateral trade between selected world regional aggregates* (main trading players) are borrowed from the World Agricultural Trade Simulation Model (WATSIM) (Kuhn, 2003)[18]. Shift parameters like population growth, income growth and preferences are taken from EUROSTAT. A main data source for shifts in supply and demand in non-EU regions is the @2030 framework of the FAO global perspective unit (FAO, 2003).

- *Data on policy variables* such as applied and scheduled tariffs, tariff rate quotas or bilateral trade agreements are obtained from the AGLINK Model (OECD) and the Agricultural Market Access Database (AMAD) (compilation by Junker et al., 2003).

- *Preferences*. Changes in demand behaviour not linked to income or prices changes are trended using ex-post time series on per capita consumption, in most cases in line with data found in the EU Prospects for Agricultural Markets (Commission of the European Communities, 2002).

- *The price framework* contained in the market module is based on representative long-term time series for world market prices of major raw and processed agricultural product, which are trend forecasted.

2.6 Conclusions

In this chapter the main physical linkages between climate change and the agricultural sector are addressed as an introduction to the issue of analysis in the following chapters. First, the global warming effect as a global negative externality is thoroughly reviewed from an economic and legislative perspective. Then, the use of economic models able to estimate GHG emissions from agricultural sources is proposed and the CAPRI Modelling system, as the selected tool of analysis, is explained in detail. This methodology has the following *advantages* for the design and estimation of environmental indicators:

- A consistent and detailed break down of agricultural production at regional level in Europe. Regions do not only differ by soil type, which affects crop yields, but also by agricultural specialisation. Related to this, there are different environmental issues that are relevant for agriculture (e.g. over-production of organic fertiliser is a problem in regions with high animal densities).

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[18] The 'World Agricultural Trade Simulation Model' (WATSIM) has been developed at the Institute for Agricultural Policy, Bonn (http://www.agp.uni-bonn.de/agpo/rsrch/watsim/wats_ov_e.htm).

- A mathematical programming approach. This makes it easily possible to include regions, agricultural production activities and environmental indicators and, additionally, alternative technologies. Moreover, it allows explicit consideration of specific policy variables (e.g. CAP direct payments).

- Endogenous prices. This is achieved either through an internal balancing of demand and supply or through the linkage between the supply and market modules. By doing this, agricultural producers' behaviour is more realistically modelled; as the aggregated effect of changes in demand and supply on market prices is taken into account.

- Data base coverage. The model consistently covers the whole agricultural sector so that the trade-off between different environmental indicators can be assessed.

Nevertheless, some *weaknesses* have to be recognized:

- Aggregation error stemming from the regional programming approach. The aggregation at Nuts 2 level does not allow the assessment of local environmental effects (e.g. different environmental problems between farms). A further disaggregation of Nuts 2 regions to lower aggregation levels could help reduce this bias.

- Environmental indicators are modelled as rather robust pressure indicators (see section 3.3). In order to improve the explanatory power of these indicators, more refined selected parameters from bio-physical or highly regionalized approaches have to be linked to the model.

CHAPTER 3 Modelling of Greenhouse Gas Emission Inventories for the European Agricultural Sector

> *The significant problems we have cannot be solved at the same level of thinking with which we have created them (Albert Einstein, Physicist).*

3.1 Introduction

A sufficient knowledge on domestic GHG emissions is the initial and most important task to be faced by governments willing to undertake global warming abatement measures. Without a comprehensive set of national sources and sinks or a suitable emission estimation procedure no effective implementation of the Kyoto mitigation instruments is feasible. For this reason, the IPCC published in 1997 and 2000 a set of guidelines and common practices to be used by governments in the construction of regional emission inventories (IPCC, 1997; IPCC, 2000)[19]. After ratifying the KP in 2002 (Council of the European Union, 2002), European countries committed themselves to monitor anthropogenic GHG emissions from different sources and evaluate the progress towards compliance with the Kyoto objectives (Council of the European Union, 2004a), agriculture being included among other sectors.

The IPCC proposed a mechanism to calculate national GHG emission inventories based on default emission factors for single polluting activities, regional differences being covered by additional bio-physical studies. This method is currently widely accepted by the scientific community for its simplicity. On the one side, it guarantees a complete data set under certain quality standards through the validation of the guidance rules and, on the other side, it allows for regular updates and the incorporation of expert data. Nevertheless, it has been somewhat controversial, mainly within the research community, since the complexity of the global warming issue cannot be fully covered by 'passive' emission factors.

One of the relevant tasks of this research study is to feed an economic model with the necessary information to calculate global warming emissions from agricultural sources. This can be done:

(1) by explicitly considering endogenous interactions with bio-physical models applied to the measurement of GHG emissions (construction of a meta-model) or (2) by including emission factors linked ex-post to activities and technologies. Since an important objective of this study is not only to measure emissions but also to analyse the economic implications of instruments of emission abatement currently discussed in international negotiations, the second option has been chosen and an existing economic model used. This will allow a higher degree of transparency and direct comparison with other research studies. Moreover, in terms of its practicability, this system has some advantages since measurement is based on transparent rules and validated parameters. This should help governments to keep monitoring and enforcement costs low and increase social acceptability.

The chapter is divided in five sections. After this short introduction, in section 3.2 the feeding and fertilising modules of the CAPRI modelling system are explained in detail. Section 3.3 focuses on modelling issues and presents the key equations used in the model for the construction of GHG emission inventories, the main agricultural emission sources being individually analysed. Regional results for emission factors per activity and methodological issues are thoroughly discussed. In section 3.4, selected results for the year 2001 are provided and comparisons to NGHGIs for agricultural sources are given. Some concluding remarks are presented in section 3.5.

3.2 Feeding and fertilising parameters in the model

The overall structure of the CAPRI model has been thoroughly explained in section 2.5. As mentioned, the main elements of this modelling system are a set of regional supply models at Nuts 2 level and a market module taking care of price interactions between the EU and the rest of the world. Moreover, the CAPRI supply component incorporates feeding and fertilising modules which are quite relevant for the construction of environmental indicators. In the following paragraphs, the interactions between these two modules are given a closer look.

3.2.1 Treatment of feeding requirements

The model covers *energy*, *protein*, *fiber* and *dry matter* requirements for 16 animal activities: *dairy cows*, *suckler cows*, *bulls for fattening*, *heifers for fattening and raising (2)*, *male and female calves for fattening and raising (4)*, *pigs for fattening*, *piglets for pig production*, *sheep*

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[19] This methodological work is being revised again at the moment and will be published by the IPCC in 2006 based on the 1997 revised guidelines, the 2000 good practice guidance and the 2003 good practice guidance for LULUCF activities.

and goats for milk and fattening (2), *laying hens*, *poultry for fattening* and *other animals*. Additionally, *dairy cows* are broken down in *low and high milk yield (2)*, and *bulls and heifers for fattening* in *low and high final weight (4)*. Overall, 4 feeding requirement functions are derived for 19 animal activities. On the supply side, crop products used for feeding (according to the EAA product balances) are aggregated into 10 feeding compounds, entering the model as inputs for the animal activities: *cereals for feeding*, *rich protein feeding*, *rich energy feeding*, *milk products for feeding*, *other products for feeding, grass*, *fodder maize*, *other fodder on arable land*, *fodder root crops* and *straw*.

The feeding module is basically divided in two parts. First of all, the need of nutrients by animals and the availability of them on feeding aggregates are defined. Requirement functions for each animal category are estimated depending on the ingestion capacity, live weight, days of production and yields (Nasuelli et al., 1997). Net energy lactation, crude protein, fiber and dry matter intake are calculated for each animal category, with the choice of ingredients included in the animal feeding being influenced by its physiological and biochemical characteristics. In practical terms, each animal has to cover its energy balance and cannot ingest above a certain volume. At the same time, feeding products are described in the model in terms of their nutritional characteristics. The feeding-mix always has to remain balanced so that the different nutritional requirements per animal in a region can be satisfied.

In equation (3.1) feeding demand by animals is a variable ($FD_{r,j,o}$) that has to satisfy previously calculated individual bio-physical feeding requirements ($REQ_{r,j,q}$). Whereas energy and crude protein requirements have to be met exactly for each animal category (equality restrictions), fiber and dry matter requirements are included as minimum values in the optimisation (inequality restrictions).

(3.1) $$REQ_{r,j,q} * d_{r,j} - \sum_{o} \left(FD_{r,j,o(=feed)} * NC_{r,q,o(=feed)} \right) \leq 0$$

Where:
REQ = requirements per animal (energy in MJ per day and rest in kg per day)
r = regional unit
j = animal activity
q = requirement type
d = days of production in a year
o = product in the model (netput for feeding activities, i.e. a product can be an output for crops and an input for animals)
FD = feeding demand (in kg per head and year)
NC = nutrient content in feeding products (energy in MJ per kg and rest in dry matter share)

As expressed in equation (3.2), total regional feeding demand has to be in line with fodder consumption in the EAA and the availability of non-tradable fodder ($FD_{r,j,o}$ is a variable entering also regional market balance constraints).

(3.2) $$\sum_{j} \left(FD_{r,j,o(=feed)} * X_{r,j} \right) = FU_{r,o(=feed)}$$

Where:
FU = regional feed use or fodder availability (in kg)
X = level of production (in 1000 heads or hectares per year)

Additional corrections are introduced in the requirements to cover ‘luxury feeding’ practices, i.e. differences between current farming practices and estimations based on engineering data. This adjustment or correction mechanism is necessary to ensure the calibration of the model to observed data and will be also used in the fertiliser module.

In the second part of the feeding module, fodder prices are estimated for non-tradable feeding compounds in the model. Prices for *grass* (extensive and intensive production), *other fodder on arable land*, *fodder maize* and *fodder root crops* are not available in the EAA, only an aggregate price index. They are therefore estimated with the help of a cross-entropy estimator which is designed to choose a product price so as to generate plausible gross margins for the corresponding activities while fixing the aggregate price index. Once all feeding products are consistently given a price, they can enter as input costs in the objective function. In the optimal solution (maximal regional agricultural income), an optimal feeding-mix per animal activity is endogenously estimated.

For the purpose of this analysis, *energy requirements* for cattle, sheep and goat activities are further divided into: maintenance, lactation, growth or pregnancy. This replicates the approach followed by the IPCC in its Good Practice Guidance for the calculation of NGHGIs. Information on sub-energy positions is relevant in order to calculate methane emissions by enteric fermentation processes following the IPCC - Tier 2 methodology[20], as pointed out further on in this chapter (section 3.3). Moreover, this approach adapts quite well to the core structure of the model, which differentiates between growth and fattening activities.

In table (4) modelled net energy requirements per animal activity, average live weight, production days and main output coefficient[21] are reported for the EU-15 as an aggregate for year 2001.

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[20] The IPCC defines different methodologies for the calculation of emissions, depending generally on the availability of data. Whereas the Tier 1 method is a simplified way of calculating emissions based generally on default emission factors drawn from previous studies, the Tier 2 method requires country-specific information.

[21] 'Milk' is the main product for dairy cattle and sheep and goats for milk, as the name already indicates. 'Meat' is considered the principal output coefficient of suckler cows, fattening and raising cattle activities, pigs, sheep and goats for fattening, hens and chickens (beef, veal, pork, lamb or poultry meat).

Table (4) Net energy intake, average live weight, production period and main yield per head (average for the EU-15)

	Net energy	Average live weight	Production days	Main yield
Bulls high weight	*71.0*	*491.5*	*313.5*	*390.9*
Bulls low weight	*58.9*	*408.8*	*146.4*	*260.6*
Calves female fattening	*26.0*	*177.3*	*172.2*	*134.0*
Calves female raising	*35.5*	*243.0*	*270.8*	*1***
Calves male fattening	*25.2*	*171.7*	*160.3*	*134.0*
Calves male raising	*34.3*	*243.0*	*274.3*	*1***
Dairy cows high yield	*175.3*	*600.0*	*365.0*	*8604.5*
Dairy cows low yield	*112.0*	*600.0*	*365.0*	*3687.6*
Heifers high weight	*58.4*	*415.5*	*288.8*	*311.6*
Heifers low weight	*46.7*	*342.6*	*106.5*	*207.7*
Heifers raising	*66.1*	*441.6*	*365.0*	*1***
Hens*	*886.5*	*1.6*	*365.0*	*1241.8*
Pigs fattening	*18.9*	*109.4*	*134.2*	*85.3*
Poultry for fattening*	*522.3*	*1.1*	*58.3*	*1809.8*
Sheep and goats for milk	*11.0*	*60.0*	*365.0*	*47.3*
Sheeps and goats for fattening	*3.5*	*12.4*	*99.5*	*14.9*
Sows	33.03	*153.5*	*365.0*	*68.7*
Suckler cows	*64.4*	*550.0*	*365.0*	*59.9*

Source: own calculations; 2001 three year average calibration year.

Measurement units: net energy (MJ per day), average live weight (kg), production days (per year) and main yield coefficient (kg or litre per head).

* Energy and yield measured for 1000 heads.

** Young animal activities as output (young cows, young bulls and young heifers).

In the previous table average energy requirements are presented for animal activities in the EU-15. High yield dairy cows deliver on average over 8600 litres of 4 % fat milk per year and need around 174 MJ per head and day of overall net energy (40 to 50 % of this energy required for the lactation process). Suckler cows need approximately 64 MJ per day when assuming one calf per year and 60 kg beef production. These values are in line with the IPCC feed intake values for Western Europe (IPCC, 1997, table B-1), measured in gross energy intake, and slightly above Kirchgeßner's estimates (Kirchgeßner, 1997, pp. 268 and 312). As reflected in the table, higher yields, heavier animals and longer periods of production are directly correlated with higher energy needs. These are the main determinants introduced in the animal requirement functions.

Crude protein requirements are also calculated in the model based on econometric functions estimated in several experimental studies taken from the literature (Nasuelli et al., 1997). Milk yields, fat content in milk and daily fattening rates enter as variables in these functions. Moreover, crude protein requirements are used to calculate nitrogen (N) intake by animals. According to the literature (Udersander et al., 1993), there is a relation of 1 to 6 between crude protein and N in feeding[22]. By combining this information with N retention rates per animal activity (IPCC, 2000, table 4.15), manure production rates can be estimated (N-intake minus N-retention)[23]. The following equation is used to calculate N delivery in manure:

$$NM_{r,j} = PI_{r,j} / 6 * \left(1 - NR_j\right) \tag{3.3}$$

Where:
NM = N in manure (in kg)
PI = protein intake (in kg of digestible intestinal crude protein)
NR = N retention rate (share)

In table (5) crude protein requirements per animal activity, N in manure and N retention rates are reported for the EU-15 as an aggregate for year 2001.

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[22] The National Forage Testing Association calculated conversion factors of 6.25 for forages and feeds and 5.7 for wheat grains. In CAPRI, a value of 6 is assumed across all products entering the feeding process.

[23] Further research was carried out in CAPRI by applying N retention functions per animal type in the calculation of N excretion produced in manure (Nasuelli et al., 1998). However, this approach will not be applied in this study since it has not proved to give significant gains compared to the currently used IPCC approach.

Table (5) Crude protein intake, manure production and nitrogen retention per head (average for the EU-15)

	Crude protein	Nitrogen in manure	Nitrogen retention
Bulls high weight	*1.7*	*83.8*	*0.07*
Bulls low weight	*1.4*	*31.7*	*0.07*
Calves female fattening	*0.8*	*21.5*	*0.07*
Calves female raising	*0.9*	*38.4*	*0.07*
Calves male fattening	*0.8*	*20.2*	*0.07*
Calves male raising	*0.9*	*38.6*	*0.07*
Dairy cows high yield	*4.3*	*210.1*	*0.20*
Dairy cows low yield	*2.7*	*129.4*	*0.20*
Heifers high weight	*1.5*	*64.4*	*0.07*
Heifers low weight	*1.2*	*20.6*	*0.07*
Heifers raising	*1.7*	*95.9*	*0.07*
Hens*	*21.2*	*900.9*	*0.30*
Pigs fattening	*0.4*	*7.0*	*0.30*
Poultry for fattening*	*7.6*	*52.9*	*0.30*
Sheep and goats for milk	*0.2*	*13.7*	*0.10*
Sheeps and goats for fattening	*0.1*	*2.0*	*0.10*
Sows	*0.9*	*36.4*	*0.30*
Suckler cows	*1.5*	*87.2*	*0.07*

Source: own calculations; 2001 three year average calibration year.

Measurement units: crude protein (kg per day), N in manure (kg per head and year) and N retention rates (shares on total N intake).

* Crude protein and N in manure measured for 1000 heads.

In this table the correlation between crude protein intake and N content in manure is presented for each animal activity. *Pigs for fattening* weigh on average slightly over 100 kg and need around 0.4 kg of raw protein per day with 7 kg of N released in manure. *Suckler cows* weigh 550 kg, require 1.5 kg per day and release 87 kg of N. Compared to Kirchgeßner's estimates, these calculations are low for dairy activities and quite accurate for pigs for fattening and suckler cows (for these last two activities he reports 0.315 and 1.340 kg per day, for 100 kg and 650 kg animals respectively) (Kirchgeßner, 1997, pp. 268, 312-314 and 237-240)[24]. Reported IPCC N retention rates vary between 1 % for sheep and goat activities and 7 % for cattle activities.

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[24] As in the case of the net energy calculation, Kirchgeßner refers only to the lactation process for dairy cows. On the contrary, the IPCC approach takes into account energy and crude protein requirements for maintenance, pregnancy and activity.

An accurate estimation of energy and crude protein requirements is necessary for the measurement of GHG emissions in agriculture. Moreover, the estimation of N production rates in organic fertiliser is of importance for the calculation of manure management emissions and a consistent N flow in agricultural soils. This aspect is analysed in the following paragraph, as part of the fertiliser module.

3.2.2 Treatment of fertilising requirements

Whereas in the *feeding module* animals demand nutrients which are supplied by crop feeding activities, in the *fertilising module* crops enter the equation as 'consumers' and need to cover their nitrogen, phosphate and potassium (NPK) nutrient needs through the application of fertiliser. This can be done by applying mineral or organic fertiliser[25] on the field. Both types of fertiliser are used to cover the nutrient need of crops, consistently linking manure production by animals and consumption of mineral fertiliser by crops at a regional level. Consequently, the approach gains in complexity since an additional link between animal and crop activities to the one mentioned in the previous section is included in the model. In the following paragraphs, the structure of the fertilising module is explained in detail.

First of all, sources and sinks of nutrients in agriculture are translated into the model. This is done according to the following equation:

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[25] Mineral fertiliser is traded according to public statistics on fertiliser consumption from FAOSTAT (http://apps.fao.org). Organic fertiliser from animals is assumed to be a non-tradable good produced in the model (based on engineering functions) and has to be applied within the region where it was produced.

$$\begin{aligned}(3.4)\quad &\sum_{k}\left[X_{k} * \left(ND_{r,k,fi} * (1 - Nfix_{k(=pulses)}) * NutCorr_{r,fi} - Natm_{r,k}\right)\right] = \\ &TRD_{r,fi} * (1 - AmmMF_{r}) + \sum_{fo}\left[\sum_{j} X_{j} * NS_{r,j,fo} * (1 - AmmOF_{r,j,fo(=N)}) * NavCorr_{r,fo}\right]\end{aligned}$$

Where:
k = crop activity
fi = NPK nutrients (as inputs)
ND = nutrient demand by crops (kg per crop and year)
Nfix = N import by biological fixation (kg per crop and year)
NutCorr = regional correction factor for over-fertilisation practices
Natm = N import from atmospheric deposition (kg per crop and year)
TRD = nutrient imports from purchased mineral fertiliser (kg)
AmmMF = nutrient losses in the application of mineral fertiliser (share)
fo = NPK nutrients in manure from animals (as outputs)
NS = nutrient supply from manure (kg per animal and year)
AmmOF = N losses through ammonia emissions from organic fertiliser (share)
NavCorr = correction factor for nutrient availability in manure (share)

Nutrients exported by cropped products ($ND_{r,k,fi}$) must be covered by purchases of mineral fertiliser ($TRD_{r,fi}$) or 'available' organic fertiliser ($NS_{r,j,fo}$). These sources are also subject to losses through application ($AmmMF_{r}$) and volatilisation as ammonia ($AmmOF_{r,j}$). Moreover, demand for nitrogenous fertiliser is reduced by N fixation ($Nfix_{k}$) and N from atmospheric deposition ($Natm_{r,k}$). As in the case of the feeding module, nutrient correction and nutrient availability factors are included and specified in the model in order to calibrate observed data on national mineral fertiliser consumption and regional manure production derived from bio-physical equations. They ensure consistency to given statistical data by covering regional over-fertilisation practices ($NutCorr_{r,fi}$) and variability of nutrient contents in manure ($NavCorr_{r,fo}$)[26].

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[26] By using a cross-entropy approach, nutrient correction factors are given a density distribution in line with over-fertilisation estimates from the Nutrient Flow model (NFM), designed by the Agricultural Economics Research Institute in Holland (LEI). On the other hand, nutrient availability in manure is trimmed across regions by allowing higher nutrient losses per hectare in regions where manure production is higher compared to the national average.

By following this approach and further disaggregating ammonia emissions by sources (Oudendag et al., 2003) a closed N balance can be calculated at a regional level. Its structure and average results for the EU are briefly presented in the following table.

Table (6) Nitrogen balance (average for the EU-15)

INPUT			**OUTPUT**		
Import of nitrogen by anorganic fertiliser	a	68.2	Export of nitrogen with harvested material	f	80.95
Import of nitrogen by organic fertiliser (in manure)	b	77.31	Nitrogen in ammonia losses from manure fallen on grazings	g	2.08
Nitrogen from biological fixation*	c	2.89	Nitrogen in ammonia losses from manure in stable	h	7.13
Nitrogen from atmospheric deposition	d	14.36	Nitrogen in ammonia losses from manure storage	i	2.53
			Nitrogen in ammonia losses from manure application on the field	j	8.34
			Nitrogen in ammonia losses from organic fertiliser	k=g+h+i+j	20.08
			Nitrogen in ammonia losses from mineral fertiliser	l	2.89
TOTAL INPUT	**e=a+b+c+d**	**162.768**	**TOTAL OUTPUT**	**n=f+k+l+m**	**103.92**
			Nutrient losses at soil level (SURPLUS)	**m=e-f-k-l**	**58.85**

Source: own calculations; 2001 three year average calibration year.

Measurement units: kg N per hectare.

* In the model pulses and some fodder activities are considered N-fixing crops.

Table (6) reflects N sources and sinks for the EU-15 on a per hectare basis. On average, around 81 kg of N are exported from the system to the harvested product (**f**) and additionally 23 kg are counted as losses through ammonia volatilisation processes (**k+l**). Different N loss factors are used according to each animal category and observed management: *manure fallen on grazings, in stables, in different storage systems and applied on the field*. These losses are covered by the application of organic and mineral fertiliser (149 kg) (**a+b**). As mentioned in the previous paragraph, organic fertiliser is estimated based on manure output functions from each animal category (total manure available for the herd size in the base year) and mineral fertiliser is collected from FAO statistics at a national level and broken down for each crop activity by using different engineering parameters. Additionally, N is imported through biological fixation processes (**c**) and atmospheric deposition (**d**), with 3 and 14 kg per hectare respectively. The difference between N output and N input is considered a surplus in the system (**m**), in our case of 59 kg per hectare. This N balance is linked to the GHG module described in the next section since ammonia and N in soils are subject to chemical reactions that release nitrous oxide emissions in the atmosphere.

In the second part of the fertilising module, regional production of organic N in manure is allocated to crop activities according to their physical characteristics and expert knowledge. Manure is assumed to be non-tradable in the model, has to be consumed within a certain region and is applied differently on land (fodder activities get in practice, for example, a much bigger share of organic fertiliser than vegetables). This is an important step in the estimation of nitrous oxide emissions from soils since some Member States apply different emission factors for mineral fertiliser and manure.

As a concluding remark, the approach adopted in the model considers *NPK nutrients in manure* and *fodder production* as netputs (output/input for animal activities and input/output for crops, respectively). They are therefore endogenously given a price in the model and compete to a certain extent with other agricultural inputs. These linkages make both crop and animal sectors interact with each other.

3.3 Modelling of single greenhouse gas sources

Measuring emissions in agriculture is a difficult task for several reasons. In the agricultural sector, there are many small sources and in most cases it is not easy to localise them geographically. Moreover, it is very costly, if not practically impossible, to measure emissions directly. There are only a few studies with top-down estimated nitrous oxide emissions (Manning et al., 2003). This is somehow easier for methane as the concentration gradients in the atmosphere are more pronounced (shorter lifetime due to its reaction with OH radicals). A more feasible approach would be therefore to estimate emissions indirectly by using certain emission coefficients which consistently incorporate the current scientific knowledge on GHG formation. This interdisciplinary approach would imply working in two opposite directions, using inputs from different sciences like biology, chemistry and meteorology.

On the one side, within a *bottom-up framework*, controlled laboratory experiments with animals, crops and soils for different management technologies can provide the necessary information on emissions at the micro-level. Regional specificities of crop production or data on emissions from different animal activities should be included in the respective emission factors. In Europe, there are several institutions running bio-physical models that are relevant for the measurement of global warming emissions released in agriculture. Amongst others, the Agricultural Economics Research Institute in Holland (LEI, The Hague, Netherlands) has been carrying out important research on *emissions from nutrients*, the University of Bologna on *emissions from animal production* and the Institut Agronomique Méditerranéen (IAMM, Montpellier, France) on *plant growth, water stress and fertiliser use*. Information from these sources can be carefully selected to complete the IPCC emission coefficients and cover some emission sources in more detail (Helming, 1998; Nasuelli et al., 1998; Flichman, 1997).

On the other side, a *top-down approach* can be considered to complement the previous one. The measurement of global GHG concentrations gives information on the changing atmospheric load and is combined with the analysis of sink processes in order to come up with reliable source estimates. With the help of laboratory experiments the radioactive properties of different gases and therefore their climate impact in the long term are estimated. This information is obtained from several bio-physical models following different methodologies: measurement of paleoclimatic carbon records in polar ice, analysis of temperature changes in the stratosphere and photo-chemistry analysis of solar radiation. This scientific basis and some estimates are reviewed by the IPCC in its Third Assessment Report[27].

In this study a *bottom-up approach* is followed and results compared with official reporting data at the national level. By getting some information on the regional structure of the European agricultural sector, information on emissions at Nuts 2 level is estimated. Agri-physical models are used to identify relevant agricultural emission sources and estimate emission factors. This information flows into a regionalised economic model, where (1) all important agricultural activities and most of the physical and economic linkages between agricultural products in Europe are covered and (2) GHG emission coefficients are included and adjusted when necessary (see figure (7)).

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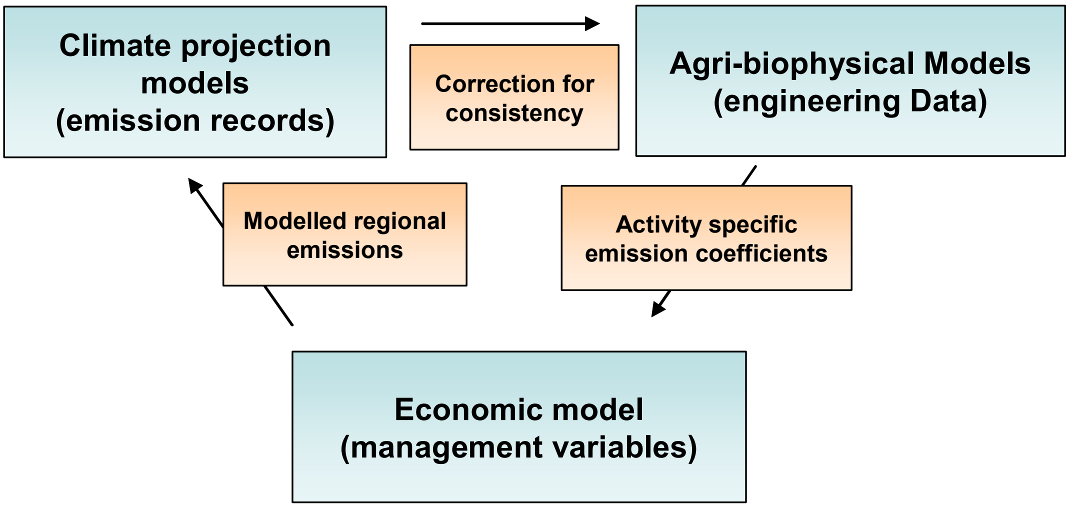
[27] In Europe model estimations and data on emissions submitted by Member States to the UNFCCC are gathered and distributed by the EEA through the European environment information and observation network (EIONET). This information is already allocated to sources, partially combining top-down and bottom-up approaches. For air emissions, the CORINAIR data base is built up (CORE Inventory of AIR emissions) covering emissions from several sectors (agriculture included) for years 1990 to 2000.

Figure (7) Information flows used in the calculation of regional emissions



This analysis with CAPRI is a first attempt to focus on the agricultural sector and model emission sources and environmental policy restrictions in a regionalised European Union. A similar structure is followed by the POLES Model[28] for the energy sector, a model aiming to provide an outlook on long-term energy systems. It performs a calculation of CO_2 emissions from energy production for the major regions in the world, analyses technical progress and tries to estimate the effects of different environmental restrictions on the energy sector.

For the purpose of modelling GHG emissions from agriculture, a *multi-strategy approach* is followed (Manne, Richels, 2000). It is important to take into account that agriculture is an important emitter of several climate relevant gases other than carbon dioxide. Therefore, in this analysis two types of pollutants are measured: methane (CH_4) and nitrous oxide (N_2O). The sources considered are: *CH_4 emissions from animal production*, *manure management and rice cultivation* and *N_2O from agricultural soils and manure management*. In this section, the main equations and data used to calculate these emission sources are described[29].

The structure of the CAPRI model is modified in this study to allow for a consistent construction of GHG emission inventories in the European agricultural sector. As already mentioned, *land use*

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[28] The POLES world energy model has been developed in the framework of the EC-DGXII JOULE Programs ‘Climate Technology Strategy’ and ‘Energy Technology Modelling” (http://www.upmf-grenoble.fr/iepe/textes/POLES8p_01.pdf).

[29] Carbon sinks are not included since the measurement of carbon dioxide absorption through agricultural biomass is highly complex (high uncertainty involved, especially in agricultural soils) and has strong linkages with other economic activities not considered in this analysis, such as bio-diesel production and forestry management.

and *nitrogen flows* are estimated at a regional level. This is the main information needed to calculate the parameters included in the IPCC Good Practice Guidance (IPCC, 2000). The following table lists the emission sources modelled:

Table (7) Agricultural greenhouse gas emission sources included in the model

Greenhouse Gas	Section	Emission source	Code
Methane	**3.3.1**	Enteric fermentation	CH4Ent
	3.3.2	Manure management	CH4Man
	3.3.3	Rice production	CH4Ric
Nitrous Oxide	**3.3.4**	Manure management	N2OMan
	3.3.4	Manure excretion on grazings	N2OGra
	3.3.5	Emissions from synthetic fertiliser	N2OSyn
	3.3.5	Emissions from organic animal waste	N2OWas
	3.3.5	Emissions from fertiliser application	N2OApp
	3.3.6	Emissions from crop residues	N2OCro
	3.3.7	Emissions from nitrogen-fixing crops	N2OFix
	3.3.8	Indirect emissions from ammonia losses	N2OAmm
	3.3.8	Emissions from atmospheric deposition	N2ODep

3.3.1 Methane emissions from enteric fermentation

Animal production is the main source of methane emissions in Europe, providing around 53 % of total CH_4 and 98 % of agricultural CH_4 emissions (year 2001, EEA data service). Of the latter, 73 % are generated in the digestion process of ruminants (enteric fermentation process) and 25 % by decomposition of organic products in animal excrements. Furthermore, emissions from ruminants are estimated to contribute to 15 % of global atmospheric methane (Boadi, Wittenberg, 2003).

The production of methane is a natural by-product of feed fermentation in the gastrointestinal tract of the ruminant animal. The utilisation of fiber, mainly cellulose, pectin and hemicellulose takes place in the intestinal tract of herbivores with the help of certain micro-organisms (Kirchgeßner, 1997). *Methanobrevibacter spp*. appears to be the major methanogen in the rumen: they ferment food carbohydrates, mainly cellulose and lignin, and release energy in the process of methane formation. This energy can be used for bacterial cell formation or can be lost as chemical compounds in faeces, urine and fermentation gases. The decomposition of these carbohydrates or fermentation process occurs in the first stomach of the ruminants. It constitutes a loss of dietary energy away from animal production and contributes to atmospheric GHG emissions since carbon dioxide, methane and, in small quantities, hydrogen are emitted. These gases are considered metabolic losses and depend on the race, age, activity and fodder composition and intake of the animal. Nowadays, it seems clear that the feed ration formulation, together with the adopted intensive/extensive production technology, play an important role in methane emission control.

The IPCC establishes a common procedure in the calculation of CH_4 emissions from enteric fermentation which will be followed in this study. In the following two equations, digestible gross energy for growth and non-growth energy classes is calculated for cattle and sheep animal activities. As a result, the conversion ratio of energy to digestible energy is estimated based on animal specific digestibility parameters for Western Europe (IPCC, 2000, p. 4.19):

$$(3.5) \qquad NEDE_{j,e(=g)} = 1.164 - \left(0.001 * 5.160 * DE_j\right) + \left(1.308 * 0.00001 * DE_j^{\,2}\right) - 37.4 / DE_j$$

$$(3.6) \qquad NEDE_{j,e(\neq g)} = 1.123 - \left(0.001 * 4.092 * DE_j\right) + \left(1.126 * 0.00001 * DE_j^{\,2}\right) - 25.4 / DE_j$$

Where:
NEDE = ratio of net energy available in a diet to digestible energy consumed for each energy class
j = animal activity
e = energy class; maintenance (**m**), lactation (**l**), activity (**a**), pregnancy (**p**) and growth (**g**)
DE = digestibility energy expressed as percentage of gross energy

This conversion parameter is used to calculate gross energy intake. Animal production and regional differences are incorporated through the variable ‘net energy’ ($NE_{r,j,e}$), which is a feeding requirement function in the model ($REQ_{r,j,q}$ in section 3.2):

$$(3.7) \qquad GE_{r,j} = \sum_{e} \left(NE_{r,j,e} / NEDE_{j,e}\right) / \left(DE_j / 100\right)$$

Where:
GE = gross energy in MJ per day
NE = net energy in MJ per day

In the following equation the fraction of gross energy transformed into methane is calculated (YM_j), energy is converted into methane emissions ($/55.65$) and these are aggregated at a regional level across animal activities for a year:

$$(3.8) \qquad CH4Ent_r = \sum_j \left[\left(YM_j * GE_{r,j} * DAYS_{r,j} / 55.65 \right) * X_{r,j} \right]$$

Where:
CH4Ent = methane emissions due to enteric fermentation processes (in tonnes)
YM = conversion factor of energy into methane (in kg of methane per MJ)
DAYS = days of production for an animal activity in a year

From the previous equation IPCC Tier 2 *enteric fermentation emission factors* can be derived per animal activity and region (without the last aggregation term). These factors are no longer equal across regions, as in the case of the IPCC Tier 1 method (more simplified method based on fixed coefficients), since energy requirements are taken into account and depend on fodder availability and fertilising activities in each region. In the next section, table (8) gives a comparison of these two estimates.

Agricultural producers have the following options to cut down methane output: (a) reduce the number of cattle and therefore enteric fermentation emissions and/or (b) improve cattle production efficiency by changing the feeding-mix. In the following chapters, abatement issues are specifically addressed.

3.3.2 Methane emissions from manure management

Livestock manure is the second most important source of methane emissions in agriculture, due to its high content of organic material (10 to 20 %). When this organic material decomposes in anaerobic conditions, methanogenic bacteria, as part of an interrelated population of micro-organisms, produce methane (IPCC, 1997, p. 4.4 of the Reference Manual). The portion of manure that decomposes anaerobically depends on how the manure is managed: *storage type and duration*, *technology of application on the field* and *state of the residues* (liquid or solid). Other regional variables such as *temperature* and *humidity* are also relevant in the methane production process. When manure is handled as solid or deposited on pastures, it tends to decompose aerobically and almost no methane is produced.

In the model degradable organic material in manure is estimated from gross energy intake by animals according to the following equation (already calculated in section 3.3.1 as a determinant of enteric fermentation emissions):

$$(3.9)\qquad VSER_{r,j} = GE_{r,j} * (1/18.45) * (1 - DE_j/100) * /(1 - ASH_j/100)$$

Where:
VSER = volatile solid excretion per day on a dry-matter weight basis (in kg dry matter per day)
ASH = ash content in manure (in percentage)

Additionally, information on management systems and climate regions has to be considered. The IPCC reports some information on manure management systems per animal type for Western Europe ($MG_{m,j}$): *anaerobic lagoon, liquid slurry, solid storage, dry lot, pasture/range, pit under and over 1 month* (only for pigs)*, daily spread, digester, burned for fuel and other* (IPCC, 1997, tables B-2, B-3, B-4 and B-6). Methane conversion factors (Ca_m) for 'warm', 'temperate' and 'cold' regions (above 25 °C, between 15 °C and 25 °C and below 15 °C respectively) are also reported and included in the model. The maximum methane conversion capacity from manure ($B0_j$) is taken into account and emissions calculated according to the following equation:

$$(3.10)\qquad CH4Man_r = \sum_j \left[\left(VSER_{r,j} * B0_j * 0.67 * \sum_m \left(MG_{m,j} * Ca_m \right) * DAYS_{r,j} \right) * X_{r,j} \right]$$

Where:
CH4Man = methane emissions from manure management (in tonnes)
B0 = maximum CH_4 producing capacity in % of the manure (in kg of methane per kg of manure)
m = management system
MG = manure management system for manure per animal activity in Western Europe (in percentage)
Ca = methane conversion factor for each manure management system in each climate region

The calculation of manure management emissions is not an easy task since little data on management systems is available at a regional level and climate parameters are quite sensitive. For this reason, the IPCC Tier 2 approach is fully adopted in the model, avoiding more complex approaches which would just introduce some more uncertainty in the current analysis. In table (8), both IPCC Tier 1 and 2 methods for the calculation of methane enteric fermentation and manure management emissions are compared for the EU-15. In table (9), maximum and minimum emission factors for animal activities are presented for Member States.

Table (8) Methane emission factors for enteric fermentation and manure management; IPCC Tier 1 and 2 methods (average for the EU-15)

	CH_4 Enteric Fermentation		CH_4 Manure Management	
	IPCC Tier 1	IPCC Tier 2	IPCC Tier 1	IPCC Tier 2
Bulls high weight	41.2	66.5	9.6	15.3
Bulls low weight	19.2	26.6	4.2	5.8
Calves female fattening	22.7	15.3	6.1	4.1
Calves female raising	35.6	31.0	9.0	7.9
Calves male fattening	21.1	14.1	5.7	3.6
Calves male raising	36.1	28.9	8.8	7.1
Dairy cows high yield	100.0	146.9	25.3	40.2
Dairy cows low yield	100.0	96.2	25.3	26.4
Heifers high weight	38.2	54.1	9.3	13.4
Heifers low weight	14.1	17.6	3.5	4.4
Heifers raising	84.0	54.2	11.7	13.4
Pigs fattening*	0.6	-	1.8	-
Sheep and goats for milk*	8.0	-	-	-
Sheeps and goats for fattening*	2.2	-	-	-
Sows*	1.5	-	5.1	-
Suckler cows	100.0	63.0	14.6	19.5

Source: own calculations; 2001 three year average calibration year.

Measurement units: kg per head and year.

* For these activities no Tier 2 method is defined and therefore the estimates from the Tier 1, if available, are taken.

For the EU-15 the model delivers Tier 2 coefficients that are on average close to Tier 1 fixed coefficients. As the table shows, Tier 1 emission factors tend to overestimate enteric fermentation emissions from suckler cows and in general underestimate methane emissions from cattle's manure. Moreover, it can be observed how activities with a high energy need have higher emission factors (e.g. raising vs. fattening activities). Activities with a high protein intake and low N retention rates, i.e. less efficient digestive process, are linked to higher methane emissions from manure management (e.g. bulls vs. pigs). In general, Tier 2 coefficients give more accurate information for activities that are subject to different intensities, e.g. dairy cows and bulls for slaughtering. This allows for the calculation of regional differences, as presented in the following table:

Table (9) Regional differences in methane emission factors for manure management and enteric fermentation – IPCC Tier 2 method (minimum and maximum average values for Member States)

	CH4 Enteric Fermentation				CH4 Manure Management			
	Maximum value		Minimum value		Maximum value		Minimum value	
Bulls high weight	Netherlands	100.8	Denmark	28.5	France	29.0	Denmark	3.7
Bulls low weight	Netherlands	45.2	Denmark	*4.4*[n]	France	12.2	Denmark	*0.6*[n]
Calves female fattening	Spain	44.0	UK	*1.4*[n]	Spain	12.2	Denmark	*0.3*[n]
Calves female raising	Sweden	32.5	Netherlands	29.2	Portugal	13.6	Netherlands	3.8
Calves male fattening	Spain	40.9	UK	*0.4*[n]	Greece	14.3	UK	*0.2*[n]
Calves male raising	Finland	30.2	Netherlands	26.8	Portugal	12.6	Netherlands	3.5
Dairy cows high yield	Sweden	170.6	Ireland	123.6	UK	72.7	Ireland	18.4
Dairy cows low yield	Sweden	106.4	Ireland	86.2	UK	47.2	Belgium	13.3
Heifers high weight	France	70.9	Finland	34.6	France	29.9	Finland	4.5
Heifers low weight	France	35.2	Finland	*4.5*[n]	France	14.9	Finland	*0.6*[n]
Heifers raising	Netherlands	55.5	Spain	52.9	Greece	22.8	Austria	7.1
Suckler cows	Italy	65.3	Portugal	62.3	France	26.6	Ireland	8.2

Source: own calculations; 2001 three year average calibration year; Luxembourg is modelled together with Belgium.

Measurement units: kg per head and year.

[n] Poor statistical representation of these regional activities.

These values reflect differences in the emission coefficients according to animal characteristics in each region (weight, yields, etc.). There are some extreme minimum values for some activities such as *calves for fattening, bulls* and *heifers low weight*. This is due to the fact that these production activities are not well represented in some regions (the activity is booked in another position or the EEA and therefore statistics on yields are underestimated). However, this does not have any relevant effect on average values and emission accounting since they are marginal values with a fairly low weight attached.

3.3.3 Methane emissions from rice production

Rice production in flooded paddy fields is the most important anthropogenic source of methane. The warm, waterlogged soil of rice fields provides ideal conditions for methanogenesis, i.e. CH_4 production through anaerobic decomposition of the organic matter carried out by methanogens. Global methane emission rates from rice paddies are estimated to range between 20 and 100 million tonnes per year, which corresponds to about 6 to 29 % of total annual anthropogenic methane emissions. Though some of the methane produced is usually oxidized in the shallow overlying water, around 90 % is released into the atmosphere through rice plants (Cicerone, Shetter, 1981). Before flooding and after drainage emissions are relatively low and during the flooding period they increase, reaching a maximum level during the panicle differentiation and maturing (Sass et al., 1990).

Research on emission factors from rice paddies has been intensively carried out over the last two decades (see table (10)). Estimates show a high variation, methane emissions depending heavily on assumptions related to soil temperature, flooding period, rice type, soil texture and quantity of organic matter in soils.

Table (10) Estimations of methane emission factors for rice cultivation found in the literature

SOURCE	Estimates
Cicerone e Shetter (1981)	0.15 – 0.18
Cicerone e Shetter (1983)	0.22 – 0.28
Seiler at al. (1984)	0.096 – 0.336
Hlzapfel-Pschorn and Seiler (1986)	0.384 – 0.504
Khalil et Al. (1991)	0.58
Sass e Fisher (1990)	1.43 – 5.03
Sass, Fisher and Harcombe (1991, a)	3.22 – 8.75
Sass, Fisher et Al. (1991, b)	6.77 – 10.52
Sass, Fisher and Wang (1992)	2.556
Zongliang et Al. (1993)	0.26 – 0.86
Sigren et Al. (1997, b)	9.6

Source: compilation by Nasuelli et al., 1998.

Measurement units: g per m^2 and day.

Nevertheless, this activity is of little relevance in Europe, having only some significant share of crop production in the warmer regions of Spain and Italy. For this reason and for comparison purposes, a uniform non-regionalised IPCC default emission factor of 20g per m^2 per season (200 kg per hectare) is adopted in the model[30] according to the following equation:

$$(3.11) \quad CH4Ric_{r,k(=rice)} = \sum_k \left(Cb * X_{r,k} \right)$$

Where:
CH4Ric = methane emissions from rice paddies (in tonnes)
Cb = methane conversion factor for rice cultivation (per hectare)

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[30] There is high correlation between seasonal methane emissions and sand percent in different soils (Sass et al., 1990). Information on temperature variations and soil types could be used to further improve this indicator and

3.3.4 Nitrous oxide emissions from manure management and from manure excretion on grazings

During manure storage and application not only methane emissions are produced, but also nitrous oxide emissions. Formation of N_2O in agricultural soils primarily results from *nitrification* and *denitrification* processes[31]. Most of the N_2O emitted from agriculture is produced when excess of nitrate in soil undergoes denitrification, either on the field or after it is leached away. Measurements indicate that about 7 % of denitrification leads to the production of N_2O. Some N_2O is also emitted through the aerobic microbial oxidation of ammonium to nitrate, or nitrification[32] (Firestone, Davidson, 1989). When nitrate for denitrification is derived from nitrification, the process is called coupled ‘nitrification-denitrification’.

Farmers feed and manage their cattle in different ways during the different stages of the production cycle. The amount of N_2O emitted depends on the system used and the stage in the cycle. As N in manure is present as organic or ammoniacal N, the aerobic process of nitrification is needed for the production of nitrous oxide (e.g. in solid storage systems or upon surface application). Under anaerobic conditions the production of methane is favoured (e.g. anaerobic lagoons or slurry tanks). Management systems can be compared in terms of net emissions.

In the following equation a weighted nitrous oxide emission factor for a bundle of management systems in Europe is calculated, in the same way as methane emissions from manure management (see equation (3.10)):

$$(3.12) \quad N2OMan_r = \sum_j \left[\left(MN_{r,j} * \sum_{m(\neq pasture)} \left(MG_{m,j} * Cc_m \right) * 44/28 \right) * X_{r,j} \right]$$

Where:
N2OMan = nitrous oxide emissions from manure management (in tonnes)
MN = N content in manure (kg of N per animal and year)
Cc = nitrous oxide conversion factor for each manure management system in each climate region
44/28 = conversion factor for N_2O-N into N_2O

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calculate an ‘adjusted seasonally integrated emission factor’ (IPCC, 2000). This information is not available in the current version of the model.

[31] Denitrification is an anaerobic process, the microbial reduction of nitrate (NO_3^-) to di-nitrogen gas (N_2). Denitrification is sometimes referred to as 'dissimilatory' nitrate reduction because it occurs in association with the dissimilation (decomposition) of organic matter. It is, however, important to notice that when the process becomes too anaerobic no release of N_2O takes place, because everything is reduced to N_2.

[32] Nitrification or 'ammonium oxidation' is a two-step respiratory process in which bacteria oxidise ammonium (NH_4^+) to nitrite (NO_2^-) and nitrate (NO_3^-).

Results in table (11) show that emission factors vary between 0 and 1.7 kg per head and year, regional differences originating from different regional manure excretion rates (correlated with crude protein content in the feeding-mix).

Table (11) Estimations of nitrous oxide emission factors for manure management (average for the EU-15 and minimum and maximum average values for Member States)

	EU-15 Average	Maximum Value		Minimum Value	
Bulls high weight	0.14	Germany	0.18	Denmark	0.05
Bulls low weight	0.05	Austria	0.07	Denmark	*0.01*[n]
Calves female fattening	0.04	Spain	0.08	UK	*0.01*[n]
Calves female raising	0.06	UK	0.08	Belgium	0.04
Calves male fattening	0.03	Spain	0.08	UK	*0.01*[n]
Calves male raising	0.06	UK	0.08	Belgium	0.05
Dairy cows high yield	0.84	France	1.68	Belgium	0.80
Dairy cows low yield	1.37	Italy	1.02	Greece	0.49
Heifers high weight	0.11	Germany	0.14	Finland	0.06
Heifers low weight	0.03	France	0.07	Finland	*0.01*[n]
Heifers raising	0.16	France	0.19	Belgium	0.09
Hens*	0.47	Denmark	0.50	Greece	0.31
Pigs fattening	0.06	Italy	0.12	Greece	0.03
Poultry for fattening*	0.03	Italy	0.04	Portugal	0.01
Sheep and goats for milk	0.01	France	0.011	Finland	0.003
Sheeps and goats for fattening	0.0013	Denmark	0.0025	Greece	0.0004
Sows	0.31	France	0.35	Ireland	0.24
Suckler cows	0.14	France	0.18	Finland	0.07

Source: own calculations; 2001 three year average calibration year; Luxembourg is modelled together with Belgium.

Measurement units: kg per head and year.

* Coefficients measured for 1000 heads.

[n] Poor statistical representation of these regional activities.

In section 3.3.2 the main manure management options considered for this calculation were listed. At this stage it is important to mention that in the UNFCCC common reporting format N_2O emissions from manure management only include N losses in housing and storage systems (N fallen on pastures is explicitly excluded). This last emission source is not considered to be part of agricultural soil emissions and is reported in another position. Its calculation follows, however, a similar approach:

$$(3.13)\quad N2OGra_r = \sum_j \left[\left(MN_{r,j} * \sum_{m(=pasture)} \left(MG_{m,j} * Cc_m \right) * 44/28 \right) * X_{r,j} \right]$$

Where:

N2OGra = nitrous oxide emissions from manure fallen on grazings (in tonnes)

Table (12) Estimations of nitrous oxide emission factors for manure excretion on grazings (average for the EU-15 and minimum and maximum average values for Member States)

	EU-15 Average	Maximum Value		Minimum Value	
Bulls high weight	1.00	Germany	1.33	Denmark	0.35
Bulls low weight	0.38	Austria	0.52	Denmark	*0.07*^{n}
Calves female fattening	0.26	Spain	0.58	UK	*0.03*^{n}
Calves female raising	0.46	UK	0.56	Belgium	0.33
Calves male fattening	0.24	Spain	0.57	UK	*0.01*^{n}
Calves male raising	0.46	UK	0.56	Belgium	0.33
Dairy cows high yield	1.25	France	1.54	Belgium	0.73
Dairy cows low yield	0.77	Italy	0.94	Greece	0.45
Heifers high weight	0.77	Germany	1.05	Finland	0.42
Heifers low weight	0.25	France	0.51	Finland	*0.06*^{n}
Heifers raising	1.15	France	1.42	Belgium	0.69
Hens*	0.57	Denmark	0.61	Greece	0.38
Pigs fattening	-	-		-	
Poultry for fattening*	0.03	Italy	0.05	Portugal	0.02
Sheep and goats for milk	0.38	France	0.490	Finland	0.130
Sheeps and goats for fattening	0.0600	Denmark	0.1100	Greece	0.0170
Sows	-	-		-	
Suckler cows	1.04	France	1.32	Finland	0.54

Source: own calculations; 2001 three year average calibration year; Luxembourg is modelled together with Belgium.

Measurement units: kg per head and year.

^{n} Poor statistical representation of these regional activities.

In table (11) activities with a higher manure production per head (higher yields and average weights) present higher N_2O coefficients. By comparing table (11) and table (12) it can be observed that N_2O coefficients for manure excretion on grazings are much higher than the ones for manure management (as previously defined). This is due to the fact that the manure management type ‘pastures’ has a relatively high N_2O conversion factor (0.02) and a high fraction of total management use (between 19 % and 38 % depending on the activity). Suckler cows have a high emission coefficient, almost as high as the one for dairy cows but producing much less manure per animal due to a higher fraction of time on pastures.

By adding up both coefficients per activity the overall manure management coefficient per activity can be derived (including emissions on pastures). As shown in table (12), pig production does not have a coefficient attached since all the production is assumed to take place in housing and storage systems and not on pastures.

3.3.5 Nitrous oxide emissions from synthetic fertiliser application, organic animal waste and total fertiliser application

An additional source of nitrous oxide emissions is mineral fertiliser application on the field. As already mentioned in this chapter, application of manure and anorganic fertiliser is allocated to crops according to calculated shares. This allows the differentiation of emission factors depending on the type of fertiliser applied. Based on several studies carried out in temperate regions of the world, the IPCC considers for synthetic and organic fertilisers an emission factor of 0.0125 kg of N_2O-N per kg N (0.019 kg N_2O per kg N). The following equation contains the approach followed in the calculation of N_2O emissions from anorganic fertiliser application:

$$(3.14) \quad N2OSyn_r = \sum_k \left[ND_{r,k,fi(=N)} * NutCorr_{r,fi} * MF_{r,k} * Cd * X_{r,k} \right] * 44/28$$

Where:
N2OSyn = nitrous oxide emissions from synthetic fertiliser application (in tonnes)
Cd = nitrous oxide emission factor for N in mineral fertiliser (in kg N_2O-N per kg N applied)
MF = share of mineral fertiliser on total fertiliser application

Total application of N in synthetic fertiliser per activity is estimated by calculating the total N application on crops (total N need by crops plus a regional over-fertilisation estimate, as previously seen) multiplied by the fraction of mineral fertiliser on total fertiliser application per crop activity. This weighting factor ($MF_{r,k}$) is calculated so that N in fertiliser statistical data published by FAOSTAT in the base year are met. Total emissions are therefore total N found in synthetic fertiliser application multiplied by an emission factor (Cd).

N_2O emissions are also produced from N content in organic waste from animals. Part of this manure is applied on crops (organic part of the N balance) and the rest is just ‘thrown away’ (if

N need by crops is fully covered)[33]. Emissions are therefore calculated according to the following equation:

$$(3.15) \quad N2OWas_r = \sum_k \left[NS_{r,j,fo(=N)} * (1 - AmmOF_{r,j,fo(=N)} * Ce * X_{r,k} \right] * 44/28$$

Where:

N2OWas = nitrous oxide emissions from animal organic waste (in tonnes)

Ce = nitrous oxide emission factor for N in manure application (in kg N_2O-N per kg N applied), IPCC default emission factor

Alternatively, total fertiliser application (synthetic and organic) can also be calculated according to the following equation:

$$(3.16) \quad \begin{aligned} N2OApp_r = \sum_k \Big[& ND_{r,k,f} * NutCorr_{r,f} * \left(MF_{r,k} / (1 - AmmMF_r) * Cd + OF_{r,k(\neq gras)} * Ce \right) \\ & * X_{r,k} \Big] * 44/28 \end{aligned}$$

Where:

N2OApp = nitrous oxide emissions from total fertiliser application (in tonnes)

In table (13) N_2O emission factors per activity for synthetic fertiliser application are presented. N_2O emission factors for total fertiliser application are also included for comparison purposes. It is important to note that although the latter source is not considered by the UNFCCC reporting guidelines it is, however, quite important from the current modelling perspective since it includes the fraction of total N in fertiliser handled in the model and therefore entering the N flow (it does not include the part of N in manure not taken up by crops).

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[33] It is important to note here that 'managed manure' (as previously defined in this chapter) is not included in the calculation of N_2O emissions from animal waste in order to avoid a double-counting problem.

Table (13) Estimations of nitrous oxide emission factors for fertiliser application on crop activities: synthetic and total (average for the EU-15)

	N_2O Synthetic Fertiliser	N_2O Fertiliser Application
Soft Wheat	2.58	2.96
Durum wheat	1.14	1.33
Rye	1.42	1.65
Barley	1.41	1.63
Oats	1.18	1.35
Maiz	2.16	2.52
Other cereals	2.12	2.43
Paddy rice	2.95	3.31
Rape	1.94	2.13
Sunflowers	1.01	1.12
Soya	3.07	3.47
Olives for oil [e]	0.42	0.45
Other oil [e]	2.86	3.17
Pulses	0.01	0.03
Potatoes	2.76	3.02
Sugar Beet	2.08	2.29
Tobacco [e]	1.71	1.90
Other industrial crops [e]	5.56	6.10
Tomatoes [e]	2.63	2.82
Other vegetables [e]	1.07	1.13
Apples [e]	0.45	0.48
Other fruits [e]	0.38	0.40
Citrus [e]	0.97	1.04
Table grapes [e]	0.65	0.70
Table wine [e]	0.41	0.44
Other wine [e]	0.42	0.45
Nurseries [e]	0.71	0.74
Flowers [e]	1.46	1.53
Other crops [e]	5.55	5.85
Maize for fodder	0.66	2.88
Fodder root crops	0.29	1.85
Other fodder on arable land	0.63	2.03
Non food production on set aside	1.60	1.75
Grass extensive	0.69	0.72
Grass intensive	1.82	1.89

Source: own calculations; 2001 three year average calibration year.

Measurement units: kg per head and year.

[e] Activities not endogenously determined in the model: either econometrically estimated (vegetables, flowers, tobacco, fruits and perennial crops; see section 2.5.5) or residual positions (other industrial crops and other crops).

By comparing both columns in table (13), it can be observed that most of the organic fertiliser applied on crops is going to maize for fodder, fodder root crops and other fodder on arable land (large differences between total fertiliser application and synthetic fertiliser application). Pulses cover a high fraction of their N need through biological fixation (see section 3.3.7) and therefore receive almost no synthetic fertiliser. Table (14) summarises the N_2O emission coefficients for total ‘unmanaged’ manure produced by animal activities in the EU-15. Emissions per head are directly related to manure production (see also table (5)).

Table (14) Estimations of nitrous oxide emission factors for animal waste (average for the EU-15)

	N_2O Animal Waste
Bulls high weight	0.76
Bulls low weight	0.29
Calves female fattening	0.19
Calves female raising	0.35
Calves male fattening	0.19
Calves male raising	0.35
Dairy cows high yield	2.52
Dairy cows low yield	1.55
Heifers high weight	0.59
Heifers low weight	0.19
Heifers raising	0.81
Hens *	10.66
Pigs fattening	0.09
Poultry for fattening *	0.70
Sheep and goats for milk	0.032
Sheeps and goats for fattening	0.005
Sows	0.45
Suckler cows	0.87

Source: own calculations; 2001 three year average calibration year.

Measurement units: kg per head and year.

* Emissions measured for 1000 heads.

3.3.6 Nitrous oxide emissions from crop residues

Crop residues left on the field are also a source of N through decomposition and therefore subject to nitrous oxide losses. It is not a very important source of emissions in Europe but it is included in the NGHGIs and reported by Member States to the UNFCCC. In the following table, the main input data in the calculation of this emission source is shown:

Table (15) Selected crop residue statistics

	Residue/Crop Product Ratio	Dry Matter Fraction	Nitrogen Fraction
Soft Wheat	1.3	0.85	0.0028
Durum Wheat	1.3	0.85	0.0028
Rye	1.6	0.90	0.0048
Barley	1.2	0.85	0.0043
Oats	1.3	0.92	0.0070
Maize	1.0	0.78	0.0081
Other Cereals	1.4	0.88	0.0070
Paddy Rice	1.4	0.85	0.0067
Pulses	2.1	0.83	0.0150
Rape	3.0	0.83	0.0150
Potatoes	0.4	0.20	0.0110
Sugar Beet	0.2	0.30	0.0110

Source: adapted from IPCC, 2000, p. 4.58. Original data from Strehler, Stützle, 1987; for sugarcane Turn et al., 1997; dry matter and nitrogen fraction data for oats, rye, sorghum, peas and peanuts from Cornell, 1994; and nitrogen fraction data for millet and soybeans from Barnard, Kristofferson, 1985.

In this analysis a simple calculation procedure based on the IPCC methodology (Tier 1b method) is used since no data on crop residues for single activities and regional residue burning practices is available at a regional level. In the following equation, the potential crop residue decomposition is estimated and weighted with the default emission factor of 0.0125 kg of N_2O-N per kg N (Ce) to calculate emissions:

$$N2OCro_r = \sum_k \Big[\sum_o \left(Yield_{r,k,o} * RSCR_o * CRDM_o * CRNI_o \right) * \left(1 - CRBU_r - CRFU_r - CRFE_r \right) * Ce * X_{r,k} \Big] * 44/28 \tag{3.17}$$

Where:

N2OCro = nitrous oxide emissions from crop residues on the field (in tonnes)

Yield = yield (tonnes of a crop product per hectare for each activity)

RSCR = fraction of residue to crop product (share)

CRDM = dry matter fraction of crop residue (share)

CRNI = N fraction of crop residue (share)

CRBU, CRFU, CRFE = fraction of crop residue burned, used as fuel or for animal feeding and, therefore, not left on the field

The amount of biomass entering the crop residue pool is calculated from regional crop production data by discounting the share of product harvested ($1 - RSCR_o$). The N content of the remaining crop residue is estimated for different products by weighting it with its dry matter ($CRDM_o$) and N fraction factors ($CRNI_o$). Additionally, residues that are burned on the field or used for fuel or feeding use are substracted[34]. Result estimates are shown in table (16), section 3.3.8.

3.3.7 Nitrous oxide emissions from nitrogen-fixing crops

Most plants make use of N in the form of ammonium or nitrate ions. The process of conversion from atmospheric N_2 to available N is called *nitrogen fixation*. One specific way of N fixation is 'biological fixation', where certain bacteria that live in symbiosis with legumes (peas, beans, clover, etc.) fix N in their roots and convert N_2 into ammonium (NH_4^+). The 'manufacture' of nitrogenous fertiliser by crops adds some amount of N to the cycle which is also subject to losses in the form of N_2O emissions through nitritification processes. In the current modelling approach, *pulses* are assumed to generate through biological fixation around 75 % of their N need, *other fodder on arable land* 10 % and *grass and grazings* 5 %. Although the N_2O conversion coefficient for biological fixation is uncertain, the default IPCC emission factor of 0.0125 kg N_2O-N per kg N is generally accepted.

In the next equation the approach followed in the quantification of these emissions is defined:

$$(3.18) \quad N2OFix_r = \sum_k \left\lfloor ND_{r,k,fi(=N)} * NutCorr_{r,fi(=N)} * Nfix_{k(=pulses)} * Ce \right\rfloor * X_{r,k} * 44/28$$

Where:

N2OFix = nitrous oxide emissions from N coming from biological fixation by certain crops (in tonnes)

3.3.8 Nitrous oxide emissions from atmospheric deposition

An additional source of N in agriculture is atmospheric deposition. N compounds are carried by rainfall, fertilising agricultural soils and consequently enhancing nitrous oxide formation. N_2O emission estimates in literature vary between 0.002 and 0.016 kg N_2O-N per kg N added to the soil. Based on these studies, the IPCC proposed to take an emission factor of 0.01 kg N_2O-N per kg N deposited on various ecosystems, including forests and grassland (IPCC, 1997, Table 4.23 of the Reference Manual), as a representative coefficient for N deposited on land. The idea

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[34] These emissions do not enter agricultural emission from soils.

behind this is that part of the N losses from mineral and organic fertiliser volatilised in ammonia are transported offsite and become available again through rainfall for agricultural soils, thus indirectly generating N_2O emissions. Cole et al. estimated that 0.75 % of the N released in ammonia losses from agricultural production evolves back to the atmosphere after deposition (Cole et al., 1995). The following equation defines the calculation of N_2O emissions from this source implemented in the model:

$$\begin{aligned} N2OAmm_r = \sum_i \big[& ND_{r,i,fi(=N)} * NutCorr_{r,fi} * MF_{r,i} * AmmMF_r * Cf + \\ & NS_{r,i,fo(=N)} * AmmOF_{r,i,fo(=N)} * Cf \big] * X_{r,i} * 44/28 \end{aligned} \qquad (3.19)$$

Where:

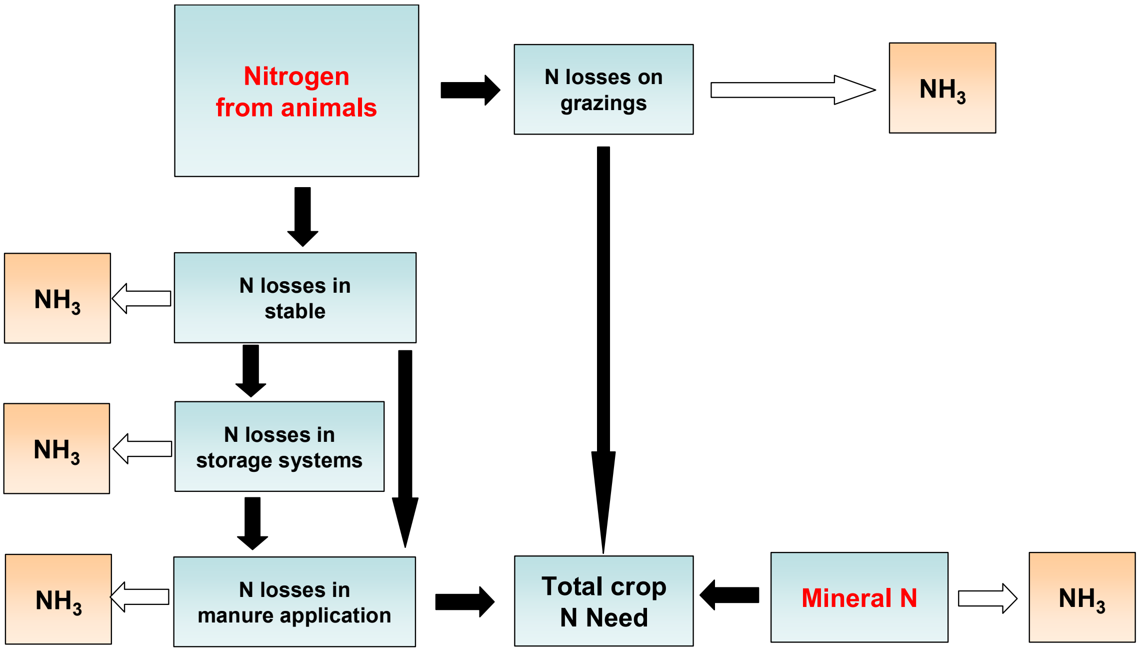
N2OAmm = nitrous oxide emissions from N in ammonia losses deposited back on agricultural soils (in tonnes)

i = production activity (animal or crop activity → k, j $\in$ i)

Cf = nitrous oxide emission factor for ammonia losses (in kg N_2O-N per kg N applied)

The CAPRI ammonia emission module in itself is based on N output from animals and includes uniform emission factors per animal activity taking into account differences in storage and housing systems between European Member States. The general approach applies factors derived from the European Emission Inventory Guidebook (2001 edition). Figure (8) shows the different ammonia sources covered in the model.

Figure (8) Structure of the ammonia emission module



Source: Adaptation of the NFM Model for CAPRI (Pérez et al., 2003).

Note: white arrows determine ammonia losses (NH_3) and black arrows N flows.

First of all, the share of time spent on grassland and in the stable is obtained for each animal type and Member State. With this information ammonia losses on grassland/pastures and in the stable are calculated, the latter being further divided into liquid and solid housing systems. Secondly, manure produced in the stable is divided according to the storage type observed ('covered', 'not covered' or 'no storage'), where again Member State specific coefficients determine NH_3 losses. Finally, losses during application of manure and mineral fertiliser on the field are also calculated. All N losses from the mentioned sources are added up in order to calculate total N losses and used, as already explained, as input in the estimation of indirect N_2O emissions.

This approach is used in equation (3.19) to calculate *indirect* N_2O emissions from atmospheric deposition (it covers only deposited N coming from ammonia emissions caused by the agricultural activity, 'closed-system' approach). However, it is important to note that this does not reflect the observed quantities of N fallen on agricultural land and, therefore, cannot be used directly by the model. On the one side, the share of ammonia emissions mentioned does not have to fall back again on agricultural land and, on the other side, N deposited on agricultural soils might also come from emissions in other sectors (e.g. industry). In order to model a consistent N balance, a second *direct* approach has to be adopted. This is based on regional data on N fallen on agricultural land ($Natm_{r,k}$). The information is condensed in the following equation:

(3.20) $N2ODep_r = \sum_k \left[Natm_{r,k} * Ce\right] * X_{r,k} * 44/28$

Where:

N2ODep = nitrous oxide emissions from N fallen on agricultural land through rainfall (in tonnes)

Information on N deposition at Member State level (between 3 and 36 kg of N per hectare) and uptake rates per crop activity (50 to 58 %) are incorporated into the model. Available N per crop from atmospheric deposition is therefore calculated by combining the observed N coming from atmospheric deposition at a regional level and N absorption capacity per crop. For example, a hectare of soft wheat in Austria gets around 12 kg of N from rainfall, 103 kg being the total observed per hectare in 2001 (average). In practice, by considering additional sources of N such as *atmospheric deposition* and *biological fixation*, the amount of fertiliser needed in certain regions is lowered and the model becomes more realistic[35].

In table (16) nitrous oxide emission factors are reported for crop residues, biological fixation and atmospheric deposition on agricultural soils:

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[35] The rest of N coming from atmospheric deposition and not taken up by crops is also subject to ammonia volatilisation but considered as part of the N surplus in the system and not analysed separately (emission from soils).

Table (16) Estimations for selected activities of nitrous oxide emission factors for crop residues, biological fixation and atmospheric deposition (average for the EU-15)

	N_2O crop residues[1]	N_2O biological fixation	N_2O atmospheric deposition (indirect) [2]	N_2O atmospheric deposition (direct)
Soft wheat	0.41	-	0.08	0.19
Durum wheat	0.13	-	0.06	-
Rye	0.66	-	0.04	0.25
Barley	0.40	-	0.04	0.16
Oats	0.56	-	0.03	0.12
Maize	1.04	-	0.09	0.14
Other cereals	0.93	-	0.07	-
Paddy rice	0.92	-	0.15	-
Rape	2.22	-	0.06	0.20
Sunflowers	-	0.29	0.04	0.11
Soya	-	-	0.17	0.13
Pulses	1.39	-	0.0005	0.14
Potatoes	0.61	-	0.08	0.20
Sugar beet	1.51	-	0.07	0.21
Maize for fodder	-	0.24	0.02	0.21
Fodder root crops	-	0.06	0.01	0.20
Other fodder	-	0.13	0.02	0.15
Grass extensive	-	-	0.02	0.17
Grass intensive	-	-	0.06	0.17

Source: own calculations; 2001 three year average calibration year.

Measurement units: kg per head and year.

[1] Only a selection of endogenous activities in the model relevant for the calculation of N_2O emissions from agricultural soils is presented.

[2] These coefficients are also calculated for animal activities (ammonia losses from manure).

Indirect N_2O emissions from deposition of N released as ammonia are attached through a coefficient to animal (NH_3 losses from manure) and crop activities (NH_3 losses from mineral fertiliser application). However, for observed atmospheric deposition only crop activities are affected (N fallen on land). In the first case, N is ‘recycled’, i.e. ammonia emissions are produced in a first stage and nitrous oxide emissions in a second. In the latter case, N from atmospheric deposition is regarded as a new and independent source of nutrients[36].

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[36] Both emission factors cannot be directly compared (see also comments in the following section about reporting and modelling issues).

3.4 Estimation of regional greenhouse gas emission inventories

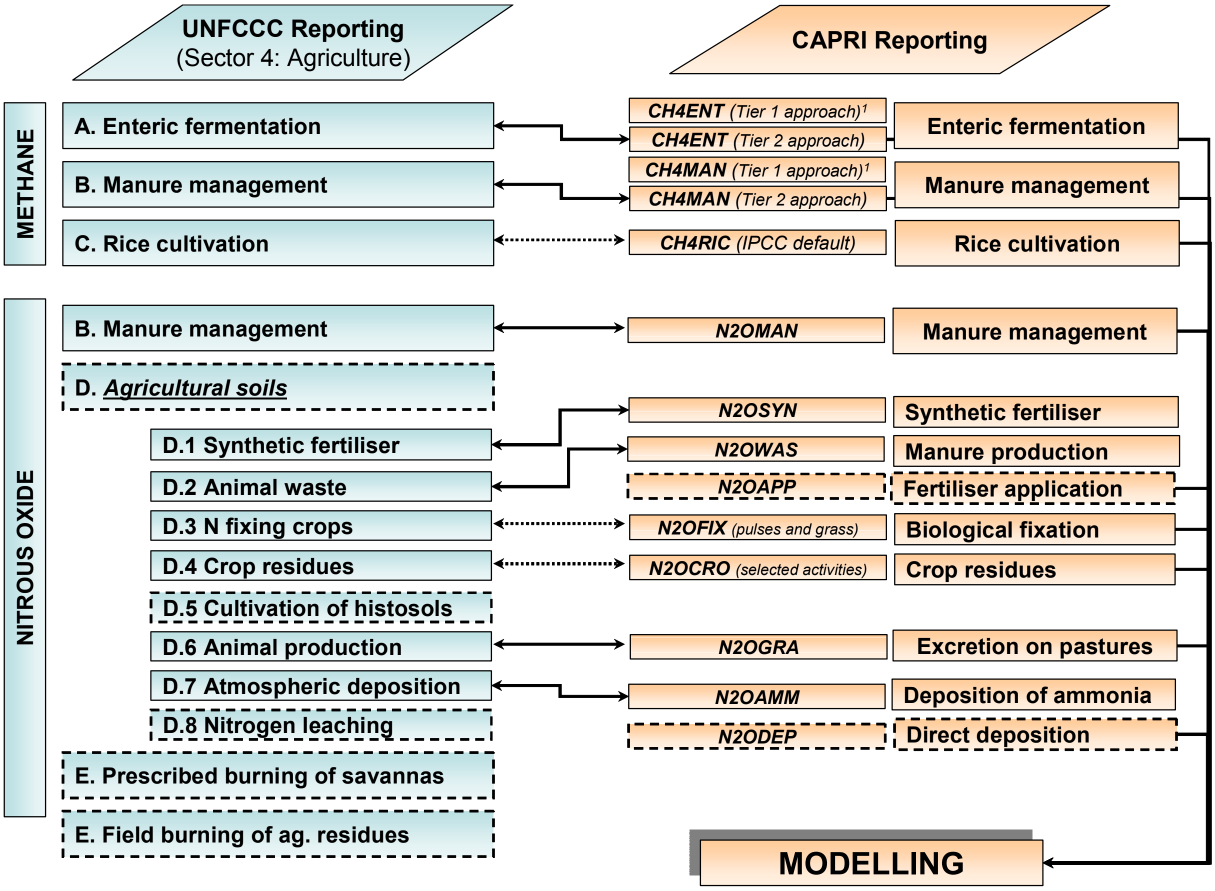
3.4.1 Defining the boundaries of the analysis: the ‘UNFCCC approach’

As previously mentioned, the UNFCCC follows a ‘closed-system’ approach so that only GHG emissions from agricultural sources are attributed to agriculture. This has two important implications for this study: the definition of the boundaries of the agricultural sector and the need for modelling tools able to consistently mimic this emission accounting approach.

For consistency purposes with the UNFCCC approach, indirect emissions from fertiliser production and energy consumption will not be calculated in the model (see appendix 6 for a possible modelling approach). Similarly, emissions from machinery production processes and transport of agricultural products will also be excluded from the analysis since they are covered in other sectors. However, from the current modelling perspective the UNFCCC approach presents two problems. First, in the presented analysis nutrient requirement functions for crop activities are endogenously modelled. This implies that although emissions from activities exogenous to the model, and therefore not covered by these functions, can be ‘passively’ calculated, they will not be included in the endogenous response of the model (simulation stage). This is the case for nitrous oxide emissions from animal organic waste, as discussed in section 3.3.5. Secondly, a ‘consistent N flow’ is modelled by the supply component of CAPRI, all N sources and sinks being included. This means that N coming from other sectors of the economy through atmospheric deposition on agricultural soils can affect the behaviour of the model. This source is, however, not included in the NGHGIs for agricultural emissions (this was briefly discussed in section 3.3.8).

Figure (9) gives an overview of the reported and modelled sources confronted with the current UNFCCC official reporting obligations.

Figure (9) Reported and modelled emission sources.



Source: the UNFCCC Reporting follows the IPCC Good Practice Guidance (IPCC, 2000). The CAPRI Codes for emission sources are defined in section 3.3 (see table (7)).

[1] Emission coefficients for these sources are given as fixed parameters by the IPCC (IPCC, 1997). They are included in CAPRI only for comparison purposes but are not further used in the modelling analysis.

In this figure a discontinuous border is drawn for emission sources not covered in both reporting systems. Sources matching both reporting systems in their definition are linked with a continuous arrow (e.g. Tier 2 calculation of methane from enteric fermentation). In the case of major differences in the definition of the source, a discontinuous arrow is used (e.g. methane from rice cultivation). Some other sources are calculated in one reporting system but not used or calculated in the other (e.g. Tier 1 calculated emission sources). They are not further used in the modelling analysis and therefore isolated in the chart. Sources endogenously entering the simulation part of the model are linked with an arrow to the word “modelling”.

All *methane* sources reported by UNFCCC parties are fully covered in the model. The only differences are found in emissions from rice cultivation which are modelled but are not subject to the degree of differentiation that is available in the NGHGIs. Tier 1 emissions from enteric fermentation or manure management (fixed emission factors) are included in CAPRI only for comparison purposes but are generally not found in the NGHGIs (at least for most European countries and sources).

In the case of *nitrous oxide*, differences are found in the definition of biological fixation and crop residues sources. The calculation for these sources is done in the model for a restricted number of crop activities. Emissions from cultivation of histosols and N leaching are reported to the UNFCCC but not calculated with CAPRI[37]. Emissions from total N in fertiliser applied to crops are covered in the model but not in the NGHGIs, as previously mentioned. Emissions from deposition of ammonia losses in the model match the rubric 'atmospheric deposition'. Additionally, emissions from direct atmospheric deposition on agricultural soils (total N coming from rainfall) are calculated for modelling purposes (see discussion in section 3.3.8).

3.4.2 Validation of results

Once emission factors are carefully specified for all agricultural emission sources, inventories of GHG emissions can be consistently calculated across sources and/or regional units. At this stage it is important to compare the estimates obtained in the model with official UNFCCC statistics, as a data validation process.

For modelling purposes the year 2001 is selected as the base year situation. A complete ex-post run of the model is therefore performed at Nuts 2 regional level, all equations of the model being solved simultaneously. The information obtained is aggregated at Member State level and compared to the official inventory data for agricultural sources reported to the UNFCCC[38]. A comparison is also included for sub-sources under the rubric 'agricultural soils'[39]. In table (17), modelled results on methane and nitrous oxide emissions are reported at Member State level.

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[37] Since they are a considerable source of emissions, they will be exogenously considered for comparison purposes (see tables and figures in section 3.4.2).

[38] The European Environmental Agency collects annually information on GHG emissions and sources for agriculture submitted by European Member States to the UNFCCC and in line with the IPCC Guidelines (EEA data service, http://dataservice.eea.eu.int/dataservice, access: January 2004).

[39] Information provided by the Joint Research Centre of the European Commission in Ispra (Italy); courtesy of Mr. Adrian Leip, Climate Change Unit.

Table (17) Methane and nitrous oxide emissions from agriculture (EU-15 Member States)

	UNFCCC					**CAPRI**						**% differences (CAPRI / UNFCCC)**			
	1000 tonnes		**Mio tonnes CO_2^{eq}**			**1000 tonnes**		**Mio tonnes CO_2^{eq}**				**Mio tonnes CO_2^{eq}**			
	CH_4	**N_2O**	**CH_4**	**N_2O**	**Total**	**CH_4**	**N_2O**	**CH_4**	**N_2O**	**Total**	**Total[c]**	**CH_4**	**N_2O**	**Total**	**Total[c]**
EU-15	**8549.1**	**705.6**	**179.5**	**218.7**	**398.3**	**7658.8**	**511.1**	**160.8**	**158.5**	**319.3**	**380.7**	**-10.4%**	**0.5%**	**-19.8%**	**-4.4%**
Austria	193.4	11.4	4.1	3.5	7.6	170.0	9.3	3.6	2.9	6.4	7.4	-12.1%	7.7%	-15.3%	-2.9%
Belgium	346.8	16.8	7.3	5.2	12.5	220.3	11.0	4.6	3.4	8.1	12.8	-36.5%	56.4%	-35.6%	2.3%
Denmark	172.9	25.5	3.6	7.9	11.6	184.0	14.0	3.9	4.3	8.2	10.6	6.4%	-14.6%	-28.9%	-8.0%
Finland	84.2	12.1	1.8	3.7	5.5	87.5	6.8	1.8	2.1	3.9	5.6	3.8%	-0.5%	-28.4%	0.9%
France	2087.5	176.0	43.8	54.5	98.4	1903.6	128.0	40.0	39.7	79.7	96.6	-8.8%	3.7%	-19.0%	-1.9%
Germany	1209.2	128.5	25.4	39.8	65.2	1190.3	96.9	25.0	30.1	55.0	64.6	-1.6%	-0.7%	-15.6%	-1.0%
Greece	175.1	20.5	3.7	6.3	10.0	158.1	12.3	3.3	3.8	7.1	7.1	-9.7%	-40.1%	-28.9%	-28.9%
Ireland	527.3	26.1	11.1	8.1	19.2	433.0	19.7	9.1	6.1	15.2	16.3	-17.9%	-11.2%	-20.7%	-15.1%
Italy	871.1	78.2	18.3	24.2	42.5	701.3	52.6	14.7	16.3	31.0	38.7	-19.5%	-1.0%	-27.1%	-8.9%
Netherlands	410.6	23.1	8.6	7.2	15.8	390.4	22.0	8.2	6.8	15.0	16.5	-4.9%	15.6%	-4.9%	4.4%
Portugal	279.8	19.0	5.9	5.9	11.8	172.7	8.2	3.6	2.6	6.2	7.6	-38.3%	-33.3%	-47.4%	-35.8%
Spain	1120.6	62.8	23.5	19.5	43.0	876.1	54.7	18.4	16.9	35.3	39.1	-21.8%	6.2%	-17.8%	-9.1%
Sweden	156.5	18.0	3.3	5.6	8.9	129.3	9.1	2.7	2.8	5.5	8.0	-17.4%	-5.7%	-37.5%	-10.0%
United Kingdom	914.0	87.7	19.2	27.2	46.4	1042.3	66.5	21.9	20.6	42.5	50.0	14.0%	3.4%	-8.4%	7.8%

Source: own calculations; 2001 three year average calibration year for CAPRI and year 2001 for NGHGIs; Luxembourg is modelled together with Belgium.

[c] For comparison purposes nitrous oxide emissions are corrected by adding up histosols and nitrogen leaching emissions from NGHGIs (they are not modelled in CAPRI).

Endogenously calculated *methane emissions* for the EU-15 lay 10.4 % below official data. For single countries, differences vary between -38.3 % for Portugal and 14 % for United Kingdom. These deviations may be due to differences in the specification of certain activities (e.g. grassland, set aside, etc.), chosen animal statistics[40], inconsistencies in EUROSTAT agricultural statistics and/or reporting differences by single Member States since similar rules for calculation of methane emission factors are used. The modelled results seem, however, quite plausible since they do not deviate much for the EU-15 aggregate and are subject to strict regional consistency rules (advantage of the selected modelling approach). For *nitrous oxide emissions*, the situation is rather different. In this case, comparison is not that straightforward since specific rules for the calculation of emission factors are used by countries and, moreover, some sources from agricultural soils are not included in the model due to lack of data (see figure (9)) For single countries differences vary between -40.1 % for Greece and +56.4 % for Belgium. Deviations in total GHG emissions (expressed in carbon dioxide equivalents) vary between

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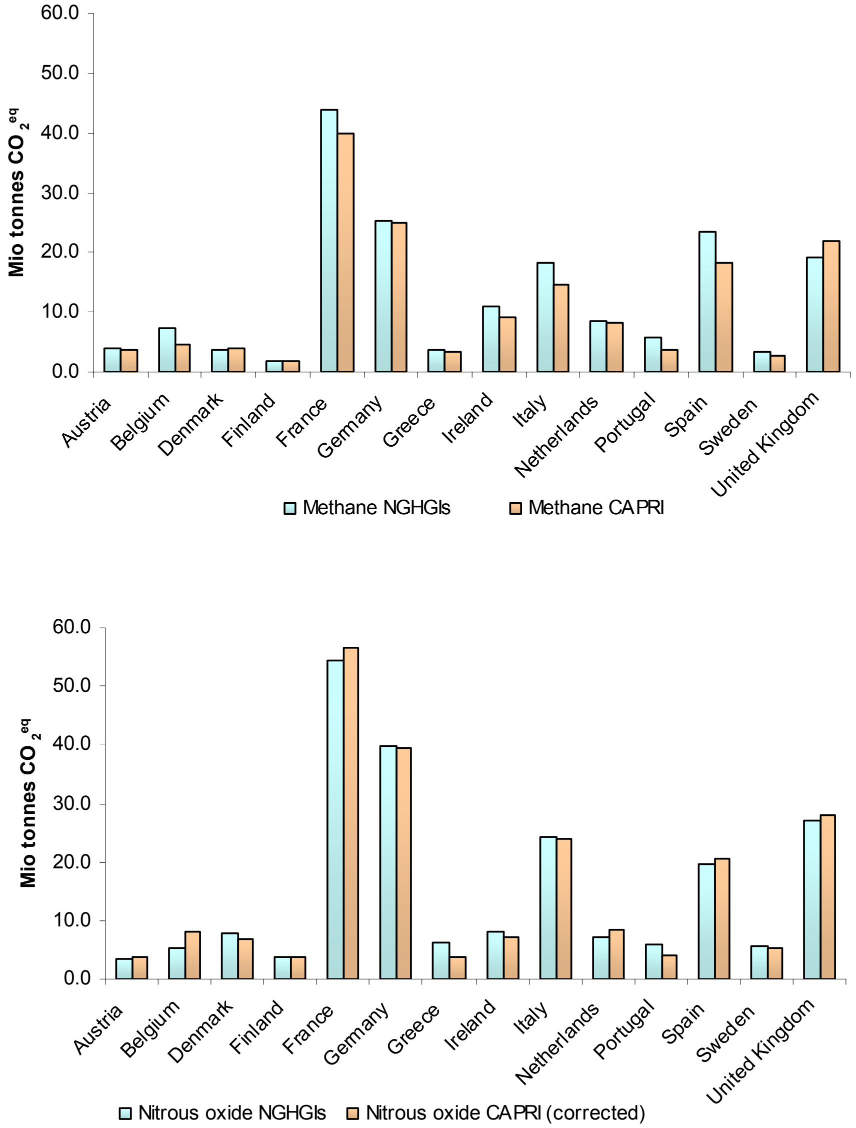
[40] Animal accounting (e.g. census) is not homogenous across countries. In the CAPRI model, data on slaughtering statistics are used.

-35.8 % for Portugal and 7.8 % for United Kingdom, with an average deviation of -4.4 % for the EU-15.

In figure (10) these differences are expressed graphically in terms of global warming potentials (CO_2^{eq}).

Figure (10) Comparison between model estimations and national greenhouse gas emission inventories for methane and nitrous oxide emissions in global warming potentials (EU-15 Member States)



Source: own calculations, 2001 three year average calibration year for CAPRI and year 2001 for NGHGIs; Luxembourg is modelled together with Belgium.

Measurement units: Mio tonnes of CO_2^{eq}.

<u>Note</u>: nitrous oxide emissions are corrected in these figures for comparison purposes (see table (17)).

From a different perspective, table (18) summarises emissions and differences with respect to official GHG emission inventories for single agricultural emission sources and sub-sources (EU-15 as an aggregate):

Table (18) Greenhouse gas emissions from agricultural sources (average for the EU-15)

	UNFCCC		CAPRI		% differences (CAPRI / UNFCCC)	
	CH_4	N_2O	CH_4	N_2O	CH_4	N_2O
4. N2O Agriculture (corrected) [1]	**8549.1**	**705.6**	**7658.8**	**709.1**	**-10.4%**	**0.5%**
4. N2O Agriculture	8549.1	705.6	7658.8	511.1	-10.4%	-27.6%
A. Enteric Fermentation	6268.1	0.0	5820.9	0.0	-7.1%	-
B. Manure Management	2155.6	69.6	1758.2	44.2	-18.4%	-36.4%
C. Rice Cultivation	111.4	0.0	79.8	0.0	-28.4%	-
D. Agricultural Soils	7.0	634.9	0.0	466.9	-	-26.5%
--- Atmospheric Deposition (ammonia vol.)	0.0	37.2	0.0	48.7	-	30.8%
--- Animal Production (N excretion on pasture)	0.0	89.8	0.0	93.8	-	4.4%
--- Crop Residues	0.0	36.3	0.0	30.9	-	-14.8%
--- N fixation	0.0	14.4	0.0	7.7	-	-46.8%
--- Org fertiliser (Animal Waste)	0.0	92.8	0.0	104.9	-	13.0%
--- Syn fertiliser (application)	0.0	166.3	0.0	180.9	-	8.8%
--- Histosols	0.0	18.0	-	-	-	-
--- Nitrate Leaching	0.0	148.2	-	-	-	-
--- Other	0.0	31.8	-	-	-	-
E. Prescribed Burning of Savannas	0.0	0.0	-	-	-	-
F. Field Burning of Agricultural Residues	7.0	1.2	-	-	-	-
G. Other	0.0	0.0	-	-	-	-

Source: own calculations; 2001 three year average calibration year for CAPRI and year 2001 for NGHGIs.

Measurement units: 1000 tonnes.

[1] Nitrous oxide emissions are corrected for comparison purposes (histosols and nitrogen leaching as exogenous).

Deviations in total methane emissions are mostly due to variations in manure management emissions (-18.4 %). One of the reasons is that the fraction of N in manure 'managed' by the model (part subject to ammonia losses) is lower than the one used by Member States, which do not always use IPCC default management parameters[41]. This is also reflected in nitrous oxide emissions (-13.4 % when summing up manure management and excretion on grazings, the latter being just an additional management type counted under agricultural soil emissions). There is also an over-estimation of N_2O animal waste emissions (13 %) due to a higher amount of manure produced in the model (through manure-output functions) than in the statistics used by Member States. However, by correcting total nitrous oxide emissions for the missing sub-sources (histosols and N leaching), official inventory data are almost perfectly matched for the EU-15 as

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[41] Closer estimates could be obtained by using country specific manure management parameters in the model. This is, however, not exempt from problems since these coefficients would have to be internationally validated and would introduce uncertainty in the calculation.

an aggregate (0.5 %). A further disaggregation of emission sources and sub-sources at Member State level is given in appendix 7.

In their construction, GHG emission inventories have been thoroughly examined by comparing emission factors and activity data for single countries used by NGHGIs (data obtained from national statistical bodies) and the model (data from EUROSTAT and FAOSTAT). The main remaining differences are due to statistical differences in activity data (e.g. application of organic fertiliser per Member State), coverage of polluting activities (e.g. atmospheric deposition) and use of different data and emission factors (e.g. crop residues)[42]. For this reason, model estimations cannot be considered as less accurate than official reporting data. As a consequence, the modelling approach can be validated, covering 100 % of methane emissions and around 72 % of nitrous oxide emissions reported (without correction for histosols and N leaching sources).

3.4.3 Interpretation of results

Manure management emissions (methane und nitrous oxide), fertiliser application (nitrous oxide) and enteric fermentation (methane) are the most important sources of GHGs in European agriculture (see table (18)). Any effective mitigation policy should carefully cover these major sources and target the corresponding polluting activities, balancing emission coverage (number of sources regulated) and transaction costs. It should also look at the regional production structure, which can alter the ranking of most emitting sources.

From the regional perspective, France and Germany are the Member States with the highest amount of estimated emissions (for methane 40 and 25 Mio tonnes of CO_2^{eq} respectively and for nitrous oxide 57 and 40). This is of course mainly related to their weight in European agriculture. In order to avoid this scaling problem, in the following two figures total methane and nitrous oxide emissions are assumed to be uniformly distributed on agricultural land within a Nuts 2 region and are reported per hectare. The result is a useful environmental pressure indicator at a regional level that is independent of the production level and therefore isolates the polluting effect of a different regional production-mix:

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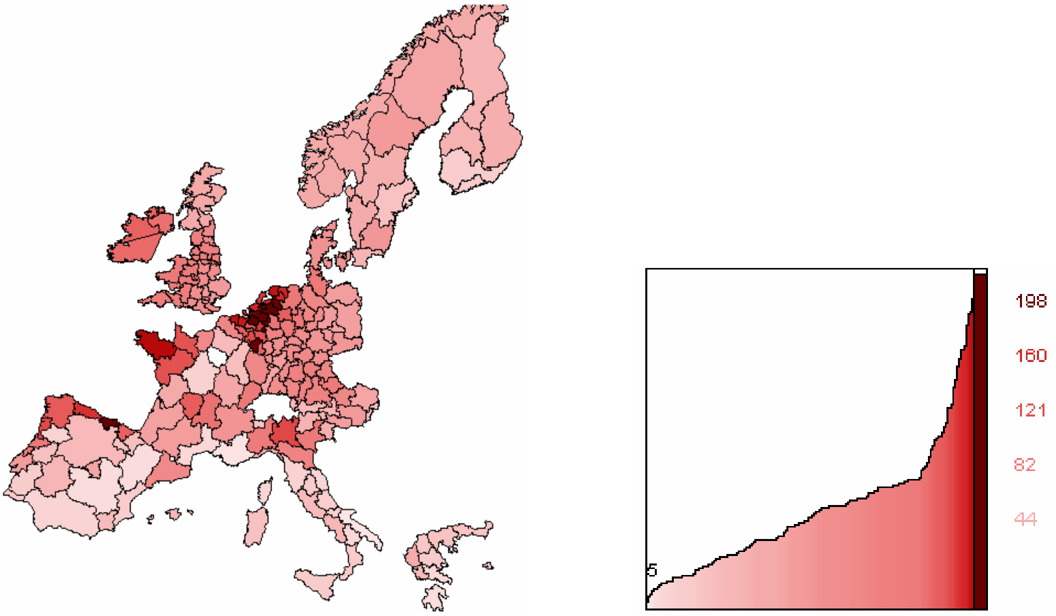
[42] A detailed analysis of these differences has been completed by the author for the expert meeting on improving the quality of greenhouse gas emission inventories for category 4D in September 2004 (Pérez, 2004a).

Figure (11) Methane emissions per hectare (Nuts 2 regions)

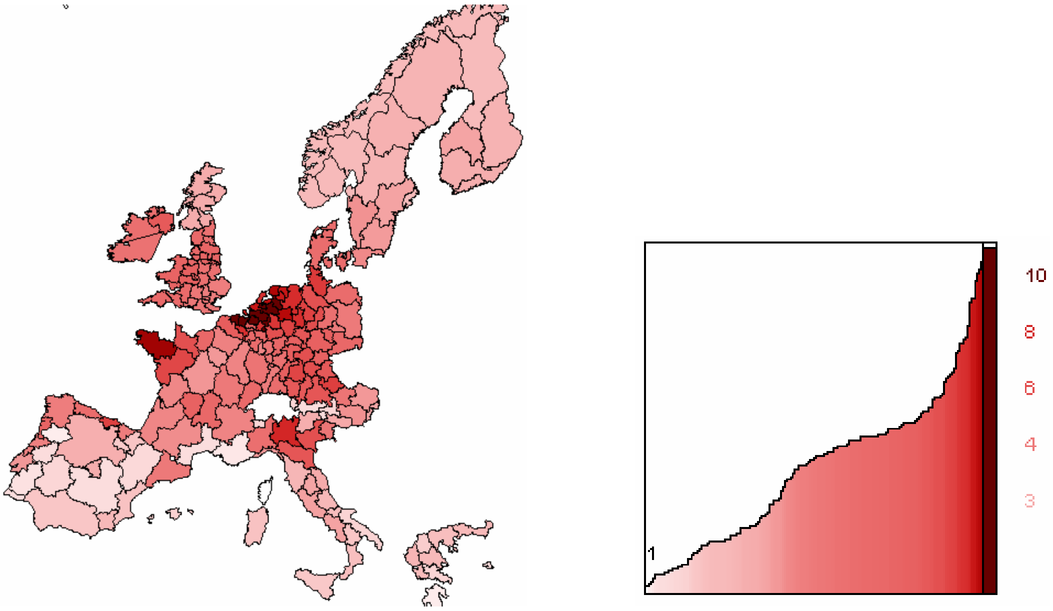


Source: own calculations; 2001 three year average.

Measurement units: tonnes of methane per hectare.

In figure (11) regions that combine intensive pig or cattle production systems and have a small surface (high stocking density) present higher emission values. This is the case for the Netherlands and some northern regions of Spain. Estimated emissions per hectare vary between 5 tonnes per hectare in Ile de France (FR100) and 267 tonnes per hectare in Gelderland (NL220). Germany, Ireland and South and Central England are characterised by medium-intensive cattle production systems (fodder produced to a large extent in the region) and show a more homogeneous range of values (between 50 and 70 tonnes of methane per hectare).

Figure (12) Nitrous oxide emissions per hectare (Nuts 2 regions)



Source: own calculations; 2001 three year average.

Measurement units: tonnes of nitrous oxide per hectare.

A similar analysis for nitrous oxide emissions is shown graphically in figure (12). Estimated emissions per hectare vary between 0.8 tonnes per hectare in Corse (FR830) and 16.8 tonnes per hectare in Noord-Brabant (NL410). As in the case of methane, nitrous oxide emissions per hectare depend not only on the share of animal-producing activities but also on high-fertilising activities. The most polluting regions are found in the Netherlands and northern part of Germany (cattle production). Southern regions of Spain and Italy present proportionally higher emissions per hectare than in the case of methane due to the presence of fruits and vegetables, activities with a high fertiliser application per hectare.

3.5 Conclusions

In this chapter the accounting approach proposed by the IPCC is highlighted as the appropriate methodology for the calculation of sectoral GHG emissions and is consequently applied to the estimation of emission factors for agricultural sources in the CAPRI model. Twelve agricultural emission sources are individually modelled by following the proposed IPCC technical guidance (IPCC, 1997; IPCC, 2000) and estimated parameters/coefficients are compared with the existing literature. With this information on emission factors and activity data used by the model, national and regional GHG emission inventories (Nuts 2 level) are calculated for the year 2001 and validated through meticulous comparison with official NGHGIs. The presented modelling methodology has some advantages for the estimation of GHG emissions from agricultural sources relative to the use of national independent studies (UNFCCC approach): (a) it enables a consistent and simultaneous analysis of emissions from crop and animal activities, (b) it makes use of transparent and accessible data sources and (c) it introduces an endogenous dose-response mechanism between production activities and emission sources which allows for further mitigation policy analysis. Nevertheless, as already mentioned, in this modelling approach not all emission sources can be covered, or fully covered, so that a certain trade-off between accuracy and applicability has to be accepted. In the following chapters, these estimates will serve as starting point for the analysis of mitigation policies.

CHAPTER 4 The Use of Emission Abatement Instruments: Tradable Permits as a Viable Option in Agriculture

> *The problem is determining the best human signals and incentives to get people's net impact on the biosphere to be sustainable [The core of reflective pricing theory] (Jack Harich, sustainologist).*

4.1 Introduction

The agricultural sector is a very heterogeneous sector. It involves many different production processes with strong physical and economical inter-linkages and has a highly disaggregated production structure. Consequently, efficient environmental policy needs to address a *complex moving target* since regulations on one activity or group of activities have indirect effects on others (pollution leakages might appear). Moreover, during the last 50 years, agriculture has proved to be a very sensitive political issue in Europe, resulting in a ‘chronically’ subsidised sector. Financial support has not been reduced although the contribution of agriculture to the European GDP has drastically decreased. This has provoked a distortion of the market forces driving the allocation mechanisms within the different common market organisations with noticeable economic losses as a consequence. In order to achieve a ‘more market-oriented agricultural policy’, economic instruments have to be chosen accordingly. Parallel to the ratification of new reform policy packages such as the ‘partial decoupling of CAP direct payments’ (Commission of the European Communities, 2003a), specific economic instruments in agri-environmental policy are expected to reduce market distortions[43].

In this chapter GHG emission standards and tradable permits, as the typical KP mitigation mechanisms, are analysed from a theoretical perspective. First, section 4.2 provides a brief history of the use of abatement instruments in pollution control. Section 4.3 gives a detailed review of the different types of abatement instruments found in the literature. In section 4.4, the basic economics of emission abatement are briefly revisited and the use of tradable emission

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[43] Most of the CAP reform efforts initiated in the last decade have been aiming at support deregulation, ‘with a view on stimulating European competitiveness’ (Commission of the European Communities, 1999).

permits in agriculture is justified by focusing on key theoretical aspects. Further, in section 4.5 the problem of implementing tradable permits in agriculture is exposed. Section 4.6 draws some conclusions.

4.2 Historical evolution of pollution abatement instruments

Instruments for pollution abatement have been generally linked to the *polluter-pays principle* (PPP)[44]. The basic idea behind this principle is to make those who are responsible for causing environmental damage pay the costs of cleaning the environment, either directly by forcing them to adopt costly technologies or indirectly through the market mechanisms. During the 1970s and 1980s environmental policy in Europe focused on direct regulation with non-compliance resulting in penalties. *Command-and-control* (CAC) instruments were used to address most environmental negative externalities such as urban air pollution, N leaching or methane emissions. As the name indicates, a CAC approach consists of a 'command' and a ‘control’ variable. Whereas the former sets a standard or maximum level of permissible pollution, the latter monitors and enforces the implementation of this standard. With these instruments, the PPP was fulfilled to a certain extent since polluters had to bear the costs of compliance, e.g. by producing less or by using different inputs and/or technologies.

However, it is this characteristic of treating all polluters equally that pushed OECD countries during the 1990s to introduce different reforms in environmental policy regulation and to adopt *market-based solutions* (e.g. emission taxes or tradable permits). These instruments use market signals in the form of a modification of relative prices, or a financial transfer, to influence behaviour and reward environmental performance through the market (Egenhofer, 2003, p. 21). By doing this, a higher economic efficiency is achieved since polluters are allowed to vary their pollution level according to their marginal costs of abatement. Nevertheless, some problems linked to the application of these instruments might arise. Firstly it is not easy for policy-makers to justify the case that environmental performance can be achieved through eventually higher levels of pollution from specific sites (political problem) and, moreover, an inequitable redistribution of the abatement effort could take place since some producers might have a much more efficient production structure than others and would be therefore less affected economically by these instruments (targeting problem).

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[44] The polluter-pays-principle was first recognised as an internationally agreed principle by the OECD in 1972 and adopted by the EC in 1975 as the basic principle in environmental policy (OECD, 1994).

In this decade, the policy agenda is beginning to include a mixing of abatement instruments. The idea is to leave the concept of perfect optimality and introduce some adjustments on economic instruments in order to increase their applicability and acceptability (Egenhofer, 2003, p. 41). Examples of these are the introduction of *minimum emission prices* in permit markets (in order to reduce the risk of 'hot air'[45]) or *regional emission targets* in tax systems (for ecological reasons).

4.3 Types of greenhouse gas emission abatement instruments: command-and-control versus market-based approaches

In environmental pollution control there are two types of instruments: *standards or command-and-control instruments* and *economic or market-based instruments*. For GHG emission abatement, there are basically three types of standards (Egenhofer, 2003; Austin, 1999): (1) a*mbient-quality standards,* which define an environmental objective to be achieved in terms of the concentration of a specific pollutant in a certain area, (2) *process or product standards,* which are technology-based standards and delimit the technologies to be applied by potential polluters in the achievement of an environmental target or the characteristics to be fulfilled by the products used in the production process[46] and (3) *emission standards* which focus on emissions of specific pollutants considered a proxy for environmental damages not easily measurable. An example of the current use of emission standards is the KP to the UNFCCC which foresees its combination with other market-based instruments.

The most important market-based instruments in terms of their application to pollution abatement are *taxes*, *subsidies* and *tradable emission permits* (OECD, 1994). *Charges and Taxes* imply a payment made by polluters for every unit of pollution released into the environment, providing a solution to the failure of the free market which does not internalise this negative externality. Whereas taxes are compulsory contributions extracted for public purposes, charges or fees are imposed on users of certain public services (the one who benefits pays the bill and vice-versa). Since in the case of GHG emissions all economic sectors benefit from emission abatement, it is more appropriate to talk about taxes[47]. There are two different types of taxes:

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[45] 'Hot air' appears in emission markets which are not able to avoid that emissions are higher in the commitment period than in the reference situation, driven by the fact that emission restrictions are not binding for some polluters which act as sellers in the market. This is more likely to happen in an imperfect world market of GHG emissions, where potential sellers such as Russia and Central and Eastern European countries (current emissions much lower than in the reference period) but not potential buyers such as USA (current emissions much higher than in the reference period) participate.

[46] They are usually combined with other standards or market-based instruments, as bans on specific processes showing high potential risks of pollution.

[47] There is, however, some room for *user charges* related to global warming emissions, e.g. road user charges, but the boundaries of the definition and the externality targeted are in most cases not clearly defined. According to

product taxes and *emission taxes*. Product taxes affect products which cause emissions as they are manufactured, consumed or disposed of (OECD, 1994). In agriculture, there are several examples of product taxes, mainly applied to inputs such as fuels and fertiliser. Emission taxes imply a direct unitary payment on pollution output, in our case GHG emissions, and are also called *green* taxes since they are applied only on key polluting activities and have low distortionary effects on other economic activities.

Direct subsidies arise from an inversion of the PPP since in this case polluters are given the right to pollute and are willing to change their behaviour in order to be compensated. Generally, subsidies for emission abatement take the form of soft loans, tax allowances and R&D payments. They try to induce a polluting sector to comply with an emission target by reducing its investment deficit on pollution control. In other words, direct subsidies can be thought of as negative taxes and are in theory paid proportionally according to the abatement effort (market-based instrument).

Tradable emission permits and their economic mechanism are explained in detail in the following sections. A market of tradable permits is defined as an economic policy instrument under which 'rights to discharge pollution or exploit resources can be exchanged' (FAO and EEA definition). The basic tradable permit system is called *cap-and-trade system*, where an emission target is fixed (cap on emissions) for a number of emitters in one or various sectors. Emission allowances are distributed among emitters, either auctioned or 'grandfathered'[48], and may then be traded. This is shown graphically for two emitters belonging to the same sector in the (A) representation of figure (13):

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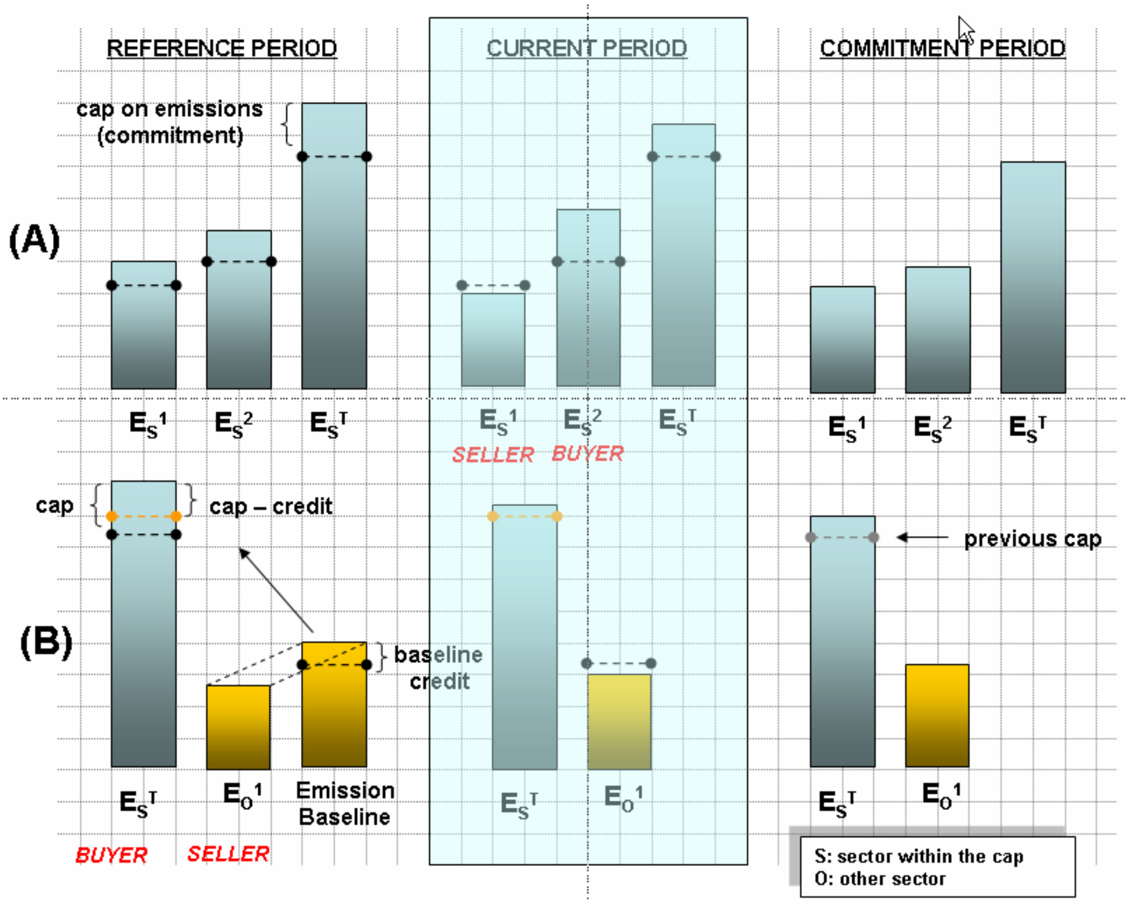
the legislation some of these charges should actually be defined as taxes but the economic literature does not always reflect these conceptual differences.

[48] Grandfathering implies a distribution of allowances 'for free', usually based on historical individual records.

Figure (13) Graphical representation of cap-and-trade and baseline-and-credit permit markets



In figure (13) - **(A)** two emitters belonging to a regulated sector ‘S’ (E_S^1 and E_S^2) receive an allocation of allowances for a commitment period which is 20% below their historical emissions in a reference period (four and five vertical units respectively). This objective can be seen from an aggregated perspective as the sectoral ‘target on emissions’ (E_S^T = seven units). The position of these two emitters as sellers or buyers in the permit market can be observed in the current period or at the beginning of the commitment period, but might vary at the end of the period depending on individual behaviour.

Additionally, there are *baseline-and-credit* tradable permit systems. For their design, a cap on emissions is a pre-requisite (‘trade’ is not necessary)[49]. In figure (13) - **(B)**, the sector ‘S’ is still affected by a cap-and-trade system, but additionally an emitter belonging to sector ‘O’ (E_O^1), a

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[49] In the literature these two systems are frequently defined as independent ‘types’ of tradable permit markets. In reality, they are not independent since credits can only be distributed within a sector regulated through an emission cap.

sector not affected by the 'cap', can voluntarily achieve emission credits by over-complying with an individual target. Contrary to the previous case, which refers to past emissions, the emission baseline for this emitter is calculated based on a certain production plan with the current technology in the commitment period (four units in the graph). Credits can only be earned by investing in new abatement technology since variations in output (e.g. capacity expansion) would imply a variation in the baseline (ex-ante instrument). The credits generated by sector 'O' can be freely sold in sector 'S' and the emission cap for this last one is reduced by the corresponding amount, as shown in the figure[50]. Trade would, however, only take place between these sectors when a potential for it exists, i.e. only if the emission cap on sector 'S' is actually binding[51].

A drawback of baseline-and-credit systems is 'uncertainty' since credits are distributed according to 'future behaviour'. Nevertheless, it opens up the participation possibilities to sectors not included in the current emission abatement policy (e.g. agricultural sector).

There are also other abatement instruments used by policy-makers and usually applied as market-based elements of the previously described instruments. On the one hand *financial enforcement incentives* try to raise the costs of non-compliance by imposing penalties over a predefined target. They are a key variable in the success of any environmental policy since no policy objective can be achieved without an appropriate enforcement mechanism. Non-compliance penalties have been one of the most difficult issues to deal with in international negotiations. On the other hand *renewable emission quotas* impose obligations on polluters to use a certain amount of renewable resources as inputs in the production process. These quotas can be basically seen as market-based technology standards on polluters since firms are not obliged to adjust their production process completely but only partially (by using renewable resources).

Standards and market-based instruments have been recently combined. As previously mentioned, these policy-mixes have been increasingly seen as a way of overcoming some of the disadvantages of economic instruments (Egenhofer, 2003). This has been basically applied to tradable permit markets, resulting in two main types of 'hybrid' instruments. *Tax-permit*

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[50] A 'gateway' is usually used to control the flow of incoming credits in these systems. It can vary across systems.

[51] A baseline-and-credit system allocates a pre-determined emissions profile to each participant and allows trade in the unused portion of that profile, known as emission 'credits'. Moreover, baseline-credit arrangements might be used to supplement a mainstream cap-and-trade system as a means of extending emission coverage to sources and activities that might otherwise be difficult to include in a trading system (Australian Greenhouse Office, 1999).

instruments impose limits on permit price variability by setting either a minimum and/or a maximum price per emission unit. On the one side, a minimum price might contribute to reducing the risk of 'hot-air' and introduces some stability in the permit price-building mechanism. Consequently, countries with very low marginal abatement costs would not have the possibility to launch an excessive amount of permits in the market at a very low price[52]. On the other side, a maximum price might contribute to increasing the acceptability in the initial stages of the system. This can be achieved by allocating an infinite amount of permits at a certain price. Both price limits would be acting for the different actors in the market as taxes on emissions and would restrict free trade of permits. *Standard-permit instruments* imply a combination of specific targets for several sectors or pollution sources, mainly already achieved in the past through Negotiated Environmental Agreements (NEAs) and the implementation in parallel of a tradable permits system. There are therefore two different objectives, an 'absolute or overall target' for all sources of pollution and regions included in the permit market and a 'relative or specific target' for single sources and/or regions which have already signed an NEA. These are therefore excluded from complying with the absolute target. Whereas trade is unrestricted for all sources covered by the absolute 'cap' on emissions (absolute target), it is only allowed with sources having a NEA (relative target) if there is no net flow of permits into the sources covered by the absolute target. This is achieved by separating both types of sources by a 'gateway' which only allows unrestricted trade between all actors as long as the marginal abatement costs for the sources covered by the absolute target are lower than for the ones having a NEA. These hybrid instruments will not be the subject of further analysis in the current study.

4.4 Theoretical issues: from emission standards to tradable emission permits

4.4.1 Economics of emission abatement

The most important explanation for pollution is the absence of a sufficient set of private property rights for environmental resources (Hanley et al., 1997, p. 130). In order to correct this market failure, incentives to environmental pollution control are introduced by governments. As mentioned, for GHG emission control, *standards*, as the typical CAC abatement instrument, and *tradable emission permits*, as the newest economic abatement instrument, can be applied. In this section, the basic economic theory behind these two instruments is explained.

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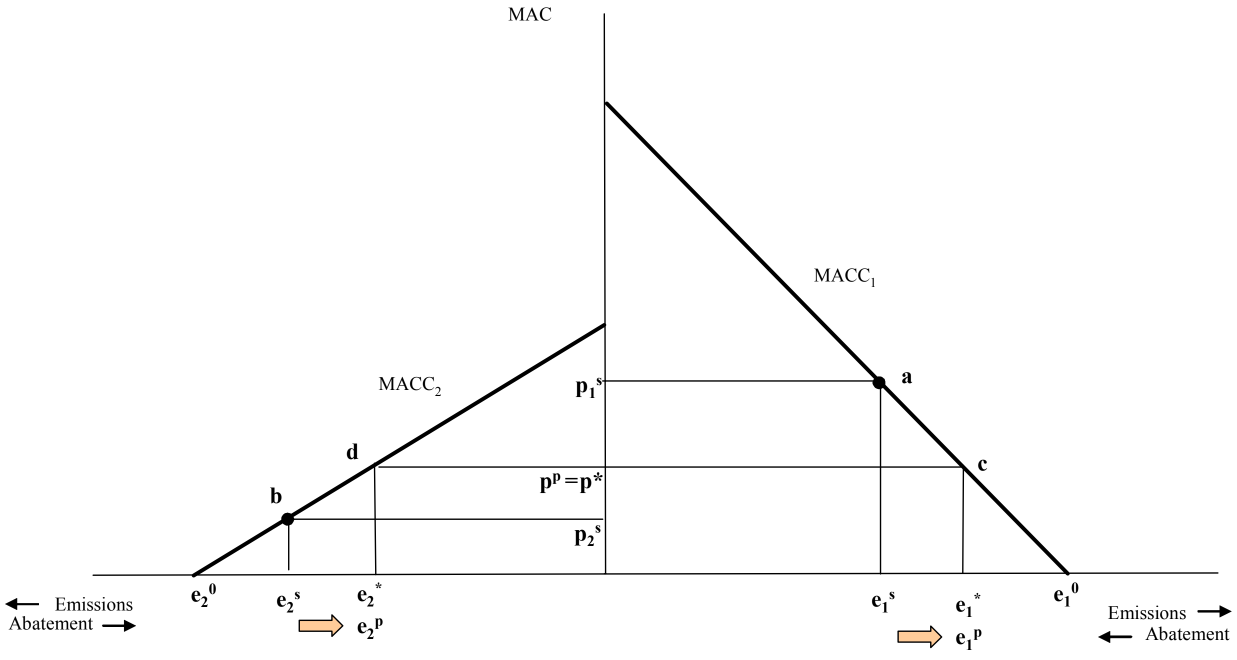
[52] This can be caused by high emission disparities between the reference period and the current one driving to an excessive distribution of permits in the initial situation (e.g. Russia in an international trading system for GHG emissions under the KP).

Emission standards are quantitative limits on the emission or discharge of a potentially toxic substance from a source. The simplest form for regulatory purposes is a uniform emission standard, where the same limit is placed on all emissions of a particular polluter. This can be graphically shown for two regions in the following figure:

Figure (14) Emission standards and trading of emission permits for two firms



Source: based on general environmental economics (Hanley et al., 1997, p. 112).

In figure (14) basic microeconomics are applied to the case of two agricultural firms with differentiated marginal abatement cost curves ($MACC_1$ and $MACC_2$)[53]. In this graphical example, both firms are required to comply with a total emission objective e^{target} which is allocated between them based on historical emissions ($e_1^s + e_2^s$). This emission target is smaller than the initial unrestricted emission level $e^{\max}$ ($e_1^0 + e_2^0$), where MACs are zero (no abatement). Perfect knowledge about the shape of the MACCs is assumed.

However, as stated in textbooks, a reduction in total abatement costs can be achieved by introducing *emission pricing* at the level p^* (total emissions do not change compared to the

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[53] Abatement costs are considered *direct costs of abatement* (revenue losses derived from production readjustment and possible expenses on new abatement technology), *associated transfer losses* (payments such as emission taxes) and *associated transfer gains* (such as emission subsidies, 'negative costs').

situation with individual emission standards). Emission pricing implies lower abatement costs for both firms (sum of the area under both firms' curves), as graphically shown:

$$\begin{aligned} Welfare\ Change &= \left(e_1^0 a e_1^s + e_2^0 b e_2^s\right) - \left(e_1^0 c e_1^* + e_2^0 d e_2^*\right) \\ &= e_1^* c a e_1^s - e_2^s b d e_2^* > 0 \ \ if \ \ e_1^* - e_1^s = e_2^s - e_2^* \end{aligned} \tag{4.1}$$

A specific case of emission pricing under a given constant level of emissions is emission permits. The idea behind this instrument is '*to create a market of emission rights which are interchangeable and allow producers to pollute*'. In the absence of intervention (optimality conditions), market forces will determine the price of permits and provide emitters with the right incentives to arrange emission levels so that a cost-minimising solution is reached. This implies that the costs faced for the last emission unit abated by these two agricultural firms (revenue losses or increases in variable costs derived from production constraints) will be equal at the optimum[54]. In the graphical case, firm 1 will buy permits from firm 2 ($e_1^p - e_1^s$ or $e_2^s - e_2^p$). By doing this, both polluters move to a market equilibrium where p^p is paid for each emission permit and face lower abatement costs of complying with $e^{t\arg et}$. The total amount of emission rights in the market is regulated to be $e_1^p + e_2^p$.

It can be observed that with rising emission levels MACs for polluters decrease. This means that an agricultural firm with a low abatement effort faces lower costs of eliminating an additional emission unit than with a high abatement effort. Whereas in the first case it will have access to cheaper and less effective methods of abatement to achieve a reduction objective, in the second case it would have to make use of very effective and expensive technologies to get a similar result. From the production perspective, agricultural firms facing already high levels of emission abatement will have less technological adaptation alternatives in the production process and will face higher costs for an additional abatement unit.

4.4.2 Arguments in favour of the use of tradable emission permits

CAC instruments are nowadays partially overtaken by market-based ones due to their specific characteristics. One of the major drawbacks of standards is the *need of effective enforcement.* Regulatory authorities must activate enough resources to increase non-compliance costs for

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[54] This analysis does not take into account the issue of transaction costs. This will be analysed in chapter 6.

polluters over the marginal costs of pollution abatement[55]. Another problem is that these instruments are *static*, which means that they need permanent regulatory update with high costs attached to laborious negotiations. Moreover, they lack the necessary incentives for *technological improvemen*t and are not *cost-effective*. Market-based instruments, on the other hand, create an ongoing incentive to reduce continually aggregate emissions by attaching an explicit price to them (Kennedy, Laplante, 1999). They rely on the market forces to achieve emission reductions indirectly.

The implementation of permit markets for abatement of agricultural GHG emissions is defended based on the following arguments:

- *Cost-effectiveness (static efficiency).* There is a common agreement in economic literature that market-based instruments such as emission taxes and tradable emission permits, perform better than CAC instruments in terms of cost-effectiveness (Baumol, Oates, 1971; Pearce, Turner, 1990, chapter 7; Hoel, 1998, p. 80). Instead of having to comply with a fixed emission target, emission pricing allows firms to choose a production program based on their individual costs of abatement (as graphically presented in figure (14)). By doing this, more abatement from 'low-cost polluters' is implicitly required, which minimises the programme's cost to the society.

  This cost-effectiveness argument should especially hold in a market-oriented agricultural sector such as the European one since agricultural producers have to compete with each other and are subject to the rules of a competitive market (coverage of variable costs, price-building mechanism, bankruptcy laws, etc.). However, from this perspective there is no difference between emission taxes and tradable permits. Taxes put a price on emissions directly by a government decision and permits indirectly by forcing existing and would-be emitters to compete in the market for a limited supply of permits (Wills, 1992, p. 1).

- *Technological change (dynamic efficiency).* In terms of dynamic incentives for the adoption of 'green' technology, market-based instruments also perform better than CAC instruments. By attaching an explicit price to emissions, they introduce an ongoing incentive for firms to reduce their emission level continually (Kennedy, Laplante, 1999, p. 1). The adoption of cleaner technologies allows a firm to achieve a lower MACC, i.e. less cost for every

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[55] It is important to note that control costs attached to non-compliance are reduced in the case of market-based instruments due to the fact that the market acts as a control variable (e.g. tax on nitrogenous fertiliser). Other

additional emission unit abated than in the previous situation. The outcome for a single firm in terms of incentives for technological change depends on the shape of the marginal damage curve, the number of firms in the market and the response of policy-makers[56].

- *Regulatory Flexibility.* This is 'the ability of the government to review all regulations to ensure that, while accomplishing their intended purposes, they do not unduly inhibit the ability of small entities to compete' (National Marine Fisheries Service, 2001, p. 1). This characteristic is quite important in the implementation phase of a new emission abatement instrument, where adjustments are needed in order to guarantee environmental effectiveness. An adjustment in the number of permits issued in the market (e.g. motivated by new scientific research in the measurement of the climate change effect or due to new international commitments) might be politically and administratively easier to face for the regulatory institution than a correction of the emission tax rate (at least from the legislative perspective). Permit trading schemes are also often preferred to taxes because emission rights can be allocated once a political process has decided upon the total level of emissions permitted. Emission levies are not able to guarantee ex-ante a certain limit on emissions in the regulated sector since the government does not have perfect information on the cost structure of the polluting firms and regular adjustments are necessary to keep the system under optimality conditions. Any such adjustments in permit markets will, however, imply some negative effects in the system from an economic perspective since intervention in the market will affect the investment plans of its players (emission permits as investment assets).

- *Enforceability*. One of the primary goals of an environmental enforcement program is to change human behaviour so that environmental requirements are complied with (EPA, 1992, pp. 1-2). In literature, there are cases of monitoring and enforcement costs being reported as higher for traditional CAC instruments than for market-based instruments (INECE, 1996, p. 194). Nevertheless, this is not a general picture since for market-based

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transaction costs might, however, also appear, having to be analysed on a more comprehensive assessment.

[56] According to Milliman and Prince, emission taxes and auctioned permits are the better facilitators of technological change. However, their analysis suggests that under auctioned permits, technological innovation will occur more rapidly and does not depend upon control adjustment (Milliman, Prince, 1989, p. 257-259). This is due to the fact that taxes, if the new technology is not patented, will be subject to a regulatory control, making the optimal outcome dependant on the firm's response (some distorting actions might take place, e.g. overstating of cost reductions to the regulator). Nevertheless, several authors state that in a general dynamic context with known marginal damage curves neither taxes nor permits are optimal if governments can not predict their changes. There is therefore no unique ranking of these two policy instruments. Moreover, Kennedy argues that it is not possible to achieve efficient pricing ex-post and at the same time create the right incentives for technology adoption ex-ante using a single instrument (Kennedy, Laplante, 1999, p. 9; Denicolò, 1999, p. 184-186; Requate, 1998, p. 159).

instruments new forms of enforcement might be required, thereby increasing their costs. It is, however, not easy to compare emission abatement instruments by means of this criterion since it does not pertain directly to economics and depends also on other factors, such as the geographical boundaries or characteristics of the regulated sector. In the case of agriculture, GHG emissions are caused by rather complex functions and are difficult to attribute to specific activities (non-point source pollution) which might not favour the use of market-based instruments. However, from the institutional perspective tradable permits have been applied in the CAP for many years (Weingarten, 2001, pp. 14-15).

The analysis in this section and the strong movement by some major global players in the last two decades towards the use of tradable permit markets in pollution control strongly suggest that emission permits might be preferred in the case of agriculture to various other types of instruments. However, the complete replacement of CAC regulation is unrealistic since (1) pricing might not be in all cases ‘socially’ acceptable, (2) there is still little experience on the static and dynamic efficiency effects of market-based instruments, (3) tradable permits require expensive systems of data collection and monitoring and (4) new types of monitoring and enforcement might be needed, these costs not being necessarily lower than for CAC regulations (INECE, 1996, p. 197). In chapter 6, these issues will be further discussed by looking at some policy implementation examples.

4.5 The problems of introducing tradable emission permits in agriculture

There are nowadays no specific implementation examples of GHG emission abatement instruments in agriculture. This is mainly because action against the negative effects of climate change has gained importance in the last decade and other sectors of the economy have been targeted first, as they present a higher share of CO_2 emissions than agriculture (e.g. energy or industry). However, as already mentioned in section 2.2.3, some progress has been made by the UNFCCC towards international agreements on the inclusion of LULUCF activities in the GHG emission inventories. The aim is to gain some understanding of the complex chemical processes involved in the calculation of GHG emissions and sinks from agricultural production activities and to generate common accounting and calculation procedures (measurement stage). Later, some of the economic instruments already tested in other economic sectors could be applied to the agricultural case (implementation stage).

In Europe there have been several examples of environmental standards which have had at least an indirect effect on GHG emissions from agricultural sources: the EU nitrate directive (Council of the European Communities, 1991) or specific limitations on animal stocking densities and fertiliser application per within country-specific extensification schemes. Other general instruments at an inter-sectoral level such as fuel taxes and pesticides have also addressed this environmental externality and have had an indirect effect on the agricultural sector[57]. Nevertheless, besides the Dutch nutrient quota trading system (Vukina, Wossink, 1999) there have been to date no signs of market-based instruments being applied exclusively to agricultural emissions.

4.6 Conclusions

In this chapter a brief overview on the principal economic instruments of GHG emission abatement is given with a special focus on emission standards and tradable emission permits. CAC and economic abatement instruments are confronted from a theoretical perspective. It is shown, that CAC instruments have two negative effects: (1) they tend to increase costs by forcing firms to apply expensive technologies for compliance and (2) they do not always allow for the development of new technologies since there is an absence of financial incentives to exceed a control target (Stavins, 2001). In other words, emission standards do not achieve an economically optimal solution. Some arguments in favour of the use of tradable emission permits are highlighted, as well as the problem of introducing them as an emission control tool in the agricultural sector.

In chapter 5, the use of marginal values in mathematical optimisation problems is thoroughly explained. This theory is applied to the calculation of MACCs for GHG emissions from agricultural sources as an alternative approach to the direct modelling of emission prices. Further, and based on this information, chapter 6 concentrates on the modelling of a feasible cap-and-trade tradable emission permit market in European agriculture.

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[57] Agricultural fuels are subsidised in most European countries and therefore instead of introducing incentives to abate, contribute to higher CO_2 emissions.

CHAPTER 5 Calculation of Marginal Abatement Cost Curves

> *A less-understood aspect of the economic costs of climate change is how global warming will raise—and likely already is raising— Texan's insurance rates […].Ultimately, global warming already is imposing real financial costs on consumers, whether they realize it or not (Joe Ridout, public citizen).*

5.1 Introduction

In chapter 4 emission standards and tradable permits have been analysed as competing instruments of GHG emission abatement in agriculture and their main economic features have been explained in detail. In this chapter, the principal element of decision behind emission abatement policy is addressed, namely the *marginal abatement cost curve*. Nowadays, it is increasingly important to articulate the differences in marginal costs of abatement between emitters. As explained in the previous chapter, a uniform abatement policy that does not consider the different cost structures of polluters might lead to significant economic losses.

The problems related to the analytical calculation of the marginal abatement cost curve have driven economic modellers to develop different methodological approaches. Within this research work, an alternative estimation approach to the usual direct modelling of carbon prices is presented. This will allow for the calculation of basic information used in the comparison between abatement instruments in the following two chapters. Section 5.2 contains a brief review on the basic mathematical programming concepts used in the model and introduces the notion of 'shadow value'. The main two modelling approaches followed by economic modellers to estimate GHG emission abatement costs are then explained in section 5.3. In section 5.4, the technical solution followed in CAPRI is explained and in section 5.5 regional MACCs for GHG emissions from agricultural sources are estimated and results analysed.

5.2 The meaning of marginal values in mathematical programming

In mathematical optimisation Lagrange multipliers are a method for dealing with constraints. Joseph-Louis Lagrange stated the general principle for maximising a function of n variables when there are one or more equations between the variables (Lagrange, 1797, p. 198)*: 'il suffira* *d'ajouter à la function proposée les functions qui doivent être nulles, multipliées chacune par une quantité indéterminée ...*'[58]. The Lagrange multiplier is found in Larew, 1919: '*The lambda's appearing in this sum are the functions of x sometimes called Lagrange multipliers.*'

The Kuhn-Tucker theorem is a generalization of the Lagrange multipliers. Albert W. Tucker and Harold W. Kuhn developed this theorem, a basic result in linear programming and published their findings in a volume of conference proceedings. They extended the Lagrange Multiplier Rule to allow for inequality constraints. A general constrained non-linear optimisation problem can be formulated as follows (Sydsaeter, Hammond, 2002, pp. 501-544):

$$\max f(x,y) \ s.t. \ g(x,y) \leq c \tag{5.1}$$

where $f(x,y)$ is the objective function to maximize and $g(x,y) \leq c$ the constraint.

For this problem the following Lagrange function can be defined:

$$L(x,y) = f(x,y) - \lambda[g(x,y) - c] \tag{5.2}$$

where λ is the shadow value or price of the restriction (price associated with increasing the right-hand side c or constraint).

At the optimum the following first-order conditions must hold:

$$\frac{\partial L}{\partial x} = f_1'(x,y) - \lambda g_1'(x,y) = 0 \ , \ \frac{\partial L}{\partial y} = f_2'(x,y) - \lambda g_2'(x,y) = 0 \tag{5.3}$$

and the 'complementary slackness' condition has to be fulfilled:

$$\lambda \geq 0 \ (= 0 \ if \ g(x,y) < c)^{59} \text{ or written } \lambda[g(x,y) - c] = 0 \tag{5.4}$$

This means that, at the optimum, λ and/or $g(x,y) - c$ have to equal zero, or equivalently any one of them may be non-equal zero (complementary inequalities). Equations (5.3) and (5.4) are

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[58] [Translated] 'It will be enough to add to the function proposed the functions which must be null, multiplied each one by an unspecified quantity'.

[59] Two possibilities: $\lambda = 0 \ if \ g(x,y) < c$ and $\lambda \leq 0 \ if \ g(x,y) = c$.

often called Kuhn-Tucker conditions[60]. Additionally the constraint ($g(x,y) \leq c$) has to be fulfilled by the possible set of values given by the first-order conditions[61].

This general application of the Kuhn-Tucker theorem can be also formulated in the following example, which is closer to the current programming problem in its primal version:

$$\begin{aligned} &\max_{x_i \geq 0} y = \sum_{i=1}^{n} mg_i x_i \\ &s.t. \sum_{l=1}^{m} a_{li} x_i \leq b_l \quad [\lambda] \end{aligned} \tag{5.5}$$

Where:
y = objective function (e.g. agricultural income)
x_i = production level of activity i
b_l = level of constraint l (physical or economic)
mg_i = gross margin of activity i
n, m = number of activities and constraints respectively
a_{li} = matrix of coefficients which link constraints and activities
λ_l = marginal value or ‘price’ associated with the constraint l

The Lagrange Function for this optimisation problem would therefore be:

$$\max_{x_i \geq 0, \lambda} L = \sum_{i=1}^{n} mg_i x_i + \sum_{l=1}^{m} \lambda_l \left(b_l - \sum_{i=1}^{n} a_{li} x_i \right) \tag{5.6}$$

Taking into account that a non-negativity restriction for x_i is also included in the problem, two complementarity slackness conditions can be derived in equations (5.7) and (5.8):

$$\frac{\partial L}{\partial x_i} = mg_i - \sum_{i=1}^{m} \lambda_l a_{li} \leq 0 \quad \perp \quad x_i \geq 0 \;\; \text{or} \;\; \left(mg_i - \sum_{l=1}^{m} \lambda_l a_{li} \right) x_i = 0 \tag{5.7}$$

According to this expression, the first derivative of the objective function with respect to x_i must be smaller or equal to the value of its constraints (‘resource cost’). In other words, production of a certain activity will take place only when its gross margin is able to cover its opportunity costs (constraints valued with shadow prices).

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[60] These conditions are ‘essentially necessary’; the sufficiency is guaranteed through the concavity of the Lagrangian.

[61] The authors recommend not differentiating with respect to lambda and equalize to zero because the inequality could hold at the optimum (if not binding). This can be therefore substituted through the constraint as an additional equation (in practical terms the feasible set of optimal values has to be checked within the constraint).

$$(5.8) \quad \frac{\partial L}{\partial \lambda_l} = b_l - \sum_{i=1}^{n} a_{li} x_i \geq 0 \quad \perp \quad \lambda_l \geq 0 \qquad \text{or} \qquad \left(b_l - \sum_{i=1}^{n} a_{li} x_i \right) \lambda_l = 0$$

From this, a complementary slackness condition can be derived so that a constraint gets a positive price ($\lambda_l > 0$) only when it is scarce ($b_l = \sum_{i=1}^{n} a_{li} x_i$). In other words, the restriction is binding. On the other side a constraint gets a value of zero ($\lambda_l = 0$) if it is not exhausted ($b_l > \sum_{i=1}^{n} a_{li} x_i$).

In mathematical programming models it is important to understand what information is hidden behind the shadow values of the restrictions. The supply component of the CAPRI model contains regional optimisation models where agricultural income is maximised subject to constraints. The idea of GHG emissions as an additional constraint with an attached shadow value depending on the emission level is exploited in the following sections.

5.3 Modelling approaches to calculate marginal emission abatement costs

5.3.1 Regulation of greenhouse gas emission abatement

GHG emission abatement costs are considered '*economic costs (in terms of income losses) faced by producers by complying with an emission abatement objective*'[62]. Emission abatement in the agricultural sector can be regulated at different levels. Firstly, emission regulation can be indirectly implemented by banning or imposing restrictions on a specific polluting activity. This would lead to a 'quota effect' in the sector with production of this activity substituted by other activities, independently of their contribution to GHG emissions (if they are not further addressed by regulations). Secondly, emissions can also be directly regulated by designing an 'emission accounting system' which tries to couple GHG emissions to all agricultural activities (weights per activity are included through emission factors). This would imply a restructuring of all production processes at the farm level so that activities with a lower contribution to farm's income per emission unit (low revenue per tonne of CO_2^{eq}) would be more likely to be affected in terms of production reduction than 'emission-efficient' activities (high revenue per tonne of CO_2^{eq}). Moreover, variations in production intensity could also appear through increasing or decreasing yields. This direct emission accounting system is followed in the current study.

Abatement costs, production and economic effects of emission abatement will therefore depend on the exact definition of emission sources per activity (see section 3.3).

5.3.2 Alternative modelling approaches

Several economic models have covered the analysis of GHG emissions in different economic sectors. Amongst others, the following models have been used: for agriculture the ASMGHG and AROPAj models (described in section 2.4), for energy the POLES Model (mentioned in section 3.3) and for the transport and industry sectors general equilibrium models such as the EPPA (Emission Prediction and Policy Analysis)[63] and RAINS (Regional Air Pollution Information and Simulation)[64]. They basically share two methodological approaches in the estimation of marginal abatement costs: one based on *direct modelling of carbon prices* and one based on *shadow prices attached to emission abatement restrictions*.

The first approach is the one most applied (used by the ASMGHG, AROPAj and POLES models). In the optimisation problem, emissions are taxed with a price that enters as an additional input cost in the objective function. By varying this carbon price iteratively a different abatement response is achieved at the optimum, thus generating a MACC as a succession of equilibrium points. Usually polluters are assumed to face a uniform emission tax so that the modelling response is different for each of them. Nevertheless, price differentiation between polluters would be also possible[65].

The second and alternative approach is to include emission restrictions directly in the optimisation problem (used by EPPA and RAINS). The marginal abatement costs are approximated by the shadow values of the emission abatement constraints. Normally, this emission restriction is considered to be equal across polluters and expressed as a percentage of emissions in a reference period. This option results in different MACs for polluters that face a similar abatement target. MACCs can be constructed by changing the emission abatement levels iteratively and storing the shadow values.

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[62] In this study no investment costs for alternative abatement technologies are considered. A brief discussion of the issue is given in chapter 8.

[63] The EPPA Model has been developed within the Joint Program on the Science and Policy of Global Change at the Massachusetts Institute of Technology (http://web.mit.edu/globalchange/www/eppa.html). For regional analysis in the EU, a version called EPPA-EU is derived.

[64] The Regional Air Pollution Information and Simulation model (RAINS) and its application to the estimation of GHG emissions (GAINS) is owned by the International Institute for Applied Systems Analysis (IIASA) and provides a consistent framework for the analysis of mitigation strategies for air pollutants (http://www.iiasa.ac.at/web-apps/tap/RainsWeb/).

[65] Remember that carbon prices and carbon emissions are closely related (theoretically explained in chapter 4).

For this study, both approaches have been analytically implemented and MACCs constructed for Nuts 2 regions. However, the second approach has been chosen based on the following criteria: (1) it allows direct modelling of emission standards at regional level, (2) it offers a more straightforward interpretation of results since emission abatement is considered as a binding restriction and not as an input cost and (3) it produces the necessary input data for further analysis on market-based abatement instruments with explicit consideration of transaction costs (tradable emission permits, see chapter 6). The inclusion of emission constraints can, however, be more problematic from the technical perspective since it implies a more complicated algorithm than the direct modelling of carbon prices through the derivation of the Lagrange function[66].

In the following table the different restrictions included in the supply module of CAPRI are listed. For each of them, a shadow value is generated in the optimisation process (zero if not binding).

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[66] In the current modelling approach several systematic infeasibilities due to the violation of neighbour restrictions were observed for high emission abatement targets. Nevertheless, this problem does not affect the current application since it remains within the feasible bounds. For additional research, the explicit use of carbon prices seems like an appropriate alternative.

Table (19) Restrictions in the supply model

Restrictions	Crop Activities	Animal Activities
Coverage of animal requirements (animal requirement minus delivery in feedingstuff) - fiber, dry matter - energy, crude protein		< 0 = 0
Dry matter intake (corrected dry matter intake minus delivery of dry matter in feedingstuff) - maximum share - minimum share		> 0 < 0
Minimum nutrient need covered by synthetic fertiliser (corrected nutrient need minus import of mineral fertiliser)	<,= 0	
Area for crop production	= total arable land	
Area for pastures and grazings	= total grassland	
Set Aside (obligatory, minimum and maximum)	=, > or < policy objective	
Quotas (milk and sugar)	<,= quota	
GHG emission abatement (methane and nitrous oxide)	<,= policy objective	<,= policy objective

These restrictions are of great importance for the construction of the MACCs since they have to be fulfilled at every point of it. As an example, the introduction of an emission abatement target in a region where the constraint on ‘minimum nutrient need covered by synthetic fertiliser’ is binding might lead to a depreciation of manure and indirectly to a drop in animal production since (1) manure is only applied so that the minimum application rate for mineral fertiliser is fulfilled and (2) crop activities making use of this minimum fertiliser amount have to remain in the regional production program[67].

5.4 Constructing marginal cost curves for emission abatement in CAPRI

5.4.1 A multi-gas strategy: the use of global warming potentials

For the construction of MACCs, different theoretical approaches can be adopted: selected abatement policy instruments on a *single gas* (e.g. standard on methane emissions), a *single source* (e.g. tax on nitrous oxide emissions from synthetic fertiliser application) or a *single region* (e.g. standard for a sensitive area). These would give different MACCs as a result since a different emission coverage is in each case represented. Some of these targeted options have been addressed and implemented in the model but will not be subject of further analysis in this study (McInerney et al., 2004)[68].

An alternative and more general approach is to consider global warming potentials, i.e. carbon dioxide equivalents, as measurement units. By doing this, a uniform abatement policy can be modelled, all gases and sources being affected at the same time. A ranking for these can be immediately derived: on the one side, some sources have a higher share of total emissions (e.g. enteric fermentation) and, on the other side, some gases have a higher conversion factor than others (e.g. nitrous oxide). It is important to take these relationships into account when looking at results.

5.4.2 Technical solution

As already mentioned, the MACC is constructed by plotting the shadow values faced by the regional supply models against different abatement targets. This restriction ensures that emissions of the current production program do not exceed the regional emission standard. Technically, marginal abatement costs are calculated by introducing uniform emission standards as constraints in the regional aggregate programming models and by reducing them stepwise (Pérez, 2004b). The following equation summarises this analytical approach:

$$\begin{array}{l} \max \quad \pi = f(x) \\ s.t.\ g(x) \le G \\ e(x) \le E \end{array} \quad \Leftrightarrow \quad \frac{\partial \pi}{\partial x} = 0 = \frac{\partial f}{\partial x} + \lambda \frac{\partial g}{\partial x} + \mu \frac{\partial e}{\partial x} \qquad (5.9)$$

Where:
μ = shadow value of the emission abatement target
E = upper bound on emissions
λ = shadow value of the other restrictions
G = allowed level of all other constraints in the model

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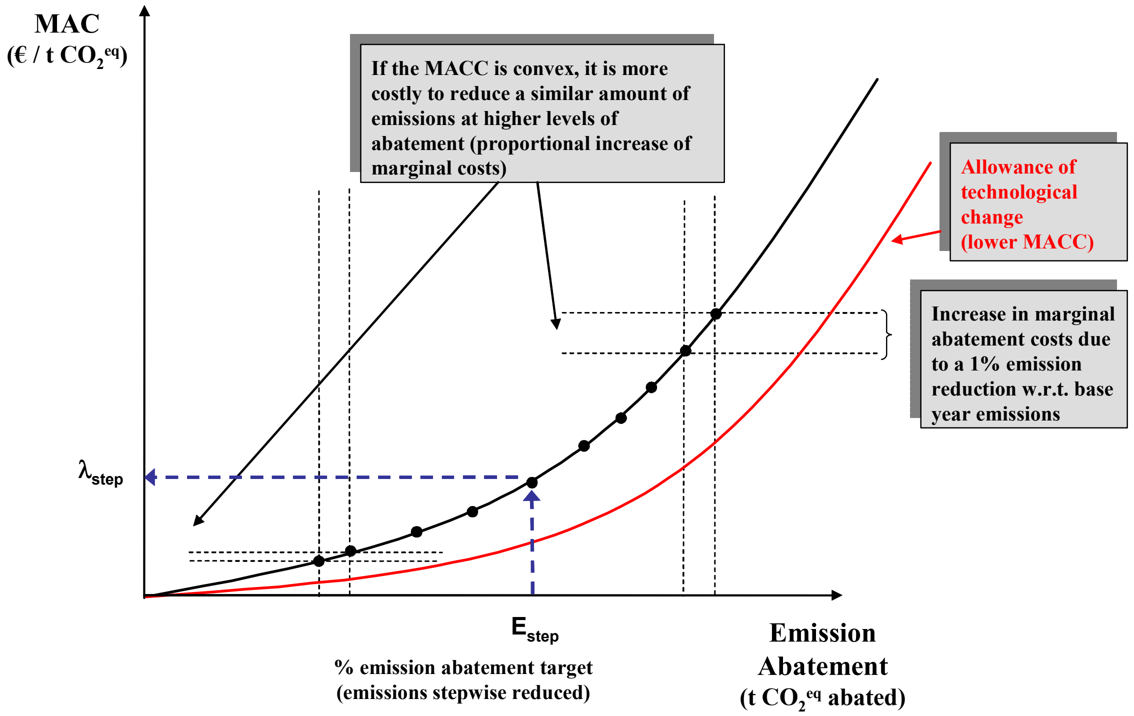
[67] A minimum share of mineral fertiliser on total fertiliser need is introduced in order to calibrate the model to the fertiliser consumption statistics published by FAOSTAT in the base year.

[68] Preliminary results for this paper were presented by the author of this thesis in the first CAPRI-DynaSpat Training Session (Zurich, 6th-9th September 2004). Support on modelling issues was also given along the project.

The shadow value of the emission constraint (μ) is equal to the regional marginal income loss at the restriction level. By repeating this optimisation problem several times for different emission standards, a series of points forming the shape of the MACC can be obtained.

The MACCs are therefore calculated iteratively in CAPRI for Nuts 2 regional units. These emissions and costs can later be consistently aggregated at regional (Nuts 1), Member State or European level. The main determinants driving the level of GHG emissions are the production level of each activity (emissions partially coupled to production), the time perspective for global warming potentials (conversion factor to carbon dioxide equivalents) and the production intensity (restricted yield variation as a technological option). The theoretical shape of the MACC is shown in figure (15):

Figure (15) Information flows used in the calculation of regional emissions



Source: modification of Pérez, 2003, p. 10.

As graphically explained in figure (15) every positive environmental target (emission abatement) is linked to a positive shadow value. In the initial situation, the shadow value would be zero since no abatement is taking place (constraint not binding). The function is therefore constructed as a succession of equilibrium points.

In the graph it can be observed that higher emission abatement levels lead to higher shadow values (the function is upward-sloping)[69]. In the previous figure, higher changes in marginal abatement costs per abated unit are plotted (higher differences). Nevertheless, convexity is not, a priori, a requirement of the function. In section 5.5.2, this is analysed with selected regional results.

Additionally, in figure (15), the possibility of technological change is presented as a way of introducing a certain degree of flexibility in the system, allowing the MACC to shift to the right (a lower marginal cost can be achieved for a certain emission abatement level). This is taken endogenously into account in the present modelling approach, through the allowance of some yield variation in the production process.

5.5 Analysis of Results

5.5.1 Assumptions

In this chapter regional MACCs for the European agricultural sector are estimated for the year 2001. This builds upon the calculation of GHG regional emission inventories from chapter 3. All regional supply models are solved ex-post several times with an incremental emission reduction (as a percentage of individual base year emissions) in order to cover a feasible range of abatement objectives[70]. The simplified approach taken here is shown in figure (16):

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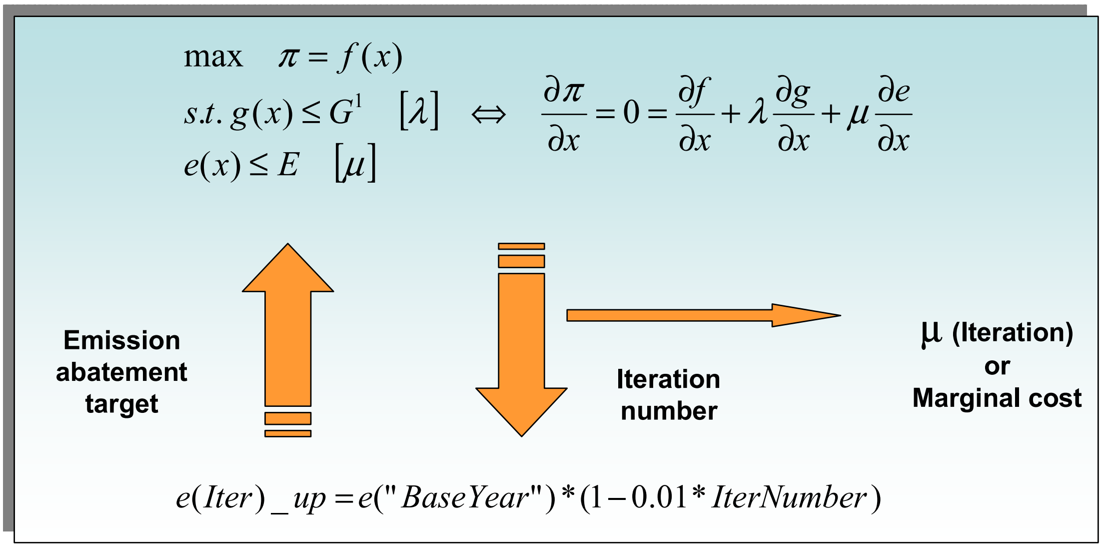
[69] Please note that the MACC can be indistinctly presented as a downwards or upward-sloping curve depending on the variable presented on the x-axis (emissions or abatement respectively).

[70] Further policy analysis with consideration of endogenous price effects (market module) is carried out in chapter 7.

Figure (16) Iterative procedure followed for the calculation of marginal abatement cost curves



[1] G summarises all other restrictions in the model (see table (19)).

In the optimisation model an upper limit on emissions is introduced for each iteration ($e(Iter)\_up$). This emission restriction is calculated by reducing stepwise base year emissions by 1 %. All the equations in the supply component of the model are solved each time and the shadow values for the different regional models stored as points of the MACC.

5.5.2 Marginal abatement cost curves

Each point of the MACC represents the implementation of a single uniform regional emission standard based on 2001 emissions (base year). Although the KP prescribes emission reductions with respect to 1990 values, this base year is not chosen in the current approach for two reasons: (1) no information gain is achieved for the calculation of MACCs or technical comparison between abatement instruments and (2) for the agricultural sector less reliable information would be obtainable since the complete EAA from EUROSTAT (economic information for agricultural activities) are only available from 1994 onwards.

In figure (17) MACCs for EU-15 Member States are presented. For its calculation, the model is iteratively solved for single Nuts 2 regions (15 iterations) and regional results are aggregated[71]. In the last step, a 15 % reduction is achieved[72].

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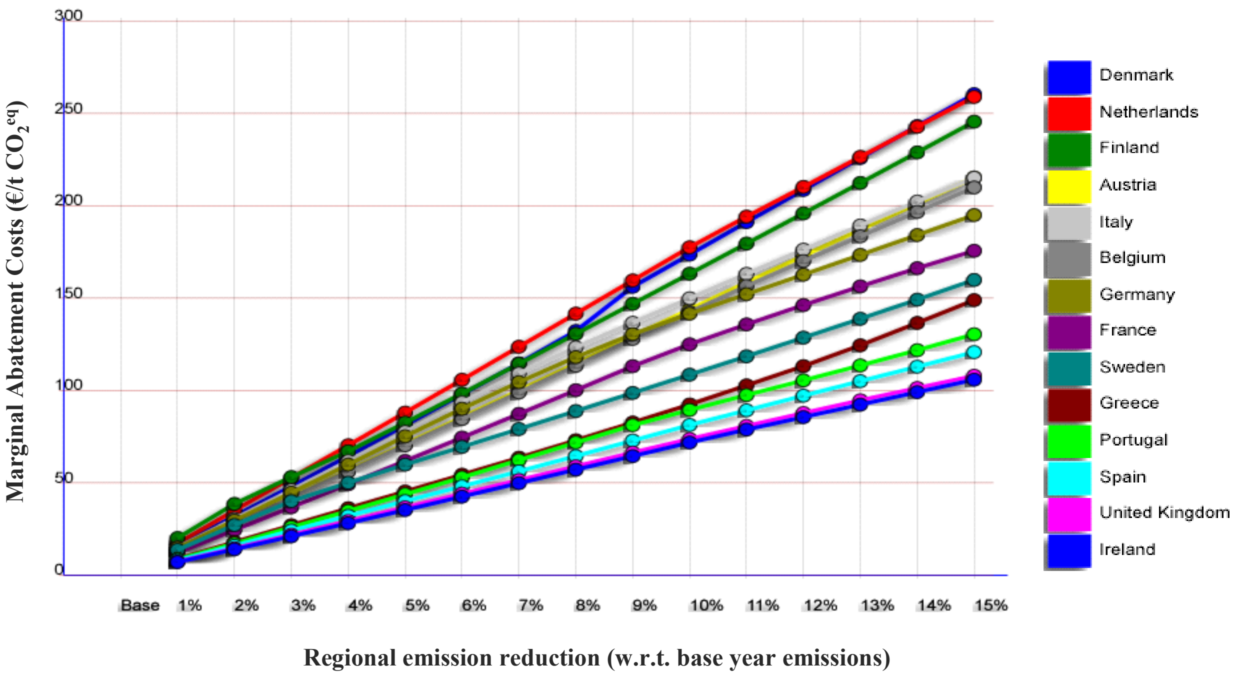
[71] For the aggregation of shadow values or, in general, prices at an upper regional level (e.g. variable transaction costs or permit prices in chapter 6) GHG emissions are used as weights: sum of all shadow values of the

Figure (17) Marginal abatement cost curves for EU-15 Member States



Source: own calculations; modification of Pérez, 2003; year 2001; Luxembourg is modelled together with Belgium.

Note: MACCs estimations for Nuts 2 regions are compiled in Appendix 8.

The previous figure clearly shows that Member States face quite different MACs for a similar abatement objective. For an 8 % emission reduction, MACs vary between 57 € for Ireland and 143 € for the Netherlands. For a 15 % emission reduction, MACs vary between 106 € for Ireland and 260 € for Denmark. Economically optimal adjustment in the regional models to the singular emission targets is achieved through production substitution and yield shifts. Since the model is calibrated to an observed regional production-mix in the base year, an optimum can only be reached through an expansion or contraction of these endogenous productive activities such as to fulfil the emission abatement goal and the rest of the restrictions in the model.

Member States such as Denmark and the Netherlands have noticeably higher estimated MACCs than the rest. This is due to their specialisation in intensive crop production, with high mineral fertiliser application per hectare together with high-yield cattle production processes. High income per hectare of Grandes Cultures is observed in these countries (revenue plus premiums minus costs), mainly due to yields above the EU average. But at the same time N_2O emissions

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sub-regional models in a region multiplied by its CO_2^{eq} emissions divided by total CO_2^{eq} emissions in this region. As already mentioned, the minimum regional unit used in the model is the EUROSTAT Nuts 2 definition.

from synthetic fertiliser application are also quite high on a hectare basis since high yields are coupled to high fertiliser application, resulting in relative low income per ton of CO_2^{eq} for these activities (see examples in table (20)). This leads to higher production losses for these activities compared to animal activities (in terms of income per emission unit)[73].

The case of Finland is a singular one since it produces many ‘other animals’ (e.g. reindeer), which are not endogenously covered by the model but are an important income source. Furthermore, it has a low share of cereals in total area due to weather conditions. The supply effects of emission abatement concentrate, therefore, on a lower number of highly profitable activities, especially on cattle production (with quite high specific national premiums, as shown in table (20)). Income losses per abated emission unit are therefore higher in Finland than in other countries.

Table (20) Results for selected Member States and activities: 85 % regional uniform emission standard

	Soft Wheat					Dairy cows high yield				
	EF_{N2OSYN}	*Rev/ha*	*Prem/ha*	*Inc/ha*	*Inc/t CO_2^{eq}*	*EF_{CH4EN2}*	*Rev/hd*	*Prem/hd*	*Inc/hd*	*Inc/t CO_2^{eq}*
Netherlands	1240.3	784.9	365.4	507.4	**0.409**	3363.3	3939.7	27.4	2226.9	**0.662**
Finland	781.0	414.3	211.4	327.0	**0.419**	3373.2	3904.2	894.8	2217.4	**0.657**
United Kingdom	903.0	850.1	371.1	592.2	**0.656**	3164.7	2893.8	17.6	1026.7	**0.324**
Spain	545.4	405.9	145.9	391.5	**0.718**	2908.7	2663.1	10.8	1606.0	**0.552**
Portugal	213.9	179.2	185.3	272.6	**1.274**	3012.6	2959.7	9.7	1250.2	**0.415**

Source: own calculations, year 2001.

EF_{N2OSYN} = emission factor for N_2O emissions from synthetic fertiliser application (tonnes of CO_2^{eq} per hectare or head)

EF_{CH4EN2} = emission factor for CH_4 emissions from enteric fermentation, IPCC Tier 2 method (tonnes of CO_2^{eq} per head)

Rev/ha, Prem/ha, Inc/ha = revenues, premiums and income per hectare respectively (€)

United Kingdom, Ireland, Spain and Portugal are able to contribute to the uniform emission standard at rather low costs. Crop production in UK and Ireland falls less sharply than in other countries as lower fertiliser application rates and higher income per emission unit are observed

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[72] Please note that a 15 % abatement target is equivalent to a 85 % emission standard. These two notions will be indistinctly used in this and the following chapters.

[73] In the model it can be observed that an x % increase in crop yields is linked to a much higher increase in emissions per hectare than a similar increase in animal yields with respect to emissions per head. In other words, it is more efficient in terms of GHG emissions to move to higher yield animals.

(see table (20)). A substitution of low-yield by high-yield dairy cows develops as the most efficient alternative (less GHG emissions per liter of milk). In general, income per head is lower in these two countries than in the previous mentioned examples. Spain and Portugal concentrate production losses on low income activities such as sheep and low yield cattle herds. In these cases, production is only maintained to receive financial support so that considerably lower regional income losses are suffered at the margin. Additionally, synthetic fertiliser application rates are quite low so no important activity cross-effects are observed.

Technically observed, MACCs have to be upward-sloping since *'a tighter (or additional) binding constraint is always linked to a higher (or additional) positive shadow value'* (model construction requirement)[74]. This can also be seen from an economic perspective. The abatement cost curve (ACC) is convex upward-sloping if higher abatement is linked to proportionally higher income losses. This is the case in the presented modelling exercise since income is maximised in the starting point and every additional abatement effort shifts income proportionally further away from the optimum with no abatement. In other words, only 'effective' abatement takes place along the modelled ACC so that the emitter always moves away from its individual optimal production/emission decision. Since the MACC is the first derivative of the ACC, and the derivative of a convex upward-sloping curve is an upward-sloping curve, it can be concluded that the MACC has a positive slope.

However, a priori, nothing can be said about the linearity or non-linearity of these curves. In order to analyse this, it is necessary to avoid aggregation. This is done in figure (18) by focusing on selected Nuts 2 regional supply models:

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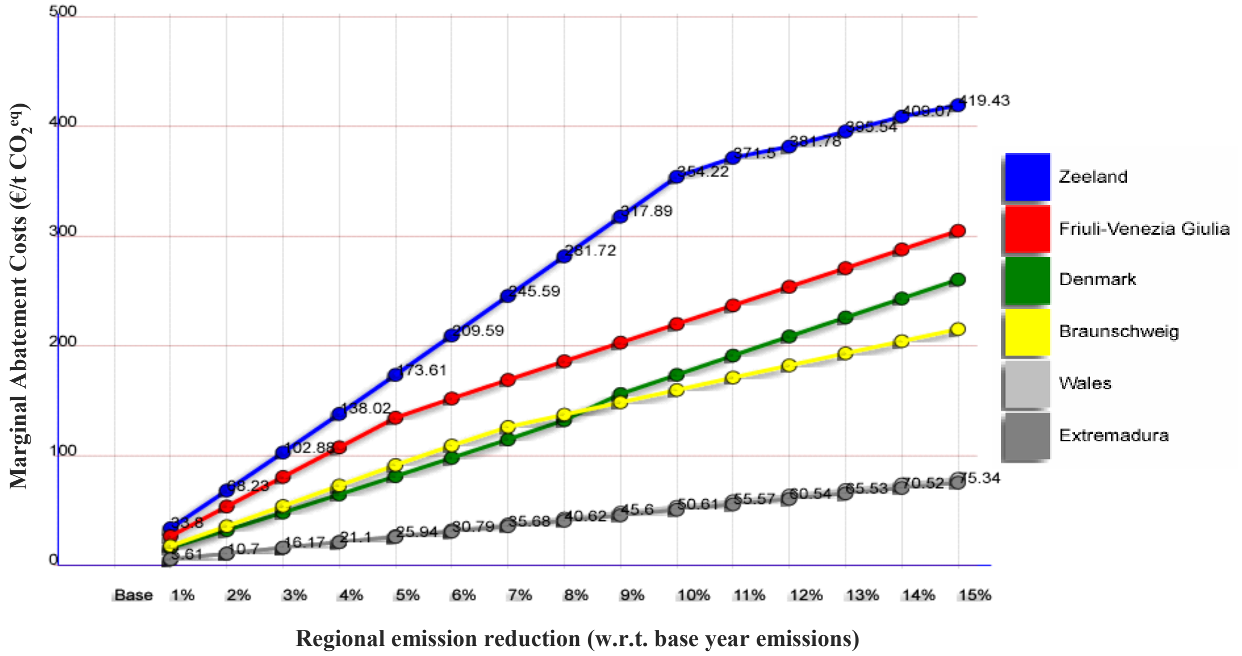
[74] It is possible to make a constraint more restrictive or to introduce an additional emission constraint. In this last case, the additional restriction would get a positive shadow value, which has to be added to the old one in order to get the overall marginal effect on the objective function.

Figure (18) Marginal abatement cost curves for selected Nuts 2 regions



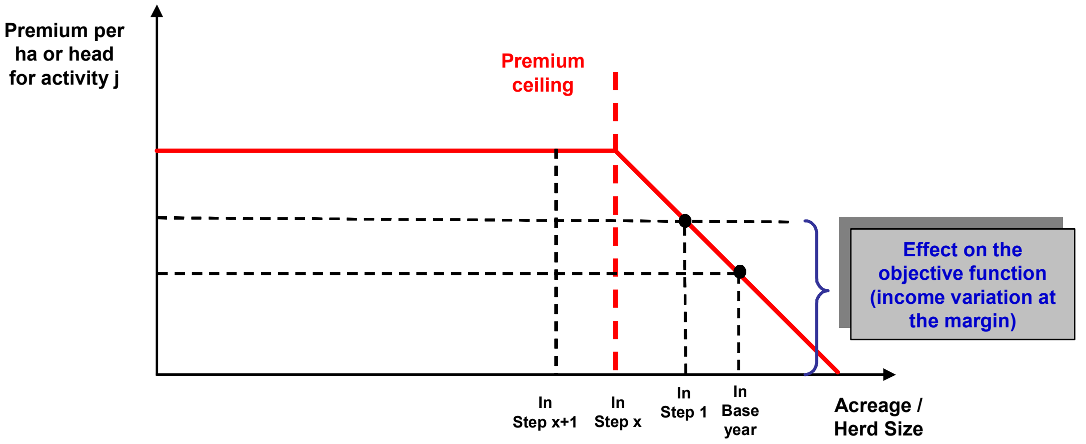
Source: own calculations; year 2001. The EUROSTAT codes for these regions are: Denmark, DK000; Wales, UKL00; Friuli-Venezia Giulia (IT330); Extremadura, ES430; Zeeland, NL340; and Brauschweig, DE910.

The region with the highest income losses for the last abated emission unit under a 15 % emission abatement is Zeeland (NL430), with 419 € per ton of CO_2^{eq}. At the other end, for Extremadura (ES430) just 75 € per ton of CO_2^{eq} are estimated. The MACCs for these regions show convex, concave and linear sections:

- *Convexities*. The MACC for Denmark is *slightly convex* along the whole range of modelled emission reduction levels (not easily observable on the figure). This is also the case for low abatement levels in other regions such as Zeeland (until 10 %), Friuli-Venezia Giulia (until 6 %) and Braunschweig (until 7 %). This corresponds with the ‘expected’ reaction of the economic model: *in order to comply with their individual emission standard the agents exploit first the ‘low-price’ options (production drops first for less profitable activities)*. Since these options become more and more scarce in every step, a higher share of more profitable activities has to contribute to the emission reduction, increasing in this way income losses per abated emission unit. This shape is typically shown in text books (see references in chapter 4).

- *Concavities*. MACCs for Zeeland, Friuli-Venezia Giulia and Braunschweig are, however, *concave* after the abatement levels mentioned in the previous paragraph, i.e. the upward movement of the MAC diminishes. This happens only at certain points[75] and the effect is mainly provoked by the explicit introduction of maximum guaranteed areas for Grandes Cultures premiums in the model[76]. In the base year situation, these regions receive direct payments per activity above a regulated physical or monetary premium ceiling. This implies a shortening of premiums for the affected activities so that the ceiling is not exceeded. By introducing iteratively tighter emission abatement restrictions, some of these activities are reduced and become implicitly higher premiums up to the point where the maximum guaranteed area is achieved (inverse process). After this point, payments per hectare or head do not change anymore and income losses are no longer affected by this variable, making the MACC flatter. This is shown in figure (19).

Figure (19) Combined effect of premium ceilings and emission abatement on agricultural income at the margin



In Zeeland, for example, the maximum guaranteed area for Grandes Cultures in 2001 is lower than the number of observed cropped hectares for these activities so that cereal premiums are linearly cut in the model to avoid an overshooting of the ceiling. However, at the 11 % emission abatement objective the area limit is reached and no further premium losses are suffered at the margin[77].

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[75] Actually convexity is the general case along the optimality path followed by the MACC. Concavities are only found at certain points, where the slope of the objective function abruptly drops.

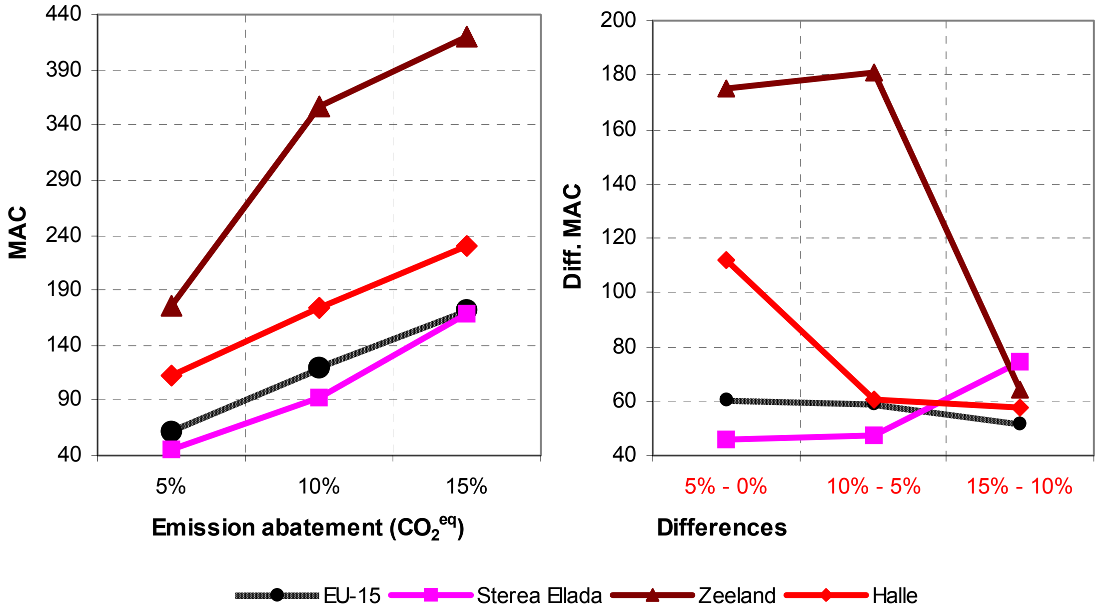
[76] Grandes Cultures are: soft wheat, durum wheat, barley, rye, oats, other cereals, maize, sunflowers, soya, pulses and maize for fodder.

[77] A further marginal effect on the objective function can be caused by activities falling to lower bounds (close to zero). In the case of Zeeland, suckler cows and heifers almost disappear after a 10 % emission standard. The variable in the model (number of animals in this case) might become in this case an increasing non-zero marginal value, so that an additional 'quota-effect' appears in the model. This effect is neglectable when aggregated over activities at lower levels of abatement (until 40%-50%) but should be considered in more radical scenarios and added up to the marginal value of the emission restriction.

- *Linearities*. For Extremadura and Wales, MACCs follow a more or less linear pattern. This is due to no big income differences between activities. Substitution effects play therefore a less important role in these regions.

The aggregated observed effect is a convex section for low emission abatement levels followed by concavity afterwards. This is reflected for the EU-15 by an ‘S-shaped’ curve with a convex course until the 8 % abatement level. In figure (20), MAC differences are shown for the EU-15 and selected regions, as an indicator for convexity or concavity.

Figure (20) Marginal abatement cost curves and differences for selected Nuts 2 regions



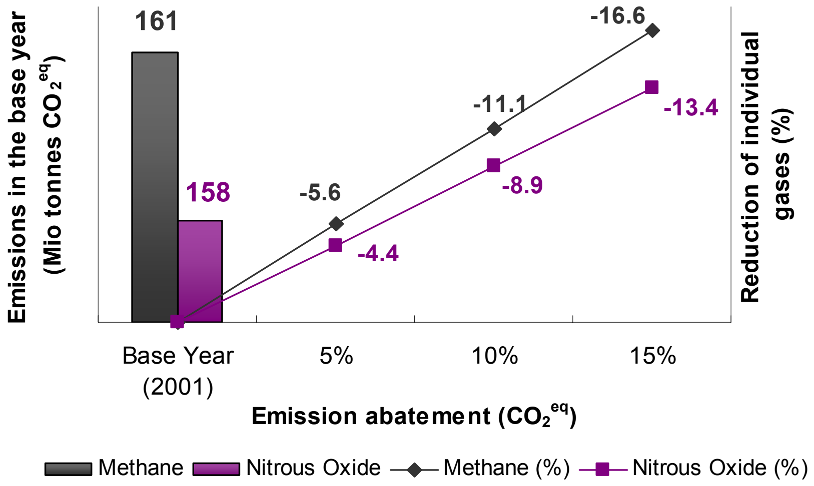
Source: own calculations; year 2001. The EUROSTAT codes for these regions are: Sterea Ellada, EL240; Zeeland, NL430; and Halle, DEE20.

In figure (20) it can be seen how MACs proportionally increase for Zeeland between a 5 % and a 10 % emission abatement. However, the upward movement of the MACC slows down between 10 % and 15 %. The MACC for Sterea Ellada is completely convex (at least up to a 15 % emission abatement) and concave for Halle. For an explanation of these shapes, see previous analysis at Member State level.

5.5.3 Evolution of single greenhouse gases and emission sources

As analysed in the previous section, the implementation of different emission standards has important implications in the optimal response of polluting activities at the regional level, depending on the income distribution across them. These effects can also be indirectly observed on the development of GHGs and emission sources. With help of the following figures these issues are briefly analysed:

Figure (21) Evolution of individual gases for different emission abatement targets (average for EU-15)



Source: own calculations; year 2001.

Figure (21) shows the reduction paths of nitrous oxide and methane emissions for a 5 %, 10 % and 15 % abatement target (CO_2^{eq}). Methane clearly follows a higher trend than nitrous oxide, indicating that animal activities contribute more to the emission reduction than crop activities (with the exception of rice, methane is only produced from animals). The distribution of the economic burden can be observed across emission sources in figure (22) and figure (23):

Figure (22) Evolution of individual nitrous oxide sources for different emission abatement targets (average for EU-15)

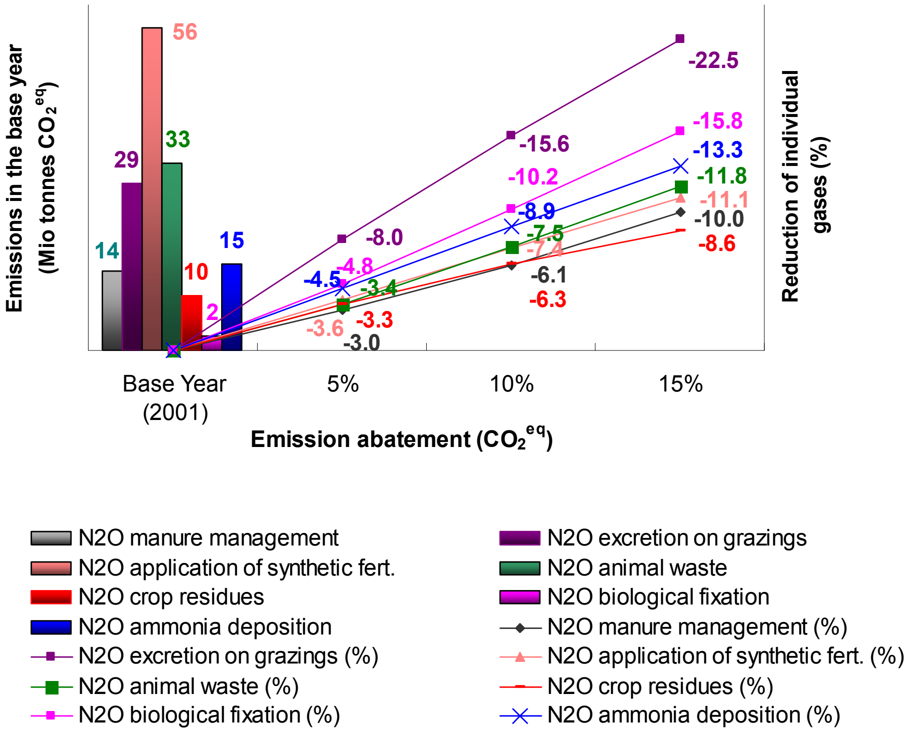
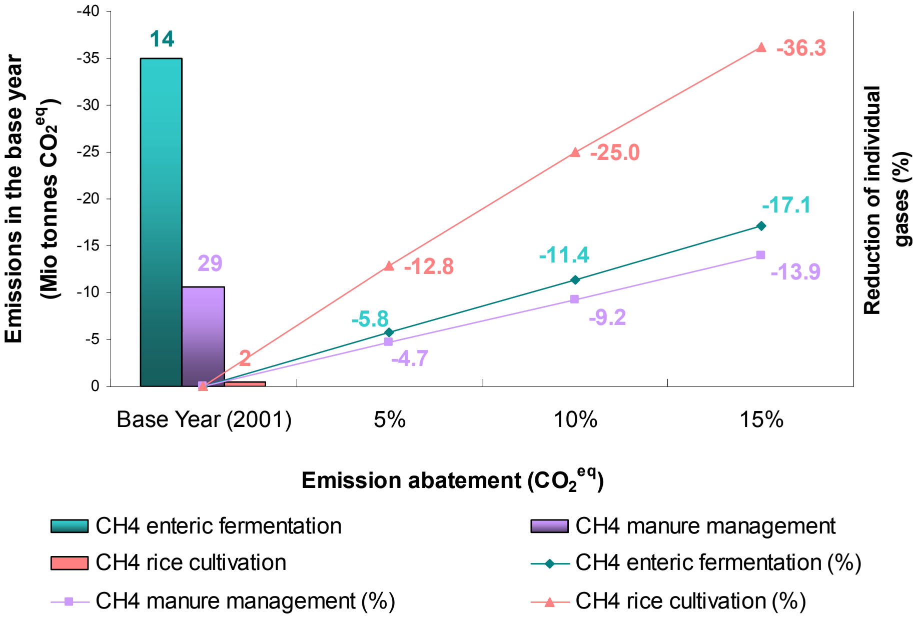


Figure (23) Evolution of individual methane sources for different emission reduction targets (average for EU-15)



Source: own calculations; year 2001.

In the previous two figures it can be observed how emission sources linked to specific low-income activities such as manure excretion on grazings, biological fixation or rice cultivation, are more affected than the rest. Nitrous oxide emissions from excretion on grazings are reduced the most. They are mainly linked to suckler cows and sheep production, the latter being a low income production activity. N fixation and rice cultivation are respectively linked to the cultivation of pulses and rice. These sources bring, however, a quite small abatement potential in Europe.

From this analysis of sources it can also be seen that methane is reduced more than nitrous oxide, indicating a higher burden on animal activities at the optimum. However, this does not give any information on how the income losses are distributed between crop and animal activities. This problem is implicitly analysed in chapter 7, where different abatement instruments are compared including price effects.

5.5.4 Comparison with results from other studies

In Europe there has been almost no work done on the estimation of costs of GHG emission abatement and most of what has been done has been focused on sectors other than agriculture (POLES, PRIMES and EPPA-EU models). Whereas POLES and PRIMES are partial equilibrium models and concentrate on the energy sector, the EPPA-EU is a general equilibrium model and estimates marginal emission abatement costs for the main sectors of the economy: electricity, transport, energy, other industries, households and agriculture (Viguier et al., 2001, pp. 20-24). It also estimates ‘shadow prices for constraints on emission reductions’ but results are not directly comparable with the current study since agriculture is not disaggregated.

Nevertheless, some estimates on marginal emission abatement costs from agriculture have been calculated with the AROPAj model (De Cara, Jayet, 2001). Although only a limited number of emission sources are considered, MACs for different emission reduction levels (5 to 20 %) are given for single Member States and can be easily compared with the results of this study. These estimates are presented in table (21):

Table (21) Comparison of marginal abatement cost estimates for EU-15 Member States

	(Pérez, 2004)				(De Cara, Jayet, 2001)			
	GWPs[1]	MAC$_{5\%}$	MAC$_{10\%}$	MAC$_{15\%}$	GWPs	MAC$_{5\%}$	MAC$_{10\%}$	MAC$_{15\%}$
EU-15	**319.3**	***60.3***	***119.5***	***171.3***	**224.3**	***150.8***	***227.5***	***280.4***
Denmark	8.2	*81.2*	*173.6*	*260.5*	5.6	*178.3*	*238.4*	*280.0*
Netherlands	15.0	*88.1*	*177.6*	*259.0*	11.0	*325.6*	*445.0*	*546.3*
Finland	3.9	*82.6*	*163.3*	*245.6*	NE	*NE*	*NE*	*NE*
Austria	6.4	*71.1*	*144.0*	*215.3*	NE[3]	*NE*	*NE*	*NE*
Italy	31.0	*77.6*	*150.0*	*215.2*	28.0	*204.2*	*288.6*	*350.3*
Belgium[2]	8.1	*70.3*	*142.5*	*209.9*	6.3	*198.9*	*322.2*	*451.0*
Germany	55.1	*75.2*	*141.6*	*195.0*	34.2	*106.7*	*222.6*	*311.2*
France	79.7	*61.9*	*125.0*	*175.7*	56.8	*114.6*	*171.7*	*216.8*
Sweden	5.5	*59.9*	*108.6*	*159.9*	NE	*NE*	*NE*	*NE*
Greece	7.1	*45.4*	*92.5*	*149.0*	6.8	*133.7*	*208.3*	*224.0*
Portugal	6.2	*43.9*	*89.5*	*130.5*	8.6	*84.0*	*140.9*	*187.9*
Spain	35.3	*40.2*	*81.4*	*120.8*	18.0	*177.9*	*219.6*	*267.6*
United Kingdom	42.5	*36.7*	*73.8*	*108.0*	34.5	*161.8*	*261.1*	*316.3*
Ireland	15.2	*35.3*	*71.9*	*105.9*	14.6	*91.7*	*183.4*	*196.3*

Source: own calculations and De Cara, Jayet, 2001, p. 13.

[1] Initial emissions calculated in the model (Mio tonnes of CO_2^{eq}, three-year average 2001); not corrected to match NGHGIs (see chapter 3).

[2] In the CAPRI model Luxembourg is modelled together with Belgium. Results from AROPAj are aggregated for comparison.

[3] NE = data not estimated.

Although this benchmark study uses the year 1998 as reference for the calculations, a systematic sub-estimation of GHG emissions is observed (30 % on average)[78]. MACs are, however, much higher than those estimated with CAPRI. These two effects might be interlinked since emission abatement on a smaller emission basis (emissions in the base year period) can be more costly in terms of income losses. This allows, together with a smaller coverage of sources, less flexibility in the modelling system to react to the constraint. In other words, emitters have a much lower range of production possibilities to comply with the emission restriction[79]. The ordering of countries follows with some exceptions a similar pattern in both modelling exercises (e.g. Netherlands, Belgium and Italy face costs above the average and Ireland and Portugal below).

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[78] Emissions are reported to be even higher in 1998 than in 2001 (2.4 % for methane and 15.4 % for nitrous oxide, according to the EEA data service).

[79] It is, however, not easy to analyse these differences since '*different models have different assumptions*' and no comprehensive documentation is available.

5.6 Conclusions

In this chapter, MACCs are constructed by plotting the shadow values faced by regional supply models for different emission abatement targets. Differences found in the course of MACCs for Nuts 2 regions in Europe underline the fact that a ‘non-uniform’ emission abatement strategy might be profitable in agriculture. This could be achieved by the introduction of market-based abatement instruments which are able to differentiate between abatement possibilities in each region. The idea behind this statement is that certain regions, especially those with low income per emission unit, are able to contribute to an emission abatement objective at rather low costs. This is tested in the following chapter with the direct modelling of tradable permits and their economic effects compared to a uniform emission standard.

CHAPTER 6 Modelling a Market of Tradable Emission Permits

> *"Trading for the sake of trading is a 'non-starter' – to be effective it must result in real, tangible changes" (Douglas Russell, Global Strategies International).*

6.1 Introduction

In previous chapters a way of estimating GHG emissions based on European activity data statistics has been presented and the introduction of emission standards for the construction of marginal abatement cost curves methodologically explained. Ex-post results on GHG emission inventories have also been thoroughly analysed for the EU-15 from a regional perspective. Furthermore, the main differences between emission abatement instruments have been described from a theoretical perspective. In this chapter, the information on MACs is applied to the explicit modelling of tradable emission permits within the CAPRI model. For this purpose, an emission trading module with the following characteristics is introduced: (1) cap and trade system, (2) 'grandfathering' of permits, (3) unrestricted trade between Nuts 2 regions and (4) direct modelling of transaction costs. This 'emission-capping' approach allows for direct comparison with the results obtained in chapter 5 with the application of uniform emission standards.

In section 6.2 the European Climate Change Program (ECCP) and the Emissions Trading Directive are highlighted. In section 6.3, the proposed modelling exercise is designed, by taking into account the current legal context. The analytical approach followed is then described in section 6.4 and results presented in section 6.5.

6.2 Current legislation

6.2.1 Climate policy in the European Union

The control of global warming emissions in the EU is a fairly new issue. From a historical perspective, three regulatory phases beginning in the early 90's can be defined.

In December 1991 the European Commission presented to the Council a 'community strategy to limit carbon dioxide emissions and to improve energy efficiency', based on the premise that reducing energy demand by increasing energy efficiency and promoting fuel-switching was the best way to reduce CO_2 emissions (Commission of the European Communities, 1992). Common action in this area was promoted through new research projects and programmes in specific areas (automobile industry, energy and renewable products). Within the following two years, the European Union adopted a monitoring mechanism on anthropogenic CO_2 and other GHG emissions not controlled by the Montreal Protocol (Council of the European Communities, 1993, **Dec. 1993/389/EEC**)[80] and approved the 'ultimate objective' of the UNFCCC (Council of the European Union, 1994, **Dec. 94/69/EC**). With these two documents, the main international agreements towards the reduction of GHG emissions were adopted by the European Community and its Member States. Additionally, the EU went somewhat further and, in 1996, launched a directive concerning integrated pollution prevention and control which laid down measures designed to prevent or reduce emissions in the air, water and land from certain polluting activities (Council of the European Union, 1996, **Dir. 96/61/EC**). This directive defined a framework for pollution prevention and control through which emission permits could be issued.

In 2000, in a second regulatory stage, the Commission approved the ECCP with the goal of identifying and developing all the necessary elements of a common strategy to implement the KP. It was based on two pillars, a *Green Paper on emission trading* and the *development of targeted measures to reduce emissions from specific sources*. The Green Paper on emission trading was published by the Commission as preparation for the ratification of the KP (Commission of the European Communities, 2000b). It was conceived to be an 'informative' and at the same time 'analytical' tool to support the future involvement of the Community in this area.

Finally, in December 2002, the KP was formally approved by the European Union (Council of the European Union, 2002, **Dec. 2002/358/EC**). With this decision an important step towards action was reached. Member States committed themselves to establish a 'European emission bubble' (foreseen in the article 4 of the KP) by which the obligations contained in the KP for the EU were considered 'internal law' (article 3). In order to achieve this commitment, the European Union was allowed to formulate an internal 'burden-sharing agreement' so that Member States would share their efforts towards the achievement of an overall emission abatement objective[81]. This decision led to the signature in 2003 of the 'emission trading directive'.

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[80] This decision was first amended by **Dec. 1999/296/EC** (Council of the European Union, 1999) and further on replaced by **Dec. 280/2004/EC** (Council of the European Union, 2004a), 'in order to take account of the developments on the international level and on the grounds of clarity'.

[81] The approval of the BSA by the Member States reflects the 'subsidiarity principle' in the Community, i.e. individual emission reduction objectives should be *achievable* for each country and avoid *unduly burdening* of ongoing industrialisation efforts by Member States. The Council agreed upon the contributions of each

6.2.2 The emission trading directive

In October 2003 the EU adopted a proposal for a directive in 'CO_2 emission trading' to be operable by January 2005 (Council of the European Union, 2003, **Dir. 2003/87/EC**). This directive established a scheme for trading GHG emission allowances within the EU in order to promote reductions of GHG emissions in a cost-effective and economically efficient manner (article 1). The following characteristics can be briefly highlighted:

- It applies to a list of energy and industrial production activities and covers all GHGs included in Annex A of the KP.[82] Nevertheless, according to the categories of polluting activities defined in Annex 1 of this directive, only CO_2 emissions are effectively covered by the scheme.

- It defines a coordinated Emission Trading Scheme (ETS) over all Member States. EU-wide trading instead of trading at the individual Member State level was a recommendation included in the Green Paper on emission trading (based on estimates from the PRIMES Model).

- It foresees an implicit voluntary opt-in for other sectors through possible amendments (article 30). Whereas trading is first applied only to industrial and energy-producing activities, other sectors might be included in the future *with a view to further improving the economic efficiency of the scheme*[83]. This might be interesting for the agricultural and forestry sectors.

- The issuing of permits must be coordinated with the existing trading schemes, such as the provisions included in the Directive 96/61/EC, where thresholds for certain polluting activities are defined and permits issued by individual Member States. The coordination of ETSs will be quite important in the future since the CDM and JI mechanisms will also imply a parallel issuing of permits[84].

Member State to the overall 8% reduction commitment at its meeting of Environment Ministers of 15-16 June 1998 in Cardiff (Commission of the European Communities , 2001, p. 3). The Council Conclusions set out the commitment of each Member State and state that the terms of this agreement will be included in the Council Decision on the approval of the Protocol by the European Community.

[82] For a list of GHGs see Appendix 4.

[83] The list of activities included in annex I of the directive might be subject to future revision.

[84] The so-called 'linking directive' (Council of the European Union, 2004b, **Dir. 2004/101/EC**) amends this 'emission trading directive' and regulates the use of Certified Emission Units (CERs) from CDM projects and Emission Reduction Units (ERUs) from JI projects (see section 2.2.3 in p. 17). These CERs and ERUs may be allowed by a Member State only up to a certain percentage of the total allocation of permits to each installation. It

- For the two defined commitment periods, 2005-2008 and 2008-2012, each Member State shall develop a national plan stating the total quantity of allowances to allocate. Among other requirements, this plan should: (a) take into account the proportion of overall emissions that these allowances represent in comparison with emissions from sources not covered by this directive, (b) be consistent with the emission reduction potential of activities covered (annex 1 of the directive), (c) facilitate the fulfilment of the Community's commitments and (d) be consistent with other legislative and policy instruments of the Community (annex 3). The allocation method is mainly 'grandfathering' with a minimum of 95 % for the first commitment period and 90 % for the second[85].

- Member States shall ensure that emitters *surrender* before the 30th April of each calendar year a number of allowances equal to the total emissions produced during the preceding year and that these are subsequently *cancelled*.

6.2.3 Cases of implementation

Trade of allowances has been already implemented in Europe for other environmental problems. Examples are quotas for ozone depleting substances (Montreal Protocol), fish catch quotas (Common Fisheries Policy) and milk quotas (Common Agricultural Policy). In all these cases, a certain degree of transferability has been introduced (Commission of the European Communities, 1992).

6.3 Designing a market of emission permits in the European agricultural sector

One of the objectives of this study is to design a feasible implementation strategy for a market of emission permits in European agriculture and simulate its economic effects within a regionalised agricultural sector model[86]. Since a feasible system must build on information that is easy to obtain, regional inventories for GHG emissions from agricultural sources in the year 2001 have been calculated based on IPCC emission factors and activity data from public European statistics (see chapter 3). This is the basic information needed in a market of emission permits where GHG

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has to be specified in its national allocation plan and must take place through the issue and immediate surrender of one EU allowance (one EU allowance against one CER or ERU).

[85] The costs of free allocation are assumed by the Commission in order to secure support from the industry, or at least to limit the degree of opposition (Convery et al., 2001, p. 12).

[86] In this section farms, agricultural firms and regions might be used indistinctly in some theoretical explanations. It is important to notice that in the model Nuts 2 regions and not agricultural firms are the agents interacting in the market of emissions. However, each region is a consistent aggregation of individual farms so that the behavioural response is the same.

emissions are replaced by 'emission rights' on a one-to-one basis[87]. Moreover, the proposed ETS is intended to be in line with the current legislation, mainly the previously described 2003/87/EC emission trading directive.

6.3.1 Allocation of allowances

There are two possible permit allocation systems: auctioning and grandfathering. The emission trading directive and several examples of quota trading (e.g. milk quotas in Denmark) have been based on a distribution of permits free of charge and linked to historical emission records *(grandfathering)* This system presents some equity problems (who has the right to pollute), efficiency problems from the point of view of the public sector (revenues from 'auctioning' are not achieved) and might prevent newcomers from entering the market since they do not have historical emission records. Nevertheless, 'grandfathering' is defended on grounds of acceptability and low transaction costs.

Following this trend, an emission trading market based on grandfathered allowances is proposed in this study for European agriculture. Agricultural producers would obtain, based on historical records, the 'right' to release a certain amount of GHG emissions[88]. The number of permits needed in the reference period would depend on various factors: the production-mix, the technology chosen (e.g. production intensity) and specific emission factors dependent on the geographical situation (climate region) and type of management system selected. A simple procedure of calculating the allocation of emission permits to a single firm in the reference period is shown in figure (24).

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[87] *Allowances*, *permits*, *certificates* or *rights* are used as synonyms in this study and refer only to GHG emissions (equivalent to 1 ton of CO_2^{eq} emissions).

[88] As already mentioned in the Green Paper (Commission of the European Communities, 1992, p. 9), emissions are linked to sources and are also reported by countries to the UNFCCC. Agricultural firms have several emission sources so that a market of emissions could also be extended to them (usually only a certain amount of activities are comprehended by a source).

Figure (24) Example of a permit allocation for an individual agricultural producer

Activity	Technology	Emission factor* (per activity)		Activity data	GWP	Number of permits allocated / needed
		(Kg Gas per ha, head or tonne)		Ha, head or tonne	(tonnes CO_2^{eq})	(Permits = Mio tonnes CO_2^{eq})
		NO_2	CH_4			
Soft Wheat	*High fertiliser application*	3.5	0	100	1085	1
	Low fertiliser application	2.5	0	0	775	1
Dairy production	*High yield*	4	160	40	4600	5
	Low yield	3	100	0	3030	3
Beef production	*Normal*	0.7	30	40	847	1
Grassland	*Normal*	0.3	0	100	93	0
				TOTAL	**10430**	**10**

Source: based on Pérez, 2004b.

Note: in this table activity data and emission factors are close to reality but symbolic. They might represent any European agricultural firm or regional unit in the current modelling exercise. Emission factors for activities are generally positive but some room could be left for activities which are also able to enhance carbon (e.g. afforestation activities).

* Further differentiation at emission source level could be introduced (in the figure emission factors are aggregated per activity and GHG).

This 'accounting card' would provide the regulatory institution with the necessary information to allocate in the initial situation emission certificates to agricultural producers (*issuing of permits*) and, at the same, time would serve as annual controlling tool for the latter, which would have to take into account the purchasing costs of additional permits in their production plans (*demand of permits*). In order to calculate the total number of certificates, activity levels are simply multiplied with their corresponding regional specific emission factors which should be calculated and published according to IPCC international standards. The accounting process mimics the calculation of NGHGIs and is therefore consistent with the KP reporting obligations (see chapter 3). The additional administrative burden for the agricultural firms would be relatively low, as these data are already needed when asking for direct income support or calculating nutrient balances at farm level.

More agricultural activities, some possibly also acting as sinks (e.g. fallow land), GHGs and management typologies could also be identified in an eventual implementation of this approach (e.g. organic production). However, these technologies will not be considered in the current modelling study due to lack of data[89].

6.3.2 Trade of emissions

The *Green Paper on emission trading* contemplated the possibility of implementing a market of permits at Member State level (decentralised approach) or at EU level, Member States trading with each other (Commission of the European Communities, 2000b). For the energy and industry sectors, the 2003/87/EC Directive approved an EU-wide trading system based on efficiency grounds. For the European agricultural sector, a further disaggregation level is proposed in this study and producers chosen as agents in the market of permits. This is currently translated into an *inter-regional permit trading scheme*[90]. This approach would be easily applicable to the European agricultural sector since similar EU-wide policy schemes have been largely implemented within the current Common Agricultural Policy and information at farm and regional level systematically collected (e.g. nitrate directive or milk quotas). Emission restrictions would be technically incorporated as a quota system on all 'polluting' agricultural activities. Agricultural producers would therefore be allowed to trade allowances with each other in order to minimise their income losses.

This trading system could be slightly modified so that agents other than agricultural firms would be considered. This approach would be based on the current European sugar market regime, where sugar quotas are owned by regional processing firms and not by agricultural firms. Trading of permits could therefore be restricted to some 'bottleneck-agents' in agricultural markets such as slaughtering houses, dairies and co-operatives. *Emission permits attached to animals activities* such as methane from enteric fermentation or manure management could be allocated to regional slaughtering houses and/or dairies and *emission permits attached to land* to local co-operatives, which regulate the flow of cropped products[91]. In figure (25) - *system (1)*, this approach is presented:

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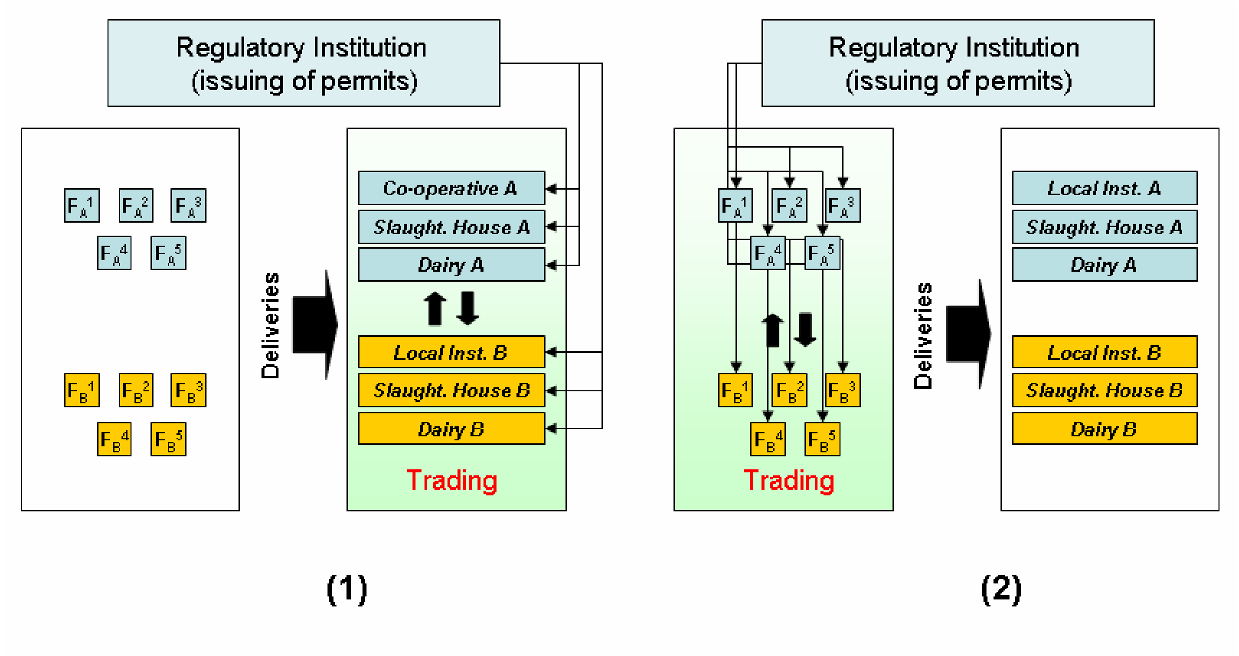
[89] With this approach the existence of additional ways of reducing GHG emissions at farm level is not neglected, e.g. through changes in feeding for ruminants or different ploughing techniques. However, modelling these options is beyond the scope of the current modelling system. Further research in this area was included by the author in the recommendations of the last 'expert meeting on improving the quality of greenhouse gas emission inventories for category 4D' (Joint Research Centre, 2004; URL: http://carbodat.ei.jrc.it/ccu/pweb/leip/home/ExpertMeetingCat4D/index.htm). Moreover, some further discussion on this topic is included in chapter 8.

[90] CAPRI is an aggregated model and Nuts 2 regions the least disaggregation level for the current analysis. Modelling at farm or farm-type level is therefore not considered.

[91] Fixed emission factors based on heads of live animals, tonnes of product and hectares of cropped land.

Figure (25) Alternative emission trading schemes for the agricultural sector



F_X^n = farm in region X

In system (1) five farms, one slaughtering house, one dairy and a co-operative are presented for each of two representative regions (A and B). These farms produce agricultural goods and deliver them to the last three agents (they serve as ‘bottlenecks’ in the system), who receive the permits and are allowed to trade with each other (sugar market approach). The aim of this system is to reduce control costs.

This system presents the problem that not all agricultural products are delivered to the afore-mentioned agents. As an example, many agricultural products are not always distributed through co-operatives and this makes the analysis inconsistent. Furthermore, transaction costs of trading at farm level might not be very high since agricultural firms already deliver the necessary activity data within the current regulations and are subject to periodical controls by CAP authorities. Therefore, direct trading between farms is proposed in this study as a feasible approach. This is shown in figure (25) - *system (2),* where permits are allocated to agricultural firms and trading is allowed between them. The cancelling of ‘used’ emissions from the previous year takes place directly by the regulatory institution.

6.3.3 Internalisation of transaction costs

Transaction costs are those costs that arise from initiating and completing transactions, such as finding partners, holding negotiations, consulting with lawyers or other experts, monitoring agreements, etc. (Coase, 1937). These costs have to be acknowledged in an ETS since a continuous transfer of property rights takes place in such a market. In figure (22), the typical transaction cost components found in a KP emission trading mechanism are listed:

Table (22) Definition of transaction cost components linked to the Kyoto Protocol emission trading scheme

Search costs	Costs incurred by investors and hosts as they seek out partners for mutually advantageous projects (e.g. market brokerage fees)
Negotiating costs	Includes those costs incurred in the preparation of the market (e.g. legal and insurance fees charged for participation in the market)
Monitoring costs	Costs needed to ensure that participants are fulfilling their obligations (e.g. costs of annual verification)
Enforcement costs	Costs of administrative and legal measures incurred in the event of departure from the agreed transaction

Source: modification of Eckermann et al., 2003, p. 2 based on PriceWaterhouseCoopers, 2000

Emission trading also requires the formation of the *necessary institutions*. This is naturally linked to the presence of 'not-negligible' transaction costs, an important issue that has often not been taken into account in policy simulations and might have a significant effect on trading (Kerr, Maré, 1995, p. 23; Stavins, 1995, p. 144). The recently approved directive on emission trading does not include any reference to this issue.

A feasible solution for an emission trading market in agriculture could be based on a central data base listing all permit holders in the scheme and their current permit endowment. An internet portal and a calling centre would be required to manage permit transactions. With this purpose, an internalisation of transaction costs is proposed in this study. This approach is based on stock-market trading, *costs being paid 'per transaction' additionally to the permit price*. This issue is considered to be very important in the current analysis for the sustainability of the scheme to be correctly evaluated.

Transaction costs can be derived from different estimates found in the literature for similar emission abatement projects[92]. Compared to a situation without transaction costs, purchase costs for permit buyers would rise and the trade volume would decrease. Consequently, a uniform permit price equal to the average MAC across firms would not be achieved (Eckermann et al., 2003, p. 3). This issue is further analysed in section 6.5.

6.3.4 Introduction of enforcement penalties

Penalties have to be introduced if emissions outweigh the number of permits allocated to the agricultural firm. Equally, a penalty should be introduced in the case of faulty or missing declarations. The current EETS foresees excess emission penalties of 40 € and 100 € per tonne of CO_2^{eq} for the first and second commitment period respectively (2003/87/EC Directive, article 16).

In a trading system penalties put an upper-limit on permit prices. In the current study, they are not needed since agents behave rationally (no cheating is considered). Model estimates can however be used to establish possible excess emission penalties in agriculture.

6.3.5 Summary of characteristics

To summarise, the proposed ETS for European agriculture considers: (1) a distribution among agricultural producers of permits free of charge and linked to historical emission records *(grandfathering),* (2) inter-regional emission trading at European level, (3) explicit transaction costs and (4) no enforcement penalties.

6.4 Methodological developments: technical implementation of a market for agricultural emissions in CAPRI

6.4.1 The CAPRI Emission Trading Module

The modelling of tradable emission permits has been implemented in the CAPRI model in a separate module since a simultaneous solution for all Nuts 2 regions was technically not feasible. With this purpose, an analogous iterative approach to the one explained in the previous chapter (see figure (16)) is proposed, where the permit trading module endogenously determines which are the optimal emission targets to introduce in the regional supply models. Nuts 2 regions are

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[92] As Stronzik recognizes in the additional report to Working Group 4 (Stronzik, 2001), almost no work has been done in the estimation of transaction costs for ETSs since this is a relatively new instrument. For that reason, estimations for specific evaluated CDM and JI projects are used as proxies in this study.

therefore allowed to trade emission permits which each other, facing different transaction costs depending on trade taking place between national agents (within a Member State) or between agents across borders (within the EU-15)[93]. Moreover, additional costs for setting up the necessary institutions (fix transaction costs) are also included in the decision-taking process.

Technically a two-stage approach is followed. Firstly, *a uniform emission standard is introduced in the regional supply models*, delivering a vector of binding emission targets and a vector of non-negative marginal abatement costs per region (as already explained in section 5.5). Secondly, *an economically optimal distribution of permits is achieved* in a parallel permit trade module. With this purpose, three identities are used:

- ‘Emission targets’ are considered ‘permit allowances’ (1 ton of CO_2^{eq} = 1 permit), with no cost attached to their distribution (“grandfathering” assumed).
- ‘Marginal abatement costs’ equal ‘permit prices’ (MAC = PermitP).
- ‘Marginal abatement cost curves’ are approached through ‘permit demand functions’ (regional supply models behaving as consumers of emission permits).

In the permit trading module regional supply models are allowed to trade their permit allowances between them so that the total amount of permits in the market is held constant and the *total rent from trading* is maximised. At the market clearing point transaction costs should account for the remaining differences in regional permit prices[94]. This can be graphically shown in figure (26) for two regions (analogous to figure (14) in section 4.4.1).

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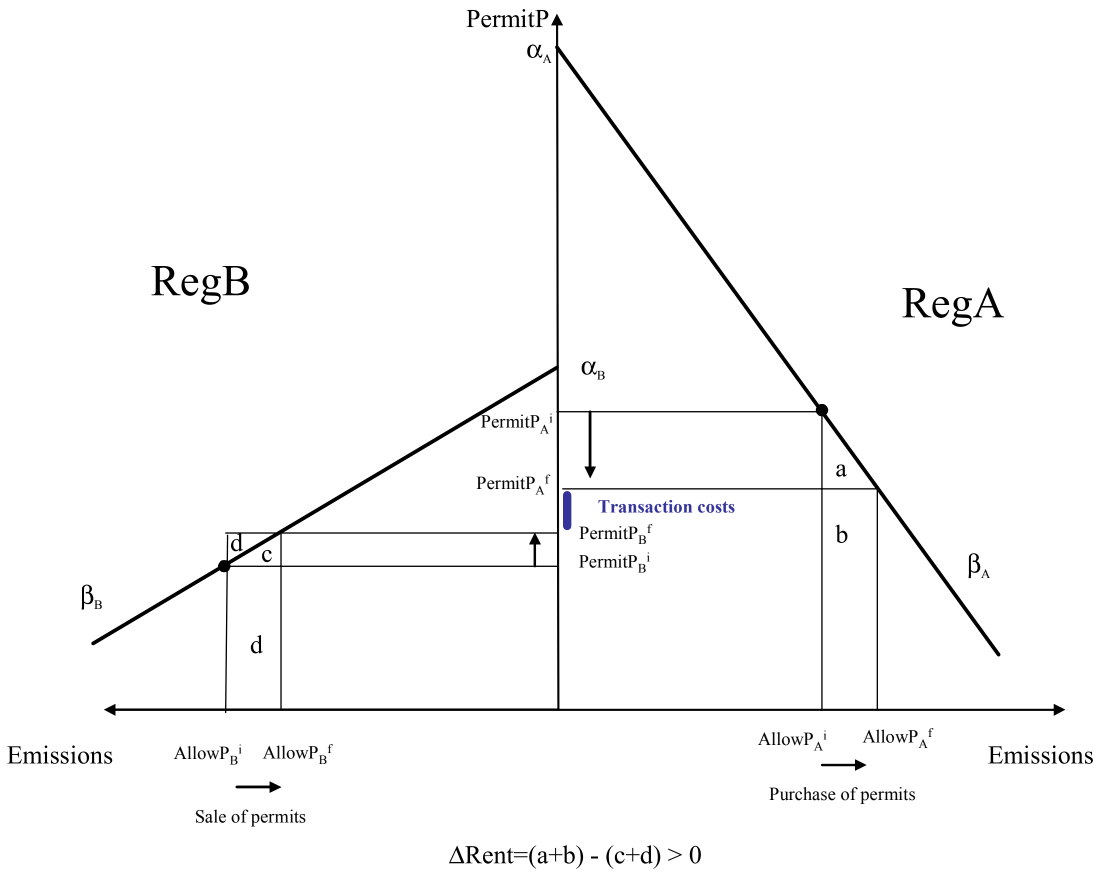
[93] It is considered realistic to assume lower transaction costs in the first case since trade between emitters ‘within a country’ is comparably cheaper in terms of the administrative burden.

[94] In the absence of transaction costs a uniform permit price for all regions would be achieved at the optimum (equi-marginality principle).

Figure (26) Graphical representation of a permit trade model for 2 regions



Source: based on Pérez, 2004b.

In figure (26) the ETS modelled in CAPRI is simplified and presented for two agents (regions A and B) with two different permit demand functions defined by parameters α_r and β_r. In the initial situation (before trading), each region receives an amount of permits representing a binding limit on emissions ($AllowP_r^i$) and has to pay a positive price for the last emission unit abated ($PermitP_r^i$). Through the trading mechanism an optimum is achieved where the total variation in the area below both individual permit demand functions is at its maximum: (a+b)-(c+d) in the graph. At this point the 'consumer rent' from permit trading is maximised[95]. The regional permit allowance moves in the final situation to $AllowP_r^f$ at the cost of $PermitP_r^f$

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[95] Technical note: in this modelling approach the change in the total area below the 'permit demand functions' between the initial and final emission levels is maximised, which leads to a minimisation of total emission abatement costs (these functions are actually cost functions). This approach differs than the one taken in a conventional quota trade model, where the quota rent is maximised as the total area below the quota demand function at the final emission level ('consumer rent'). Moreover, it allows explicit modelling of transaction costs

per emission certificate. At the optimum the remaining differences in regional permit prices correspond to variable transaction costs, which are assumed to be paid by the permit buyer (in this case region A).

For the modelled multi-regional case, the permit trading module is analytically constructed as a maximisation problem:

$$
\begin{aligned}
(6.1)\qquad Max\ \ Obje = \sum_r \Bigg[& \frac{1}{2}\left(PermitP_r^i - PermitP_r^f\right) * \left(AllowP_r^f - AllowP_r^i\right) \\
& + \left(AllowP_r^f - AllowP_r^i\right) * PermitP_r^f \\
& - \left(BuysIn_r + BuysOut_r\right) * VarTC\_Inst \\
& - \left(BuysIn_r * VarTCIn + BuysOut_r * VarTCOut\right)\Bigg]
\end{aligned}
$$

subject to several restrictions:

$$(6.2)\qquad AllowP_r^f = AllowP_r^i + \left(BuysIn_r + BuysOut_r\right) - \left(SalesIn_r + SalesOut_r\right)$$

$$(6.3)\qquad \sum_r \left[SalesOut_r\right] = \sum_r \left[BuysOut_r\right]$$

$$(6.4)\qquad \sum_{r \in MS} \left[SalesIn_r\right] = \sum_{r \in MS} \left[BuysIn_r\right]$$

$$(6.5)\qquad PermitP_r^i = \alpha_r + \beta_r * AllowP_r^i$$

$$(6.6)\qquad PermitP_r^f = \alpha_r + \beta_r * AllowP_r^f$$

Where:

Obje = welfare from emission trade

α, β = intercept and slope of the regional permit demand function

AllowP^i = initial distribution of permits (initial upper-bound imposed on emissions)

AllowP^f = final distribution of permits for the region (after trading)

PermitP^i = initial permit price (shadow price of the emission restriction, μ in chapter 5)

PermitP^f = final permit price (after trading)

BuysIn = permits bought by region r from national regions (same Member State)

BuysOut = permits bought by region r from foreign regions

SalesIn = permits sold by region r to national regions (same Member State)

SalesOut = permits sold by region r to foreign regions

VarTC_Inst = unitary transaction costs linked to the pre-implementation and implementation of the scheme (institutional transaction costs)

---

and prices without requiring bilateral permit trade flows and additional spatial arbitrage conditions (net-trade approach).

VarTCIn = unitary transaction costs directly linked to trade within the same Member State (e.g. brokerage fees)

VarTCOut = unitary transaction costs directly linked to trade with foreign regions (e.g. brokerage fees)

In the optimisation problem presented in equation (6.1) the sum of the areas below the regional permit demand functions between the initial and the final situation is maximised. This is achieved by moving away from $AllowP_r^i$ to $AllowP_r^f$. The area change below the permit demand functions is comprehended by the objective function and divided in two terms: a triangle ($0.5 * \left(PermitP_r^i - PermitP_r^f\right) * \left(AllowP_r^f - AllowP_r^i\right)$) and a rectangle ($\left(AllowP_r^f - AllowP_r^i\right) * PermitP_r^f$). For region A, these are graphically presented in figure (26) by areas ‘a’ and ‘b’ respectively. Variable transaction costs enter as economic restrictions for permit buyers and are substracted from the obtained rent.

The constraints of the problem are:

(1) *Equation (6.2)*: the total amount of permits allocated to a region in the market has to be equal to the initial allocation plus purchases minus sales.

(2) *Equation (6.3)*: total permit sales to foreign regions has to be equal to total permit purchases from foreign regions (international permit trade balance).

(3) *Equation (6.4)*: total permit sales and permit purchases between national regions in a Member State have to be equal (national permit trade balance).

(4) *Equation* (6.5*)*: the initial permit price has to belong to the permit demand function and can be defined through the intercept, the slope and the initial allocation of permits.

(5) *Equation (6.6)*: the permit demand function has to pass through the estimated permit price, which is defined through the intercept, the slope and the new amount of permits used by the regional supply models.

This approach is analogous to a consumer rent maximisation problem: agricultural producers behave as consumers and demand permits according to their marginal willingness to pay given by the individual permit demand functions. With fixed output prices trade of emission allowances must lead to income gains compared to a no-trade situation (solely the uniform emission standard, as described in chapter 4).

6.4.2 Technicalities

Linear permit demand functions

For technical reasons, a proxy for changes in marginal abatement costs or permit prices[96] is implemented through *linear* permit demand functions. These functions relate regional GHG emission abatement and marginal abatement costs. They are a linear approximation of the marginal abatement cost curves and, therefore, modelled to pass in each iteration through the initial regional permit price ($PermitP_r^i$) which results from the application of the uniform regional emission standard at the starting point and that estimated in the final situation ($PermitP_r^f$).

Iterative approach

It is important to remember that the presented ‘emission trade model’ would deliver in just one step the optimal demand of permits per region (transaction costs considered) if the estimated permit demand functions would correspond to the real MACCs. This is not the case in CAPRI since these curves are not modelled by an explicit functional form (and therefore are not linear) but represented through a set of estimated points. Moreover, even assuming that the MACCs would be linear and the true slopes known at the optimum, the solver demonstrated to have difficulties achieving a feasible optimum for all Nuts 2 regions at the same time. For these two reasons, the equilibrium is approached in an iterative way:

– In the first iteration a set of permit allowances and their corresponding permit prices are estimated in the regional supply models (first stage in section 6.4.1, p. 122). By fixing an arbitrary intercept and slope for all linear permit demand functions, the problem is solved and a ‘maximum rent from trading’ achieved.

– In the second iteration the information delivered by the trading module (solved in the first iteration) in the form of regional permit allowances ($AllowP_r^f$) is re-used by the regional supply models as emission restrictions to calculate a new vector of shadow values. With this information intercepts and slopes for the permit demand functions can be already estimated since two equilibrium points coming from the supply model (points belonging to the real MACCs) are already available:

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[96] Remember that in this analysis permit price and MAC are used indistinctly, they are related 1 to 1. Transaction costs are considered an economic restriction in the model (price wedge) and not directly included in the permit price.

(6.7)[97] $$\beta_r = \left(\mu_r^{step-2} - \mu_r^{step-1}\right) / \left(emission_r^{step-2} / emission_r^{step-1}\right)$$

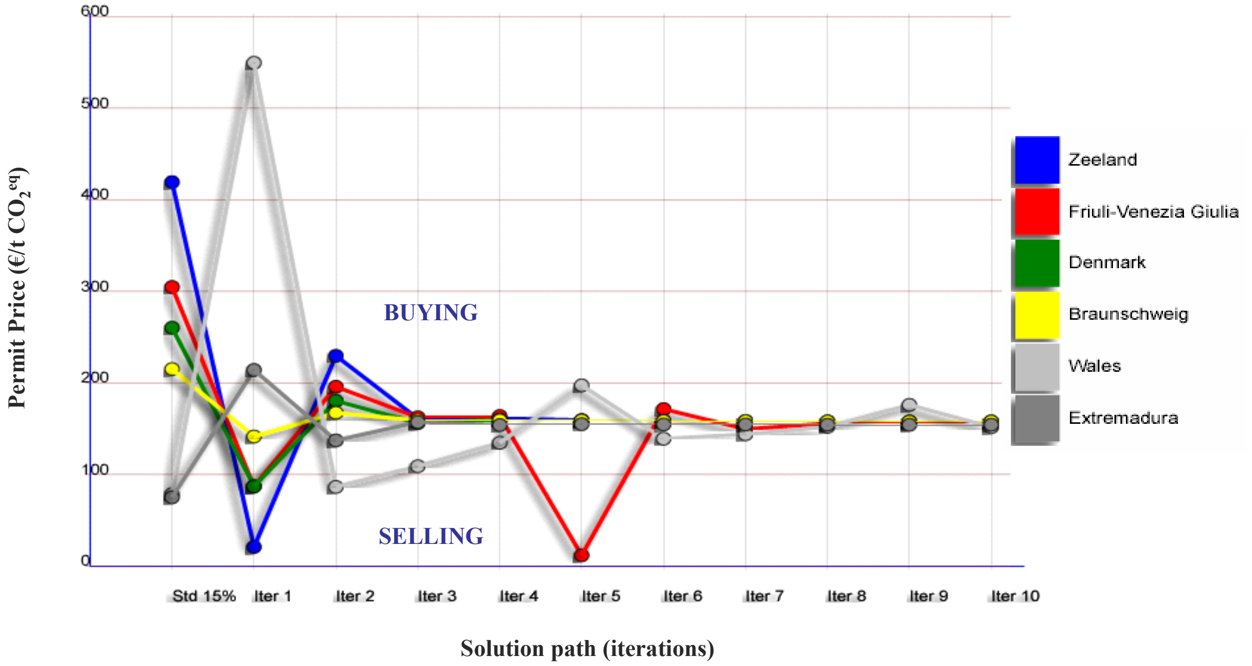
$$\alpha_r = \mu_r^{step-1} - \beta_r * emission_r^{step-1}$$

By doing this, the regional linear permit demand functions are re-shaped and through emission trading a new vector of permit allowances and prices estimated.

– The process is iteratively repeated until no noticeable price changes are observed between the results delivered by the supply model and the permit trading module for a vector of permit allowances (the value of the objective function of the permit trading module is at its maximum). At this stage, the final equilibrium is achieved.

This internal solution path is shown graphically in figure (27) for selected regions. Those facing high MACs (Region A in our previous graphical example) enter the permit market as buyers and those with low MACs (Region B) as sellers. By exchanging permits the first group of regions are able to relax their emission constraint and reduce the permit price paid for the last emission unit. At the equilibrium point MACs are only differentiated by transaction costs.

Figure (27) Trade of emission permits between selected regions (internal solution path)



Source: own calculations; simulation scenario 85 % emission standard plus emission trading; year 2001.

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[97] Notation from equation (5.9).

Fix transaction costs

When estimating the economic benefits of an ETS, it is quite important to estimate transaction costs in relation to the size of the trading scheme planned. With this purpose, fix transaction costs (e.g. annual costs related to the specific institutional set-up) are internalised in the current modelling exercise and, therefore, assumed to enter the objective function as a variable additional cost for permit buyers. The objective is to model a *'self-financing permit trading scheme'*, i.e. buyers choose to pay a permit price at the optimum such as to cover the variable and fix transaction costs attached to the permit market. In order to include these costs in the optimisation, the iterative mechanism is used and they are re-distributed in every step according to the following equation:

$$(6.8) \qquad VarTC\_Inst = TC\_Inst / \sum_r \left(BuysIn^{step-1} + BuysOut^{step-1} \right)$$

Where:

TC_Inst = fix transaction costs attached to the institutional set-up (total € per year)
BuysIn$^{\mathbf{step-1}}$ = level of permits bought from national regions at the equilibrium point
BuysOut$^{\mathbf{step-1}}$ = level of permits bought from foreign regions at the equilibrium point

By doing this, fix transaction costs are introduced as variable in the objective function ($VarTC\_Inst$). This reflects the fact that the number of permits traded also depends on the amount of fix transaction costs to internalise (they are indirectly related, i.e. trade shrinks by increasing fix transaction costs).

6.5 Analysis of results

6.5.1 Definition of modelling parameters

- In this chapter a 15 % reduction of 2001 European GHG emissions is modelled as *'cap' for a European inter-regional trading scheme*. This means that 85% of regional 2001 emissions are allocated as permits to each Nuts 2 region (see first iteration in figure (28), p. 132) and trade is between them allowed. This facilitates the comparison with the model results obtained in the previous chapter (see last point of the regional MACCs in figure (17), p. 102).

- *Market effects* are further excluded so that prices remain exogenous and efficiency effects derived from the use of instruments of abatement can be directly observed in the regional supply models. In chapter 7, this modelling approach is extended to consider price effects (trade between the main trade blocks in the world is included) and different mitigation instruments for a similar emission reduction objective (uniform emission cap) are analysed.

- As mentioned earlier in this chapter, *variable and fix transaction costs* are introduced in this modelling exercise as marginal costs. *Variable transaction costs* are mainly brokerage fees and are paid by permit buyers. In the current study, they are assumed to be 5 € for purchases within a Member State (trade with national agricultural producers) and 10 € for purchases from abroad (trade with foreign agricultural producers). These values are based on estimates from various studies which report handling fees in international trading schemes to be between 2 and 10 % of the transaction value (compilation by Eckermann et al., 2003, p. 16). For the selection of the 'appropriate' values in relation to the final permit price, a simple 'sensitivity analysis' for different values is carried out with the model (the impact of different transaction costs on trading are presented in appendix 10). Moreover, a further 10 Mio € are assumed as institutional costs of the trading scheme (2 Mio € per year with 5 years amortisation). These are also assumed to be supported by permit buyers and therefore distributed over transactions. They are defined based on information found in the literature for CDM and JI projects in different economic sectors and project sizes (compilation by Eckermann et al., 2003, pp. 6-8).

6.5.2 Inter-regional flows of permits

By implementing the afore-mentioned parameters in the model, a market of 271 million permits is simulated[98]. From these, 6.9 Mio permits result to be effectively traded between Nuts 2 regions, representing a 2.5 % of the total. This amount defines the size of the trading market and is linked to the heterogeneity of marginal abatement costs and the level of transaction costs. The distribution of allowances and trade flows between Member States is presented in table (23):

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[98] Exactly 85% of 2001 estimated global warming emissions in the EU-15 (319 Mio tonnes of CO_2^{eq}, as reported in table (17)).

Table (23) Permit transactions between EU-15 Member States

	Initial Permit Price * (Std 85%) Euro	Final Permit Price Euro	Total amount of permits 1000 Units	Purchases inland ** 1000 Units	Purchases abroad 1000 Units	Sales abroad 1000 Units	Total purchases 1000 Units	Total Sales 1000 Units
European Union	**171.3**	**157.6**	**271393**	**952**	**5984**	**5984**	**6936**	**6936**
Denmark	260.4	161.2	7448	0	469	0	469	0
Netherlands	259.0	161.2	13554	0	786	0	786	0
Finland	245.6	161.2	3546	0	198	0	198	0
Austria	215.3	161.2	5714	0	240	0	240	0
Italy	215.2	160.9	27573	37	1205	0	1242	37
Belgium	210.0	160.8	7119	4	276	0	279	4
Germany	195.0	160.8	48496	5	1704	0	1709	5
France	175.7	159.5	68821	690	1102	0	1792	690
Sweden	159.9	159.1	4714	12	5	0	17	12
Greece	149.0	154.2	5999	33	0	52	33	85
Portugal	130.5	151.9	5091	5	0	163	5	168
Spain	120.8	151.8	28358	90	0	1681	90	1771
United Kingdom	108.0	151.2	33141	76	0	2982	76	3058
Ireland	105.9	150.9	11819	0	0	1106	0	1106

Source: own calculations; simulation scenario 85 % emission standard and emission trade; year 2001; Luxembourg is modelled together with Belgium; further regionalised results can be found in appendix 9.

* Initial permit prices are in line with the $MAC_{15\%}$ results in table (21).

** Purchases inland are equal to sales inland for a Member State.

There is a group of Member States that face very high initial MACs and act only as buyers in the market: Denmark, Netherlands, Finland and Austria. It is rational for these countries to increase emissions in order to achieve a lower abatement cost. By doing this, permits can be achieved at a lower price. These countries end up using 4 % to 6 % more permits than in the initial allocation.

A second group of countries is comprised by Italy, Belgium, Germany, France, Sweden and Greece. Purchases also take place but in smaller proportion relative to the initial situation (1 % to 4 % more permits than in the initial allocation). However, the picture in these countries is not homogeneous since several regions face lower MACs than the national weighted average and sell permits. Some Nuts 2 regions sell permits at a national level (e.g. Sardegna in Italy and Midi-Pyrenées in France) and even to foreign regions (e.g. Ipeiros in Greece).

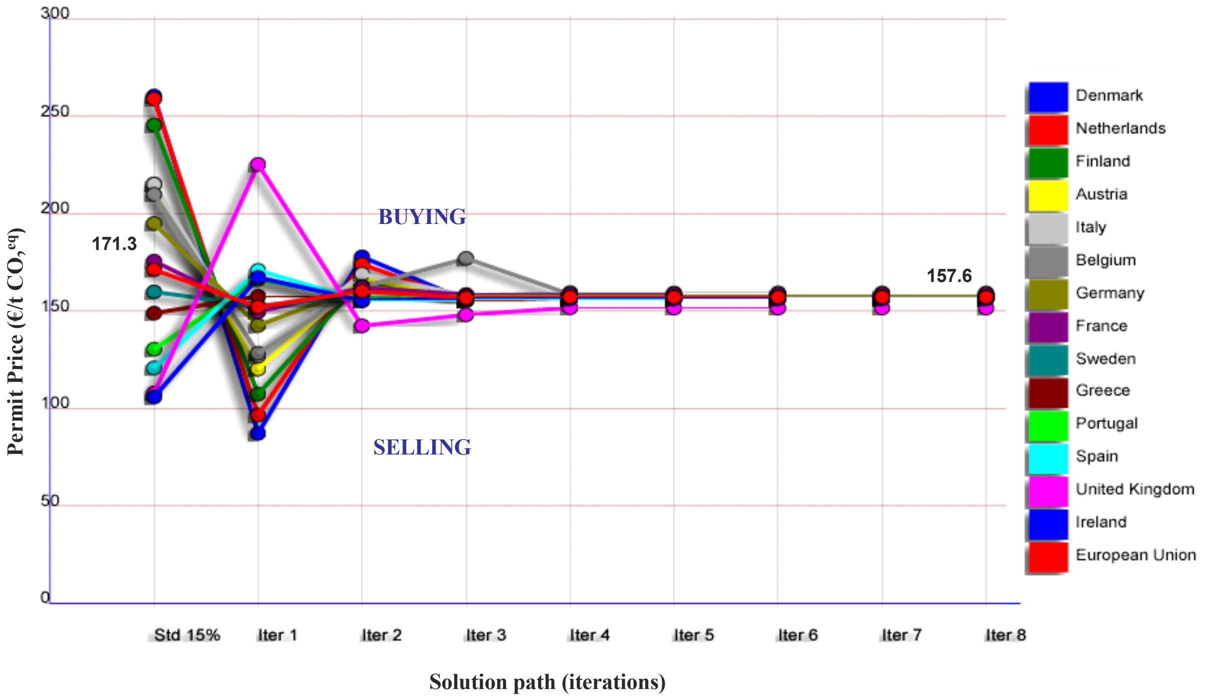
The last group of countries is formed by Portugal, Spain, United Kingdom and Ireland, in which mainly permit selling takes place. Regions in these countries face MACs below the average equilibrium point of the EU-15. Some permit purchases are still observed but only from national regions.

6.5.3 Income effects of trading: comparison of tradable permits and emission standards

On the one side, *permit buyers* (regions with high MACs in the initial situation) have to pay for the permits they need (in order to emit more) and support the transaction costs originated by the trading scheme. On the other side, *permit sellers* (regions with low MACs in the initial situation) see their rent increased by the revenues coming from permit transactions. For the former group of regions, purchase costs are however compensated at the trading market clearance point by lower total abatement costs and, as a consequence, higher production possibilities (the emission constraint is 'relaxed'). On the contrary, the latter group of regions see their revenues increase from permit sales and over-compensate higher abatement costs with this new source of income.

By plotting the internal solution path on an aggregated level for Member States in figure (28), it can be observed how the average weighted MAC in the European Union falls from 171.3 € to 157.6 € through emission trade. Regional differences in prices are minimised along the solution path so that after iteration 6 almost no changes are observed.

Figure (28) Trade of emission permits between Member States (internal solution path)



Source: own calculations; simulation scenario 85 % emission standard and emission trade; year 2001; Luxembourg is modelled together with Belgium.

In chapter 4 it was argued from a theoretical perspective that tradable emission permits are preferable to emission standards based on efficiency grounds. This issue is re-examined here, where the overall impact from both abatement instruments on regional agricultural income is simulated. With this purpose, the results of the afore-parameterised simulation for emission trading are confronted with a simulation for a EU-wide regional uniform emission standard. In order for results to be comparable, the latter is set exactly to the ‘emission cap’ used for the market of tradable permits. The results at Member State level are shown in table (24):

Table (24) Income effects of emission trading for EU-15 Member States

	85% emission standard [2001] *differences to : GHG Inventories Base Year [2001]*			**85% emission standard + trade [2001]** *differences to : 85% emission standard [2001]*		
	Agricultural income [1] **Mio Euro**	**Revenues/costs from emission trade*** **Mio Euro**	**Total Income** **Mio Euro**	**Agricultural income** **Mio Euro**	**Revenues/costs from emission trade** [2] **Mio Euro**	**Total Income** [3] **Mio Euro**
European Union	165567.54 *-5920.67*	0	165567.54 *-5920.67*	166198.21 *630.67*	-66.6	166217.9 *564.06*
Belgium	3697.18 *-108.34*	0	3697.18 *-108.34*	3735.19 *48.01*	-44.4	3737.7 *3.61*
Denmark	4112.55 *-261.73*	0	4112.55 *-261.73*	4208.47 *95.92*	-75.7	4211.6 *20.27*
Germany	21766.98 *-1412.37*	0	21766.98 *-1412.37*	22179.44 *412.46*	-274.7	22217.0 *137.72*
Austria	2848.98 *-174.13*	0	2848.98 *-174.13*	2898.51 *49.53*	-38.6	2901.3 *10.89*
Netherlands	10903.64 *-356.64*	0	10903.64 *-356.64*	11052.07 *148.43*	-126.6	11056.5 *21.83*
France	34831.65 *-992.78*	0	34831.65 *-992.78*	35070.56 *238.91*	-181.2	35089.1 *57.71*
Portugal	3953.94 *-9.21*	0	3953.94 *-9.21*	3933.24 *-20.70*	24.5	3930.4 *3.79*
Spain	26104.67 *-565.27*	0	26104.67 *-565.27*	25912.43 *-192.24*	253.3	25887.3 *61.06*
Greece	8953.98 *-215.54*	0	8953.98 *-215.54*	8949.72 *-4.26*	7.7	8946.9 *3.44*
Italy	30383.43 *-836.80*	0	30383.43 *-836.80*	30638.28 *254.85*	-194.4	30652.2 *60.45*
Ireland	3093.61 *-143.11*	0	3093.61 *-143.11*	2959.46 *-134.15*	166.9	2945.3 *32.76*
Finland	1534.15 *-111.00*	0	1534.15 *-111.00*	1578.31 *34.16*	-31.9	1580.1 *2.22*
Sweden	1970.51 *-175.07*	0	1970.51 *-175.07*	1972.7 *2.19*	-0.9	1975.1 *1.25*
United Kingdom	11412.27 *-558.67*	0	11412.27 *-558.67*	11109.85 *-302.42*	449.5	11087.5 *147.08*

Source: own calculations; year 2001; Luxembourg is modelled together with Belgium.

[1] In cursive differences to original income data in the base year situation: no emission restriction (in Mio €).

[2] In cursive differences to original income data in the 85 % emission standard scenario (in Mio €).

[3] Total income is equal to agricultural income (from the supply regional models) plus revenue minus costs from emission trading.

In the first three columns, the 85 % emission standard simulation scenario is represented. All Member States suffer income losses derived from the implementation of the emission standard (between -1412 Mio € for Germany and -9 Mio € for Portugal) compared to the base year situation (no emission restriction). As already analysed in previous chapters, these income losses are very heterogeneous in percentage and depend on the marginal abatement costs faced by regions. In this first scenario, total income equals agricultural income since no revenues or costs from trading take place (middle column).

With the implementation of emission trading between Nuts 2 regions, income losses still remain with respect to the base year situation (the emission cap is still binding) but efficiency gains are achieved with respect to the uniform application of the emission standard (agricultural income increases by 630 Mio €). These revenues are however dampened by the costs of the trading scheme, i.e. negative rents coming from transaction costs (-66 Mio €), as defined before. For the EU-15 as a whole, 564 Mio € are estimated as total efficiency gains[99]. On the one side, *sellers* are able to compensate income losses from production substitution effects through permit rents: for example, the United Kingdom moves from potential losses of -302 Mio € to 147 Mio € gains through permit sales). On the other side, *buyers* cover purchase costs of permits through higher revenues from production: for example Germany moves from potential income gains of 412 Mio € to 138 Mio € through permit purchases. All Member States are “better-off” through permit trading (consistent with microeconomic theory).

Looking at the results, it could be argued that the optimal distribution of emission targets at regional level could be achieved through *regional non-uniform emission standards*, if the information on MACCs would be available. By doing this, no transaction costs from permit trading would have to be paid, thereby increasing the overall efficiency effect of abatement policy. Nevertheless, this would imply that the regulatory institution has to update the information on marginal costs every year so that the overall emission goal is permanently achieved. Transaction costs from permit trading can therefore be seen as the price to pay for a permanent optimal response of the agents in the emission market.

6.6 Conclusions

In this chapter a deep analysis of the current European legislation on climate policies is offered. The legislative efforts achieved in Europe towards the implementation of the KP flexible mechanisms are analysed with special focus on the EETS. A feasible strategy is designed and modelled within the CAPRI modelling system with the idea of a transfer of efficiency gains derived from this instrument to European agriculture, which is not currently included in the EETS. The potential effects of tradable emission permits on agricultural income are then compared with those achieved by a uniform emission standard. From this modelling perspective some interesting conclusions can be extracted: (a) emission trading proves to be a cost-effective solution for Member States due to the heterogeneity of their marginal abatement costs and (b) the income effects of this instrument depend heavily on the transaction costs linked to its implementation.

In the following chapter a set of simulation scenarios for European agriculture in the context of variable prices are carried out. The economic and environmental effects of a ‘future KP-like agreement’ on emission abatement from agricultural sources, based on 2001 reference emissions, is discussed. The previously analysed mitigation instruments and a specific ‘burden-sharing agreement for agriculture’ are compared with each other.

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[99] Note that in this comparison between instruments prices are held constant, so that efficiency gains and income gains are the same (no price interference). In the following chapter, this assumption will be relaxed and several simulation scenarios analysed.

CHAPTER 7 Comparison between Emission Abatement Instruments including Price Effects

> *"Man shapes himself through decisions that shape his environment" (Rene Dubos).*

7.1 Introduction

In the previous chapters the implementation of *emission standards* and *tradable emission permits* in European agriculture has been defined, modelled and analysed, by means of cost-effectiveness, within a 'fixed price' approach. Two important conclusions were obtained: (1) the implementation of GHG emission abatement imposes a real economic burden on agricultural producers and (2) these income losses might be reduced by using economic instruments such as tradable emission permits. In this chapter, these two conclusions are revised from a wider perspective, i.e. European agriculture has an influence and at the same time depends on the evolution of world agricultural markets. With this purpose, different mitigation instruments are analysed under the assumption of variable prices for a 15 % abatement objective with respect to base year emissions (consistent with the analysis carried out in chapter 6). Moreover, a welfare analysis is carried out by considering welfare effects of these instruments on agricultural producers, consumers, taxpayers and processing industry.

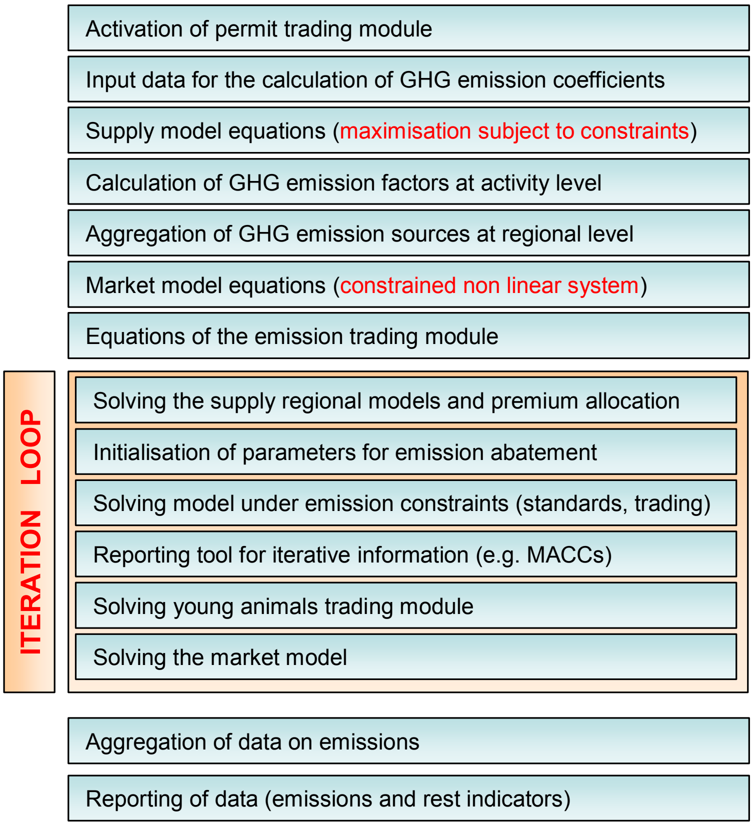
In section 7.2 three alternative simulation scenarios are constructed, following the main KP emission mitigation mechanisms. In section 7.3, results are analysed by focusing on supply, price, income and welfare indicators.

7.2 Definition of simulation scenarios

7.2.1 Structure of the modelling approach

As already mentioned, in CAPRI an iterative approach is chosen in order to solve the different components of the model, namely *regional supply models*, *market model*, *premium allocation* (consideration of premium ceilings) and *young animal markets*. Figure (29) presents graphically the model structure followed when introducing emission abatement measures:

Figure (29) Running a modelling scenario under consideration of greenhouse gas emission abatement



Source: CAPRI Modelling System

On a first stage the necessary input data for the different modules of the model are included. In this case, special consideration is made to the calculation of GHG emission inventories per activity and region, as explained in chapter 3. Moreover, the equations of the supply, market and permit trade models are defined. On a second stage, the iteration loop is started and the solve statements for the different modules included in the system. As already mentioned, in each iteration the market model interacts with the regional supply models via prices-quantities, trying to reach the economic optimum. Within this mechanism a young animal trade module, a premium distributor and an emission trade module are solved. On a third stage, the estimated information is stored (last step), aggregated to different regional levels and reported[100].

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[100] Several reporting tools are used in CAPRI in the analysis of results: a JAVA mapping tool, xml tables and xsl graphical tools (copyright: Wolfgang Britz).

7.2.2 Base and reference scenario

A three-year average around the year 2001 is selected as the 'base situation' for simulation purposes. This corresponds with the results already analysed in chapter 3, where regional GHG emission inventories were modelled. In the current analysis, no projections to the future are simulated, in order to avoid further exogenous information influencing the results of the model (population growth, inflation, development of preferences, etc). Therefore, all simulation scenarios will refer to the year 2001, base and reference scenario being the same[101]. For this year, all behavioural equations in the model are calibrated to observed statistical data.

7.2.3 Simulation scenarios

The following three scenarios are constructed:

- *Simulation scenario 1: 85 % regional uniform emission standard (85-STD)*. A similar abatement target as the one taken in the previous chapter is considered, prices being now considered as endogenous variables. With this purpose, all Nuts 2 regions in the model are constrained to emit 15 % less GHG emissions than in the reference situation. The model is run during 15 iterations in order to achieve a situation 'sufficiently close' to the equilibrium point (prices and quantities not changing anymore).

- *Simulation scenario 2: burden sharing agreement for the agricultural sector (85-BSAA).* The 'burden of emission abatement' is distributed across Member States (non-uniform emission standard). This mechanism was allowed by the KP to parties acting jointly such as the European Union (see footnote 81, p. 114). The EU 'burden-sharing agreement' was an important internal decision in the international climate change negotiations. In this simulation study, however, only agricultural emissions are considered so that the same general agreement does not apply[102]. In table (25), the evolution of GHG emissions from agricultural sources since 1990 is presented and a possible BSA for agriculture (85-BSAA) in 2001 designed for modelling purposes.

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[101] A simulation in the future would not add any significant additional information to the current approach since no specific commitment on agricultural emission abatement has been adopted to date. However, with the CAPRI model several studies have been done in the past for scenarios in the medium-term.

[102] The targets approved in the official BSA range from emission increases of 40 % and 20 % for Portugal and Spain, to emission decreases of -40 % and -23 % for Luxembourg and Denmark respectively. They refer to emissions from all sectors, so that no relation with agricultural emissions can be derived. Additionally, the current study presents the limitation of considering only *'binding emissions'* so that emission increases w.r.t. the base year cannot be justified from an economic perspective (if marginal abatement costs are zero in the reference situation).

Table (25) Evolution of emissions since 1990 and emission abatement targets for simulation scenarios 1 and 2 (EU-15 Member States)

	UNFCCC		CAPRI		% differences	SIM 1: 85-STD	SIM 2: 85-BSAA
	1990	2001	1990*	2001	2001-1990	2001-2001	2001-2001
EU-15	**428.0**	**398.3**	**342.9**	**319.3**	**-6.9%**	**-15%**	**-15%**
Austria	8.1	7.6	6.9	6.4	-6.7%	-15%	-10%
Belgium	12.7	12.5	8.2	8.1	-1.7%	-15%	-10%
Denmark	14.3	11.6	10.0	8.2	-17.7%	-15%	-5%
Finland	6.9	5.5	4.9	3.9	-19.0%	-15%	-10%
France	104.8	98.4	84.7	79.7	-5.9%	-15%	-15%
Germany	81.7	65.2	69.4	55.0	-20.6%	-15%	-10%
Greece	8.4	10.0	6.2	7.1	15.2%	-15%	-5%
Ireland	17.9	19.2	14.2	15.2	6.8%	-15%	-25%
Italy	42.8	42.5	31.3	31.0	-0.9%	-15%	-5%
Netherlands	17.5	15.8	16.6	15.0	-9.7%	-15%	-5%
Portugal	12.3	11.8	6.5	6.2	-4.9%	-15%	-20%
Spain	37.4	43.0	30.8	35.3	14.6%	-15%	-20%
Sweden	9.5	8.9	5.9	5.5	-6.1%	-15%	-10%
United Kingdom	53.7	46.4	49.0	42.5	-13.2%	-15%	-30%

Source: own calculations; 2001 three year average calibration year for CAPRI and years 1990 and 2001 for NGHGIs; Luxembourg is modelled together with Belgium.

Measurement units: Mio tonnes of CO_2^{eq}.

* The CAPRI values for 1990 are calculated backwards by assuming the same differences found in the NGHGIs. They are just reported in this table for comparison purposes and no further used in the analysis.

As presented in the figure, in scenario 1 (85-STD) a 15 % emission reduction is modelled for all European regions. Scenario 2 considers a similar target in average for the EU-15, but differentiates emission abatement targets between countries: (1) Regions in the United Kingdom and Ireland face a 30 % and 25 % abatement target respectively, due to their relative low marginal abatement costs (see chapter 5); (2) Portugal, Spain and France, countries where restructuring is necessary and low abatement efforts have been achieved in the past, become a 20 %, 20 % and 15 % target respectively; (3) Nuts 2 regions in Austria, Belgium and Luxembourg, Finland, Germany and Sweden are forced to emit 10 % less emissions than in the reference situation, following a trend below the average; (4) Denmark, Greece, Italy and the Netherlands are only affected by a -5 % abatement target, due to their high marginal abatement costs.[103]

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[103] It is important to note that this ‘burden-sharing agreement’ for agriculture is arbitrarily designed in this study by taking into account marginal abatement costs and the development of emissions in the past. It should provide a ‘half way’ point between a uniform standard and an optimal distribution of abatement targets (obtained through the use of tradable emission permits).

- *Simulation scenario 3: cap-and-trade permit system (85-TRD).* In this case, a 85 % emission standard is again simulated but with additional trade of emission permits. The design of this permit market is analogous to the one presented in chapter 6: *cap-and-trade*, *inter-regional dimension* and *explicit consideration of transaction costs* (see definition of modelling parameters in section 6.5.1, p. 129). As in the previous two simulation scenarios, the market component of the model is in this case activated so that prices are allowed to vary until an equilibrium is achieved.

7.3 Analysis of results

7.3.1 Greenhouse gas emissions

The analysis begins equally for the three simulation scenarios: *GHG emissions are constrained to be 15 % below base year emissions (85 % emission standard)*. The distribution of the abatement burden among regions can vary depending on the instrument selected. In the following figure, the estimations of GHG emissions from individual agricultural sources are presented for the defined simulation scenarios:

Table (26) Variation in greenhouse gas emissions at source level for simulation scenarios 1, 2 and 3 (average for the EU-15)

	SIM 1: 85-STD [2001] *% deviation to: NGHGIs base year [2001]*			**SIM 2: 85-BSAA [2001]** *% deviation to: NGHGIs base year [2001]*			**SIM 3: 85-TRD [2001]** *% deviation to: NGHGIs base year [2001]*		
	Total	**Amount per ha**	**Impact in CO_2^{eq}**	**Total**	**Amount per ha**	**Impact in CO_2^{eq}**	**Total**	**Amount per ha**	**Impact in CO_2^{eq}**
CH_4 total emissions	6468.4 *-15.5%*	47.9 *-15.5%*	135836.3 *-15.5%*	6450.7 *-15.8%*	47.8 *-15.8%*	135464.1 *-15.8%*	6454.7 *-15.7%*	47.8 *-15.7%*	135548.8 *-15.7%*
N_2O total emissions	437.3 *-14.5%*	3.2 *-14.3%*	135556.9 *-14.5%*	438.9 *-14.1%*	3.3 *-14.0%*	136045.9 *-14.1%*	438.2 *-14.3%*	3.2 *-14.3%*	135844.3 *-14.3%*
CH_4 from enteric fermentation	4900.1 *-15.8%*	36.3 *-15.8%*	102902.4 *-15.8%*	4904.1 *-15.8%*	36.3 *-15.8%*	102986.0 *-15.8%*	4884.3 *-16.1%*	36.2 *-16.1%*	102570.6 *-16.1%*
CH_4 from manure management	1533.9 *-12.8%*	11.4 *-12.8%*	32211.9 *-12.8%*	1501.9 *-14.6%*	11.1 *-14.6%*	31539.0 *-14.6%*	1527.4 *-13.1%*	11.3 *-13.1%*	32075.1 *-13.1%*
CH_4 from rice production	34.4 *-56.9%*	0.3 *-57.6%*	722.0 *-56.9%*	44.7 *-44.0%*	0.3 *-44.1%*	939.1 *-44.0%*	43.0 *-46.1%*	0.3 *-45.8%*	903.1 *-46.1%*
N_2O from manure management	41.0 *-7.3%*	0.3 *-9.1%*	12709.4 *-7.3%*	41.2 *-6.9%*	0.3 *-6.1%*	12772.0 *-6.8%*	41.5 *-6.1%*	0.3 *-6.1%*	12872.4 *-6.1%*
N_2O from excretion on grazings	74.5 *-20.6%*	0.6 *-20.3%*	23086.2 *-20.6%*	74.0 *-21.1%*	0.6 *-20.3%*	22946.5 *-21.1%*	73.3 *-21.9%*	0.5 *-21.7%*	22710.5 *-21.9%*
N_2O from synthetic fertiliser	152.5 *-15.7%*	1.1 *-15.7%*	47258.0 *-15.7%*	153.5 *-15.2%*	1.1 *-14.9%*	47590.0 *-15.2%*	152.6 *-15.6%*	1.1 *-15.7%*	47318.6 *-15.6%*
N_2O from organic animal waste	93.4 *-10.9%*	0.7 *-11.5%*	28956.2 *-10.9%*	93.5 *-10.9%*	0.7 *-11.5%*	28979.4 *-10.9%*	93.9 *-10.4%*	0.7 *-10.3%*	29120.5 *-10.4%*
N_2O from crop residues	26.9 *-13.0%*	0.2 *-13.0%*	8343.6 *-12.9%*	27.1 *-12.3%*	0.2 *-13.0%*	8411.7 *-12.2%*	27.2 *-12.0%*	0.2 *-13.0%*	8432.8 *-12.0%*
N_2O from biological fixation	6.3 *-18.4%*	0.1 *-16.7%*	1941.1 *-18.3%*	6.3 *-17.6%*	0.1 *-16.7%*	1959.6 *-17.6%*	6.3 *-18.3%*	0.1 *-16.7%*	1943.7 *-18.2%*
N_2O from atmospheric deposition	42.8 *-12.2%*	0.3 *-11.1%*	13262.6 *-12.2%*	43.2 *-11.4%*	0.3 *-11.1%*	13386.7 *-11.4%*	43.4 *-11.0%*	0.3 *-11.1%*	13445.9 *-11.0%*

Source: own calculations; year 2001. In cursive % differences in total emissions, amount per hectare and impact in CO_2^{eq} w.r.t. the base year.

Measurement units: 'total emissions' are in 1000 tonnes of gas, 'amount per hectare' in tonnes per hectare and 'impact in CO_2^{eq}' in 1000 tonnes of CO_2^{eq}.

It can be observed how methane emissions (mainly from animal production activities) are slightly more affected than nitrous oxide emission. These results are directly linked to the supply changes presented in the following section and consistent with the evolution of individual emission sources presented in section 5.5.3 (last abatement target in figure (21) to figure (23)). In this case, though, different results are obtained due to the price effects coming from the market component of the model: methane emissions are less affected (changes between 15.5 % and 15.8 % depending on the scenario) and nitrous oxide emissions more (changes between 14.1 % and 14.5 %). It can be noticed that, through price endogeneity, the burden of emission abatement is more uniformly distributed among emission sources.

In the following table the regional emission abatement targets endogenously obtained after reaching an optimum in the emission permit market are reported.

Table (27) Final emission abatement targets for simulation scenario 3 (EU-15 Member States)

	SIM 3: 85-TRD [2001]
European Union	**-15.0%**
Austria	-9.8%
Belgium	-7.0%
Denmark	-6.8%
Finland	-8.5%
France	-13.9%
Germany	-11.8%
Greece	-6.0%
Ireland	-26.8%
Italy	-7.5%
Netherlands	-8.0%
Portugal	-21.6%
Spain	-17.4%
Sweden	-11.8%
United Kingdom	-28.3%

Source: own calculations; year 2001; Luxembourg is modelled together with Belgium.

Measurement units: % reduction of CO_2^{eq}.

These ‘optimal’ regional emission abatement targets are aggregated for Member States in this table and can be directly compared to the ones assumed in the burden-sharing agreement (see table (25)).

7.3.2 Agricultural supply

The overall effect of emission abatement measures on agricultural markets is a reduction in production. This is not very surprising since only a structural response is allowed from regional supply models in the fulfilment of the emission target. Nevertheless, this effect can vary across *activities* depending on the emission weight attached by the ‘emission accounting system’ (income/emission relationship) and *regions* depending on the substitution possibilities found in each regional model (agricultural income is always maximised subject to constraints). In table (28), the supply effects on the main activity aggregates are presented for the EU-15:

Table (28) Supply details for activity aggregates (average for the EU-15)

	SIM 1: 85-STD [2001]			SIM 2: 85-BSAA [2001]			SIM 3: 85-TRD [2001]		
	% deviation to: NGHGIs base year [2001]			*% deviation to: NGHGIs base year [2001]*			*% deviation to: NGHGIs base year [2001]*		
	Hectares or herd size	Yield	Supply	Hectares or herd size	Yield	Supply	Hectares or herd size	Yield	Supply
	1000 ha or heads	kg /ha or head	1000 t	1000 ha or heads	kg /ha or head	1000 t	1000 ha or heads	kg /ha or head	1000 t
Cereals	33003.36	5601.91	184881.75	33386.51	5613.63	187419.37	33282.27	5621.65	187101.14
	-12.02%	*-1.14%*	*-13.02%*	*-11.00%*	*-0.93%*	*-11.83%*	*-11.28%*	*-0.79%*	*-11.98%*
Oilseeds	4697.04	2954.25	13876.26	4738.35	2960.82	14029.42	4754.1	2963.58	14089.15
	-11.53%	*0.00%*	*-11.53%*	*-10.75%*	*0.23%*	*-10.55%*	*-10.46%*	*0.32%*	*-10.17%*
Other arable crops	6740	35686.73	240528.62	6749.87	35809.61	241710.3	6763.87	35829.38	242345.15
	-2.68%	*0.20%*	*-2.49%*	*-2.54%*	*0.55%*	*-2.01%*	*-2.34%*	*0.60%*	*-1.75%*
All cattle activities	66328.47	2305.29	152906.34	66472.05	2299.25	152835.59	66303.65	2300.67	152542.78
	-18.88%	*15.88%*	*-6.00%*	*-18.70%*	*15.58%*	*-6.04%*	*-18.91%*	*15.65%*	*-6.22%*
Beef meat activities	19849.43	228.42	4533.93	19550.65	232.75	4550.33	19433.14	229.14	4452.91
	-26.95%	*15.58%*	*-15.57%*	*-28.05%*	*17.77%*	*-15.27%*	*-28.48%*	*15.94%*	*-17.08%*

Source: own calculations; year 2001; In cursive % differences in hectares or herd size, yield and supply w.r.t. to the base year situation.

A slight extensification effect can be observed for cereals in all three scenarios (reduction in yields). At the optimum it is profitable for agricultural producers to reduce the amount of fertiliser applied (and indirectly N_2O emissions) and maintain some production on land which otherwise would have been abandoned, i.e. the drop in supply is higher than the drop in hectares of cultivation. This effect is less accused for ‘other arable crops’ such as pulses, potatoes and sugar beet. For cattle and beef meat activities, however, higher yields are modelled. For the latter group, it is optimal from an ‘emission accounting perspective’ to heavily increase yields (up to 18 %) and further reduce the cattle herd (up to -17 %). Through this intensification effect animals become more efficient in terms of GHG emissions (higher income obtained per emission unit).

In the previous table it is also shown that in scenario 1 (85-STD) higher drops in crop production are estimated. The introduction of non-uniform standards, explicitly through a burden-sharing-agreement (85-BSAA) or implicitly through emission trading (85-TRD), implies a relaxing of the emission constraint at the regional level and indirectly production is less affected.

7.3.3 Prices

As mentioned before, prices are now considered an endogenous variable for simulation purposes. This means that world markets have an influence on European agricultural markets and, therefore, monetary variations in supply are not anymore equivalent to variations in income, as presented in the previous two chapters. The following two tables show the effect on agricultural prices (consumer and producer prices) for the modelled abatement mechanisms:

Table (29) Variation in consumer and producer prices for selected primary products (average for the EU-15)

	SIM 1: 85-STD [2001]		SIM 2: 85-BSAA [2001]		SIM 3: 85-TRD [2001]	
	Consumer Price	Producer Price	Consumer Price	Producer Price	Consumer Price	Producer Price
Soft wheat	*0.80%*	*15.57%*	*0.73%*	*14.05%*	*0.79%*	*15.25%*
Durum wheat	*0.98%*	*7.90%*	*0.89%*	*7.35%*	*0.96%*	*7.89%*
Rye and meslin	*0.70%*	*19.66%*	*0.53%*	*15.01%*	*0.68%*	*19.29%*
Barley	*0.30%*	*7.49%*	*0.27%*	*6.67%*	*0.29%*	*7.29%*
Oats	*0.85%*	*19.46%*	*0.65%*	*14.96%*	*0.84%*	*19.20%*
Grain maize	*0.17%*	*2.81%*	*0.19%*	*3.22%*	*0.16%*	*2.71%*
Paddy rice *		*22.51%*		*16.79%*		*21.84%*
Pulses	*0.03%*	*2.98%*	*0.01%*	*1.72%*	*0.03%*	*2.75%*
Potatoes	*0.39%*	*15.54%*	*0.35%*	*18.83%*	*0.38%*	*17.56%*
Sugar beet *		*8.81%*		*6.98%*		*8.38%*
Beef	*0.00%*	*3.43%*	*0.00%*	*2.95%*	*0.00%*	*2.93%*
Veal	*45.54%*	*99.36%*	*39.23%*	*85.23%*	*44.13%*	*97.63%*
Pork meat	*42.47%*	*100.13%*	*36.63%*	*84.31%*	*41.18%*	*98.29%*
Sheep and goat meat	*6.74%*	*21.79%*	*5.69%*	*18.54%*	*6.66%*	*21.65%*
Poultry meat	*41.67%*	*78.95%*	*43.23%*	*86.07%*	*40.88%*	*81.26%*
Cow and buffalo milk *		*2.48%*		*2.77%*		*2.60%*
Sheep and goat milk *		*49.35%*		*36.91%*		*48.76%*

Source: own calculations; year 2001; differences w.r.t. prices in the base year situation.

* These products are processed in the model; consumer prices for processed products are reported in table (30).

Table (29) shows the main variations in consumer and producer prices for primary products. It can be observed how producer and consumer prices increase for the main activities in all three scenarios, especially for animal products. This effect has to be considered parallel to the supply effects explained in the previous section and is due to the market barriers applied by the EU on agricultural markets. Amongst other measures, tariff rate quotas for cereals and beef remain binding in the different simulation scenarios (MFN tariffs are quite restrictive compared to preferential tariffs). These make imports quite ‘steaky’ and indirectly transfer the burden to exports, which drop heavily in order to fulfil internal demand (see structure of the market model in section 2.5.4). Consequently, demand slightly shrinks and consumer prices increase.

Table (30) Variation in consumer prices for processed products (average for the EU-15)

	SIM 1: 85-STD [2001]	SIM 2: 85-BSAA [2001]	SIM 3: 85-TRD [2001]
Butter	*14.23%*	*10.57%*	*13.23%*
Skimmed milk powder	*20.70%*	*17.23%*	*19.90%*
Cheese	*10.16%*	*8.14%*	*9.59%*
Fresh milk products	*11.49%*	*11.82%*	*10.73%*
Cream	*14.05%*	*10.45%*	*13.07%*
Concentrated milk	*13.54%*	*13.95%*	*12.66%*
Whole milk powder	*13.51%*	*13.91%*	*12.62%*
Soya oil	*4.77%*	*4.38%*	*4.71%*
Rice milled	*2.71%*	*2.22%*	*2.69%*
Sugar	*1.37%*	*1.33%*	*1.36%*

Source: own calculations; year 2001; differences w.r.t. prices in the base year situation.

There is also a general increase in prices for processed products. Nevertheless, these are lower than the price increases of the raw agricultural products applied in their production (e.g. sugar beet prices increase by 7 to 9 % and processed sugar by 1.3 to 1.4 %). Therefore, the processing industry suffers a negative welfare effect since it has to pay much higher input costs (the price increase of the raw material is not completely transferred to the processed product).

At this stage, from the analysis on supply and prices it can be extracted: (1) that consumers suffer high economic losses through the implementation of an emission constraint on agricultural production (consumer prices increase) and (2) that these losses are lower in the case of 'non-uniform' emission abatement scenarios (85-BSAA and 85-TRD) than in the case of a 'uniform' standard (85-STD). Nothing conclusive can however be said about how agricultural producers are affected since they produce less but at higher prices. In order to further analyse the welfare effects of emission abatement measures, these two variables are combined in the following section and agricultural income per activity estimated.

7.3.4 Income details

Agricultural income is constructed as the sum of revenues (production multiplied by price) and premiums minus input costs. In table (31), income details for selected activities are presented.

Table (31) Income details for selected activities (average for the EU-15)

	SIM 1: 85-STD [2001] *% deviation to : NGHGIs base year [2001]*				SIM 2: 85-BSAA [2001] *% deviation to : NGHGIs base year [2001]*				SIM 3: 85-TRD [2001] *% deviation to : NGHGIs base year [2001]*			
	Revenues	**Costs**	**Premiums**	**Income**	**Revenues**	**Costs**	**Premiums**	**Income**	**Revenues**	**Costs**	**Premiums**	**Income**
Cereals	697.15 *9.14%*	300.54 *-1.45%*	329.52 *3.42%*	726.13 *11.30%*	692.75 *8.45%*	299.12 *-1.92%*	330.15 *3.62%*	723.78 *10.94%*	700 *9.58%*	300.77 *-1.38%*	330.2 *3.63%*	729.44 *11.80%*
Oilseeds	550.84 *10.53%*	259.43 *-1.99%*	298.3 *0.53%*	589.72 *11.18%*	543.14 *8.99%*	258.67 *-2.27%*	298.52 *0.60%*	582.99 *9.92%*	554.09 *11.18%*	260.12 *-1.73%*	299.6 *0.96%*	593.57 *11.91%*
Other arable crops	3204.77 *4.96%*	736.12 *1.23%*	356.93 *1.62%*	2825.58 *5.53%*	3190.41 *4.49%*	737.52 *1.42%*	355.17 *1.12%*	2808.06 *4.88%*	3208.59 *5.08%*	738.73 *1.59%*	354.96 *1.06%*	2824.82 *5.50%*
All cattle activities	1967.85 *92.86%*	1011.5 *51.75%*	70.06 *4.83%*	1026.4 *144.03%*	1837.76 *80.11%*	989.31 *48.42%*	68.65 *2.72%*	917.11 *118.04%*	1999.32 *95.95%*	1052.8 *57.94%*	68.63 *2.69%*	1015.19 *141.36%*
Beef meat activities	1432.13 *115.40%*	1066.44 *70.25%*	185.63 *12.58%*	551.32 *171.08%*	1366.14 *105.47%*	1043.18 *66.54%*	184.1 *11.65%*	507.06 *149.32%*	1452.99 *118.54%*	1113 *77.69%*	184.49 *11.89%*	524.47 *157.88%*

Source: own calculations; year 2001.

Measurement units: € per hectare or head.

In cursive % differences w.r.t. revenues, total costs, premiums and income in the base year.

An interesting result of the model is that for most agricultural activities and scenarios income increases. Considerable production losses per activity are therefore over-compensated by increases in prices. In the previous table, it can be observed that, whereas revenues increase between 11 % and 12 % for crop activities, variable costs remain more or less constant or even drop. Moreover, premiums also contribute to a higher income level due to less pressure on regional premium ceilings (less ‘premium cutting’ is necessary to meet the national premium ceiling, as explained in figure (19), p. 106). For animal activities, this effect is even stronger. For example, cattle activities more than duplicate income w.r.t. the base year situation.

From the perspective of the different abatement mechanisms, income gains are generally higher in the first scenario (85-STD) than in the two latter (directly derived from the price development). However, nothing conclusive can be said since this effect depends on the relative competitiveness of the different crop activities in each scenario. For some aggregates, such as cereals and cattle activities, income increases are higher in the 85-TRD scenario than in the 85-BSAA.

Summarising, consumer losses and producer gains are observed in all three scenarios. In order to get a general picture, these two indicators are integrated in the following section within a consistent welfare analysis. Public sector expenditure (welfare losses from taxpayers) and profits from the dairy and oil-crushing processing industry are also considered.

7.3.5 Welfare effects

The welfare measure in CAPRI is based on production and consumption shifts of agricultural primary goods, as well as an aggregate of ‘all other goods’[104], driven by price changes. Its main elements are producer surplus, consumer surplus and budgetary expenditures (paid by taxpayers). Additionally, profits from the oil-crushing and dairy processing industry are included (Pérez, Wieck, 2004):

- *Consumer surplus* is calculated by using the money metric indirect utility function (Varian, 1992, p. 110). The money metric measure is the minimal expenditure needed to incur by consumers in order to reach the utility level of the simulation year at prices of the reference situation (= calibration point). Final consumption is modelled by a generalised Leontief expenditure function, allowing the explicit derivation of this indirect utility function. Changes in consumer prices derived by the implementation of an emission abatement instrument affect the money metric, giving an indirect measure of consumers’ welfare change.

- *Producer surplus* is calculated as agricultural income according to the gross value added concept of the Economic Accounts of Agriculture (output revenues minus input costs). The current analysis explicitly includes direct payments and revenues/costs from permit trading (scenario 85-TRD).

- *Profits of the processing industry.* Production of processed products from the dairy and oilseed industry is approached in CAPRI through the derivative of a normalised quadratic profit function (one input product and several processed products). Production of milled rice is calculated through fix processing factors (one raw product and one processed product).

- *Budgetary expenditure* comprise of all direct payments for agricultural commodities (premiums) as well as export subsidies and costs for intervention purchases.

The main welfare effects observed for the EU-15 are resumed in table (32):

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[104] This ‘bundle of goods’ closes the demand balance.

Table (32) Welfare effects (average for the EU-15)

	NGHGIs base year [2001]	**SIM 1: 85-STD [2001]** ***differences to: NGHGIs base year [2001]***	**SIM 2: 85-BSAA [2001]** ***differences to: NGHGIs base year [2001]***	**SIM 3: 85-TRD [2001]** ***differences to: NGHGIs base year [2001]***
Budgetary expenditure	37498.51	35542.07 *-1956.44*	35596.96 *-1901.55*	35464.59 *-2033.92*
Money metric	4397054.81	4354880.43 *-42174.38*	4359747.4 *-37307.41*	4356338.21 *-40716.6*
Output revenues	276654.8	330326.12 *53671.32*	322002.14 *45347.34*	334291.92 *57637.12*
Input costs	135626.88	146042.86 *10415.98*	145194.06 *9567.18*	150025.26 *14398.38*
Premiums	30460.29	27928.57 *-2531.72*	27953.55 *-2506.74*	27880.7 *-2579.59*
Transaction costs from permit trading				95.07 *95.07*
Agricultural income	171488.21	212211.84 *40723.63*	204761.64 *33273.43*	212052.3 *40564.09*
Profit of processing industry	70071.25	64219.98 *-5851.27*	67457.54 *-2613.71*	64325.9 *-5745.35*
TOTAL WELFARE	4601115.76	4595770.18 *-5345.58*	4596369.62 *-4746.14*	4597251.82 *-3863.94*

Source: own calculations; year 2001.

Measurement units: Mio € (in cursive differences w.r.t. the base year).

Note: in the table total welfare is defined as positive transfers to consumers (money metric) + agricultural income (output revenues - input costs + premiums - transaction costs from permit trading) + profits from the processing industry - budgetary expenditures (transfers from taxpayers).

As previously observed at activity level, agricultural income (= producer surplus) increases in all simulation scenarios. Whereas in the 85-STD scenario 40.7 Bio € are estimated as economic transfers to producers, in the 85-BSAA and 85-TRD 33.3 Bio € and 40.6 Bio € are achieved (for the latter transaction costs of permit trading included). This positive effect is due to the general increase in producer prices. On the other side, transfers to consumers (money metric utility measure) diminish due to an increase of consumer prices: -42.2, -37.3 and -40.7 Bio € in the defined scenarios respectively. Since public expenditure remains more or less constant (-2 Bio €), the effect on total welfare is mainly determined by the difference between gains achieved by producers and losses suffered by consumers and processing industry.

The total welfare effect is estimated negative for all simulation scenarios: -5.3 Bio € in 85-STD, -4.7 Bio € in 85-BSAA and -3.8 Bio € in 85-TRD. It is interesting to see, that whereas agricultural income is highest in the 85-STD scenario (‘quota-effect’), welfare losses are minimised with the introduction of tradable emission permits. It can be therefore extracted that the introduction of emission permits achieves a more efficient solution than emission standards from an overall perspective (uniform or non-uniform).

It is important to highlight that the presented welfare analysis does not take into account the benefits obtained by future generations through a ‘better environment’, i.e. only ‘private welfare’ is considered. Welfare effects derived from the reduction of GHG emissions do not enter this calculation since their estimation goes beyond the scope of this study (e.g. reduction of damage costs from emission abatement). It is however important to remark this aspect since it is the key of climate policy: *most of the directly observed economic losses might be outweighed by future environmental benefits*.

7.4 Conclusions

In this chapter three typical KP emission abatement instruments are simulated in European agriculture: *a regional uniform emission standard*, *a specific burden-sharing-agreement for agriculture* and *a market for emission permits*. They are compared in the year 2001 by looking at supply, income and environmental effects. Through the introduction of price variability, a consistent analysis of welfare effects on consumers, agricultural producers, taxpayers and processing industry is allowed.

The results show how production restrictions in European agriculture, indirectly introduced through emission abatement policy, might lead to welfare gains for agricultural producers. This ‘quota effect’ is caused by the isolation of European agricultural markets from world markets through effective barriers to trade (import tariffs, export subsidies and tariff rate quotas). The decrease in domestic production plus a parallel restriction on imports increase pressure on internal demand, with higher producer and consumer prices as a consequence. From an overall perspective, total (private) welfare is estimated to be negative. This effect is however dampened with the introduction of tradable emission permits.

CHAPTER 8 Discussion

"Kangaroos offer a clue to global warming: researchers believe it might be possible to use bacteria found in the stomachs of kangaroos to reduce methane output from cows and sheep" (BBC News World Edition, 3rd of January 2002).

8.1 Limitations of the current research study

8.1.1 Uncertainty about the global warming effect across time

The global warming effect is still the 'big unknown' in emission abatement policy. Whereas climate change is 'certified' by the majority of the scientific community (not yet without discussion), nobody is capable of estimating the real dimension of it. Emission factor estimates are continuously updated, trying to reflect the new scientific findings. As a consequence, current policy proposals do not consider a 'full internalisation' of the environmental damage caused by GHG emissions on future generations. In other words, no proper discounting of economic effects in the future is carried out, due to lack of reliable estimates.

In the current study, emission factors published by the IPCC in 2000 have been used to estimate GHG emissions from agriculture. Nevertheless, the IPCC already published in 2001 an update of these and the UNFCCC re-calculated national GHG emission inventories in 2004. It is important to take into account these issues when comparing results since the sensitivity of the economic model used relies heavily on these parameters.

8.1.2 Carbon sinks

In GHG emission abatement accounting of carbon absorption by certain activities has been allowed. This issue has become very important in the current international negotiations and in some cases has been the trigger for dispute (e.g. USA decided not to sign the KP because its 1990 reference period would not cover massive re-forestation efforts carried out in the 80's). In the last UNFCCC meeting of the subsidiary bodies (June 2004, Bonn), further agreement was achieved on the estimation of carbon sinks from agriculture and forestry.

In the current analysis 'carbon sinks' have not been considered for the calculation of GHG emission inventories since the UNFCCC approach has been followed and they are not yet included in the common reporting format (CRF tables). However, several models have done this in the past and some emission factor estimates are already available in the literature.

8.1.3 Shadow value approach

Mathematical programming models rely on assumptions which might not always hold in reality. The current mathematical programming approach is logically not an exception and some hurdles have to be recognized in its application to the estimation of marginal abatement costs. In CAPRI, agricultural supply is modelled by using PMP calibration techniques. Whereas income is directly obtained by multiplying producer prices and quantities and adding up direct payments, costs for agricultural activities are calibrated in the base year to the Economic Accounts of Agriculture in order to ensure that ‘regional revenue is exhausted’. This is achieved through quadratic cost functions which rely on some exogenous direct and crossed point-elasticities.

In this study MACs have been indirectly estimated by shocking the model with an additional restriction. As already mentioned, the shadow value of this emission restriction can be interpreted as the marginal effect on the objective function. This effect depends partially on the regional cost structure assumed and can be slightly affected by the price elasticities used by the model. Nevertheless, continuous research on sensitivity issues has been carried out by the CAPRI team and model results, especially marginal values from restrictions, have proved to be quite robust to exogenous shocks in the system. Comparability with other models should, however, take into account these issues.

8.1.4 Production technologies

In the version of the model used for this study, limited yield variability for crop and animal activities has been allowed (apart from the activities which are explicitly modelled on different technological intensities, e.g. dairy cows high and low yield). This introduces an extensification or intensification effect at the margin which might indicate the trend of an agricultural activity reacting to an exogenous shock (e.g. policy reform). Other models work with explicit agricultural production technologies or management options (e.g. organic farming, tillage intensity or different crop rotations). These are at the moment not considered in the model due to data restrictions (in Europe there is still little regional data on agricultural management options).

8.2 Greenhouse gas emission abatement and Common Agricultural Policy reform

The latest CAP Reforms have had a relevant side-effect on the shrinking of GHG emissions from the European agricultural sector. After the reduction of intervention prices for subsidised activities, mainly cereals, and the implementation of environmental regulations in Agenda 2000 (e.g. set-aside, afforestation measures, nitrate directive, etc.), some extensification effects have been observed. Moreover, the decoupling options introduced by the recently adopted CAP Reform (Council of the European Union, 2004c) are expected to intensify this effect: whereas agriculture in rural areas is protected from abandonment for its environmental benefits, subsidisation leading to over-production is avoided. The reduction of Agenda 2000 direct payments and administrative prices and the introduction of modulation and partial decoupling mechanisms for subsidised agricultural activities will probably lead to somewhat similar effects than the enforcement of GHG emission abatement in European Agriculture, namely a *reduction in production* (in the first case due to an ‘ironing of inefficiencies’ and in the second case due to the linkage between emissions and agricultural production) and *an overall increase in agricultural income* (in both cases due to increases in producer prices, border protection being maintained). Nevertheless, the production and income effects of the CAP reform on single activities and regions will certainly not be the same. Whereas emission abatement instruments will increase the burden on activities with a low emission/income relationship and regions with low substitution possibilities (as presented in chapter 7), policy reform will mainly affect previously subsidised activities (e.g. cereals). Moreover, the direction of change for *total welfare* might be of different sign. Whereas in the current study a reduction in welfare is predicted (driven by higher consumer prices), the adopted policy reform is expected to lead to welfare gains if overall budgetary support is maintained[105].

The parallel consideration of the CAP 2003 policy reform in the current analysis of abatement measures would definitely change the reference scenario assumed (indirect link between ‘decoupling of premiums’ and ‘level of GHG emissions’). Although some simulation analysis has been done with the CAPRI model in this direction (Pérez et al., 2003), the environmental effects of policy reform in the medium-term have not been considered within the current analysis in order to avoid the introduction of additional assumptions.

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[105] This is however difficult to predict (e.g. support might decrease in real terms in the period of application) and not the objective of this study.

8.3 Emission mitigation technologies in agriculture

GHG emission mitigation measures can be categorised into (1) structural measures, (2) management measures and (3) technological measures (Oenema et al., 2004). In the current study, the first category has been analysed by looking at the indirect changes in land use caused by the explicit introduction of instruments of emission abatement. Structural variables of agriculture such as the type or size of farming are affected by environmental regulation. However, as in other sectors, *management changes* and *technological innovation* in agriculture have a high mitigation potential and might be a key issue in the future[106]. These can effectively target GHG emissions from agricultural sources, as presented in the following examples:

- Methane emissions from enteric fermentation can be reduced by *optimising the lifetime of dairy cows* (higher replacement rate) or *improving feeding* (diet manipulation).

- Manure management emissions (methane and nitrous oxide) can be targeted by *reductions in livestock density*, *manipulation of storage systems* (e.g. promotion of aerobic digestion by high-C additives), *introduction of end-of-pipe systems* (e.g. filters or ventilation systems) and *bio-gas production*.

- Methane emissions from rice production can be minimised by *shortening the flooding periods* in the year.

- Nitrous oxide emissions from manure excretion on grazings can be reduced by *restricting cattle grazing* or by *applying nitrification inhibitors* on pastures.

- Nitrous oxide emissions from synthetic fertiliser application can as well be minimised by *improving soil drainage* or by *using nitrification inhibitors*.

This non-exhaustive list of mitigation options is not addressed in the current study due to lack of data (partially related to the problem highlighted in section 8.1.4). Nevertheless the future implementation of emission abatement policies in agriculture should take them into account and develop appropriate controlling and sanctioning instruments.

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[106] Oenema differentiates between *management measures*, which focus on improving resource use efficiency and refer to the tactical and operational management decision, and *technological measures*, which require significant capital investment. In this chapter, both are considered together as an alternative to *structural measures*.

8.4 Environmental effectiveness and the problems of regulating an 'emission bubble' in European agriculture

In this study agricultural production has been considered as an indirect emitter of GHGs and therefore targeted from a sectoral perspective. This corresponds to a direct application of the polluter-pays-principle: only those who pollute bear the environmental costs of pollution. From this perspective, agriculture is an emitter of methane (from animal production, manure management and rice cultivation) and nitrous oxide (from agricultural soil management practices). It would therefore be justified to focus pollution control on activities for which GHGs are a by-product and extrapolate this approach to other sectors and regions in the world so that all agents contributing directly to the climate change externality would be included in a global GHG emission abatement system (*upstream approach*). Moreover, in order to minimise transaction costs, it would also be possible to consider only producers with a minimum pollution level so that an important share of emissions is covered by the system (e.g. US sulphur dioxide trading scheme).

However, this problem can also be observed from the demand side: consumers of certain polluting goods are, through their consumption, indirectly responsible for the emission of GHGs. Agriculture is an important consumer of mineral fertilisers, fuel or machinery, products which have attached GHGs as by-product in their production processes (mainly carbon dioxide). It could therefore be argued that agricultural firms, as single consumers of these goods, should bear the external costs of production (*downstream approach*)[107]. This approach could also be used to regulate emissions at a sectoral level and sectors be considered by environmental policy as independent entities. In order to keep transaction costs low, only important sources, or in this case applications, could also be considered so that a sufficient amount of emissions is included in the system (similar pattern as in the previous approach).

These approaches have direct implications on the environmental effectiveness of the economic emission abatement instrument selected depending on the size of the targeted externality. In the case of a *global emission abatement scheme* (aim of the KP), both approaches would be probably justified in terms of effectiveness (no leakages since all produced or consumed emissions are involved) and efficiency (derived from the introduction of emission pricing). However, the first approach would be preferred in terms of feasibility since producers are much less than

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[107] The household sector would have to pay in this system for emissions linked to food production.

consumers. The issue of transaction costs was already discussed in chapter 6 for the case of an emission permit market targeting agricultural producers.

Nevertheless, the case of the European Climate Change Program is a different one, its aim is ‘to internalise a global externality within certain physical borders’ (bubble policy). The issue of ‘abatement accounting’ has to be analysed more carefully since *the import-export share of environmental polluting products might change across time*. This implies that emission leakages could appear by targeting abatement on a pollution-producing sector (*upstream approach*) if Member States have the possibility of freely import ‘high polluting’ products from non-EU countries[108]. If this is the case, emissions could then be shifted to other world regions and not abated from a global perspective (environmental target not achieved). This problem could be minimised by choosing a *downstream approach* so that emissions are accounted from a demand perspective. The domestic demand for these products would have to drop parallel to the amount of emissions allowed in the scheme, this constraint being reflected on price increases (e.g. household demand for electricity). For products for which demand is fairly elastic, some further control would have to be introduced to avoid a possible export increase (emission leakage towards other non-EU countries).

These considerations are quite important when considering an ‘emission bubble’ and also affect the agricultural sector. Some examples of emission leakage in agriculture from an *upstream perspective* could come through higher imports of products for which a high application of mineral fertiliser is needed (e.g. vegetables and flowers). From a *downstream perspective* emission leakage could come through increases in exports of young animals (produced but not consumed as adult animals within the European boundaries).

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[108] This expression refers to products for which a high amount of GHGs is emitted in their respective production process.

CHAPTER 9 Summary and Conclusions

> *"In the long term, economic sustainability depends on ecological sustainability" (America's Living Oceans, Pew Oceans Report, 2003).*

9.1 Modelling of European greenhouse gas emission inventories

In this research study the CAPRI model, a widely applied agricultural model, is used as the main tool for estimating GHG emissions from agricultural sources. The approach followed makes use of the information on emission factors published by the IPCC (IPCC, 1997; IPCC, 2000) and activity data from public data bases (NEWCRONOS and REGIO domains of EUROSTAT). The presented modelling methodology has some advantages for the estimation of GHG emissions from agricultural sources relative to the use of national independent studies: (a) it enables a consistent and simultaneous analysis of emissions from crop and animal activities, (b) it makes use of transparent and accessible data sources and (c) it introduces an endogenous dose-response mechanism between production activities and emission sources which allows for further mitigation policy analysis.

Twelve agricultural emission sources are individually modelled: *methane* from enteric fermentation, manure management and rice production, and *nitrous oxide* from manure management, manure excretion on grazings, application of synthetic fertiliser, organic animal waste, application of total fertiliser on the field, crop residues, biological fixation, ammonia losses and atmospheric deposition. With this information, GHG emission inventories at Nuts 2 level are estimated for the year 2001 and validated through meticulous comparison with official NGHGIs.

EU-15 *methane emissions* are estimated to be 7.7 Mio tonnes in the year 2001, laying 10.4 % below official data. The main emitters are France and Germany, with 1.9 and 1.2 Mio tonnes respectively. Deviations with respect to official data may be due to differences in the specification of certain activities, inconsistencies in the EUROSTAT agricultural statistics and/or reporting differences by single Member States since similar rules for calculation of methane emission factors are used. For *nitrous oxide emissions,* estimates for the EU-15 are 0.5 Mio tonnes and match in average UNFCCC statistics. In this case, comparison is not that straightforward since specific rules for the calculation of emission factors (especially for emissions from agricultural soils) are used by Member States. Measured in carbon dioxide equivalents, GHG emissions from agriculture are 380.7 Mio tonnes, with an average deviation of -4.4 % for the EU-15. In this calculation, the endogenous emissions calculated by the model are corrected in order to cover some other sources not modelled (histosols and N leaching). Overall, 100 % of methane emissions and 72 % of nitrous oxide emissions are covered by the current modelling approach (see table (17) in section 3.4.2).

Looking at emission sources, *enteric fermentation* is the main source of methane (5.8 Mio tonnes) and *application of synthetic fertiliser application* the main source of nitrous oxide (0.18 Mio tonnes). Deviations in methane emissions are, however, mostly due to variations in *manure management emissions* (-18.4 %). One of the reasons is that the fraction of N in manure 'managed' by the model is lower than the one used by Member States, who do not always use IPCC default values for their GHG emission inventories. This is also reflected in nitrous oxide emissions (-13.4 % when summing up manure management and excretion on grazings). There is also an over-estimation of N_2O animal waste emissions (13 %) due to a higher amount of manure produced in the model (through manure-output functions) compared to the statistics used by Member States (see table (18) in section 3.4.2).

To summarise, on the one side, a slight under-estimation of *methane emissions* with respect to official NGHGIs can be observed. On the other side, *nitrous oxide emissions* in some big countries such as France, United Kingdom and Spain are slightly over-estimated but no clear pattern is observed. The modelled results seem, however, quite plausible since they do not deviate much for the EU-15 aggregate and are subject to strict regional consistency rules (advantage of the selected modelling approach).

9.2 Differences in marginal emission abatement costs across European regions

MACCs are a decisive tool of policy analysis since they deliver the necessary information to regulate emission abatement. They might help policy-makers in two ways: (1) estimating the economic effects on individual agents of command-and-control abatement instruments and (2) estimating the total mitigation effect of a market-based abatement instrument. MACCs are modelled in CAPRI by estimating the shadow values faced by regional supply models for a certain emission abatement target.

Member States face quite different MACs for a similar abatement objective. For an 8 % emission reduction, MACs vary between 57 € for Ireland and 143 € for the Netherlands and for a 15 % emission reduction MACs vary between 106 € for Ireland and 260 € for Denmark. Economically optimal adjustment in the regional models to the singular emission targets is achieved through production substitution and yield shifts. Since the model is calibrated to an observed regional production-mix in the base year, an optimum can only be reached through an expansion or contraction of these endogenous productive activities such as to fulfil the emission abatement goal and the rest of the restrictions in the model. Some Member States such as Denmark and the Netherlands have noticeably higher estimated MACCs than the others. This is due to their specialisation in intensive crop production, with high mineral fertiliser application together with high-yield cattle production processes. Income per hectare of Grandes Cultures (revenue plus premiums minus costs) in these countries is quite high, mainly due to yields above the EU average. But at the same time nitrous oxide emissions from synthetic fertiliser application are also quite high since high yields are coupled to high fertiliser application with the result of low income per ton of CO_2^{eq}. This leads to higher production losses for these activities compared to animal activities (more profitable in terms of income per emission unit).

9.3 Efficiency gains of tradable emission permits

In general, acknowledging that "something must be done" to avoid irreversible environmental degradation in the future it seems economically rational to minimise economic losses of this emission mitigation action from a sectoral perspective. Robust, detailed and consistent modelling tools are applicable to the climate change externality and can be useful for the policy-making process. With this purpose a market of emission permits in European agriculture is regarded as a feasible option and efficiency gains with respect to other abatement instruments estimated. Emission trading is modelled with the following characteristics: (1) cap and trade system, (2) ‘grandfathering’ of permits, (3) unrestricted trade between Nuts 2 regions and (4) direct modelling of transaction costs.

With the implementation of emission trading between European regions, income losses still remain with respect to the base year situation (the emission cap is still binding) but efficiency gains are achieved compared to the application of a uniform emission standard (agricultural income increases by 630 Mio €). These revenues are however dampened by the transaction costs linked to the emission trading scheme. For the EU-15 as a whole, 564 Mio € are estimated as efficiency gains. On the one side, *sellers* are able to compensate income losses from production substitution through permit rents: for example, United Kingdom moves from potential losses of

-302.4 Mio € to 146.7 Mio € gains through selling of permits). On the other side, *buyers* cover purchase costs of permits through higher revenues from production: for example Germany moves from potential income gains of 412.4 Mio € to 137.7 Mio € through buying of permits. All Member States are "better-off" through permit trading (consistent with microeconomic theory).By plotting the internal solution path for Member States, it can be observed how the average weighted MAC in the European Union falls from 171.3 € to 157.6 €.

To summarise, some relevant observations can be extracted: (a) emission trading proves to be a cost-effective solution for Member States due to the heterogeneity of marginal abatement costs and (b) the income effects of this instrument depend heavily on the transaction costs linked to its implementation.

9.4 Emission abatement including price effects

An important issue of emission abatement policy is the distribution of welfare effects between consumers and producers when trade policy measures are explicitly modelled and price variability is allowed. With fixed prices, model results show that any emission abatement policy in the agricultural sector imposes an economic burden on producers, which have to reduce production in order to fulfil individual emission targets. Nevertheless, by introducing price variability this effect does not hold anymore since income depends not only on production changes but also on output prices. In this study, *modelling results show how production restrictions in European agriculture, indirectly introduced through emission abatement policy, might lead to welfare gains for agricultural firms ('quota effect')*. This is caused by the isolation of European agricultural markets from world markets through effective barriers to trade (import tariffs, export subsidies and tariff rate quotas as binding constraints). Reductions in domestic production and parallel restrictions on imports increase pressure on internal demand with higher producer and consumer prices as a consequence.

At an aggregated level, agricultural income (= producer surplus) increases in all simulation scenarios. Whereas in a *uniform emission standard scenario* 40.7 Bio € are estimated as economic transfers to producers, in a *non-uniform emission standard (burden sharing agreement)* and a *market of emission permits* 33.3 Bio € and 40.6 Bio € are achieved (for the latter transaction costs are included). This positive effect is due to an increase in producer prices. On the other side, transfers to consumers (money metric utility measure) diminish due to an increase of consumer prices: -42.2, -37.3 and -40.7 Bio € in the defined scenarios respectively. Since public expenditure remains more or less constant (-2 Bio €), the effect on total welfare is mainly determined by the difference between gains achieved by producers and losses suffered by consumers and processing industry, the latter due to higher input costs. Total welfare is estimated negative in all simulation scenarios. It is, however, interesting to see, that whereas agricultural income is highest in the *uniform emission standard scenario* (‘quota-effect’), welfare losses are minimised with the introduction of tradable emission permits. It can be therefore extracted that *the introduction of emission permits achieves a more efficient solution than emission standards from an overall perspective.*

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Appendices

Appendix 1 Summary of Montreal Protocol Control Measures

Ozone Depleting Substances	Developed Countries	Developing Countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995[a]	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
Carbon tetrachloride	Phased out end of 1995[a]	Total phase out by 2010
Methyl chloroform	Phased out end of 1995[a]	Total phase out by 2015
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996[b] 35 % reduction by 2004 65 % reduction by 2010 90 % reduction by 2015 Total phase out by 2020[c]	Freeze in 2016 at 2015 base level Total phase out by 2040
Hydrobromofluorocarbons (HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl bromide (horticultural uses)	Freeze in 1995 at 1991 base level[d] 25 % reduction by 1999 50 % reduction by 2001 70 % reduction by 2003 Total phase out by 2005	Freeze in 2002 at average 1995-1998 base level 20 % reduction by 2005[e] Total phase out by 2015
Bromochloromethane (BCM)	Phase out by 2002	Phase out by 2002

[a] With the exception of a very small number of internationally agreed essential uses that are considered critical to human health and/or laboratory and analytical procedures.

[b] Based on 1989 HCFC consumption with an extra allowance equal to 2.8 % of 1989 CFC consumption.

[c] Up to 0.5 % of base level consumption can be used until 2030 for servicing existing equipment.

[d] All reductions include an exemption for pre-shipment and quarantine uses.

[e] Review in 2003 to decide on interim further reductions beyond 2005.

Source: Australian Government, 2004.

Appendix 2 Annex I countries of the UNFCCC

Australia	Germany	Norway
Austria	Greece	Poland [1]
Belarus [1]	Hungary [1]	Portugal
Belgium	Iceland	Romania [1]
Bulgaria [1]	Ireland	Russian Federation [1]
Canada	Italy	Spain
Czechoslovakia [1]	Japan	Sweden
Denmark	Latvia [1]	Switzerland
EU	Lithuania [1]	Turkey
Estonia [1]	Luxembourg	Ukraine [1]
Finland	Netherlands	UK and North Ireland
France	New Zealand	USA

Source: Annex I of the UNFCCC (UN, 1992b).

[1] Countries that are undergoing a transition process to a market economy.

Appendix 3 Annex II countries of the UNFCCC

Australia	Greece	Portugal
Austria	Iceland	Spain
Belgium	Ireland	Sweden
Canada	Italy	Switzerland
Denmark	Japan	Turkey
EU	Luxembourg	UK and North Ireland
Finland	Netherlands	USA
France	New Zealand	
Germany	Norway	

Source: Annex II of the UNFCCC (UN, 1992b).

Appendix 4 Greenhouse gases and sources in the Kyoto Protocol

GHGs
Carbon Dioxide
Methane
Nitrous Oxide
Hydrofluorocarbons
Perfluorocarbons
Sulfur hexafluoride

Sectors /Source categories
Energy
Fuel combustion
Fugitive emissions from fuels
Industrial processes
Solvent and other product use
Agriculture *
Waste

Source: Annex A of the Kyoto Protocol (UN, 1997).

* Comprehended in the current modelling analysis are emissions from enteric fermentation, manure management, rice cultivation and agricultural soils (see chapter 3).

Appendix 5 Emission Reduction Commitments in the Kyoto Protocol

Australia	108	Hungary [1]	94	Poland [1]	94
Austria	92	Iceland	110	Portugal	92
Belgium	92	Ireland	92	Romania [1]	92
Bulgaria [1]	92	Italy	92	Russian Federation [1]	100
Canada	94	Japan	94	Slovakia [1]	92
Croatia [1]	95	Latvia [1]	92	Slovenia [1]	92
Czech Republic [1]	92	Liechtenstein	92	Spain	92
Denmark	92	Lithuania [1]	92	Sweden	92
EU	92	Luxembourg	92	Switzerland	92
Finland	92	Monaco	92	Ukraine [1]	100
France	92	Netherlands	92	UK and North Ireland	92
Germany	92	New Zealand	100	USA	93
Greece	92	Norway	101		

Source: Annex B of the Kyoto Protocol (UN, 1997); percentage reduction with respect to 1990 emissions.

[1] Countries that are undergoing a transition process to a market economy.

Appendix 6 Indirect greenhouse gas emissions not included under the rubric ‘agriculture’ of national greenhouse gas emission inventories

App. 6.1. Carbon dioxide emissions from diesel consumption in machinery use

The most important source of carbon dioxide in agriculture is machinery use (tractors, harvesting machines, etc). Little for not to say no attempts have been made to model CO_2 emissions from diesel consumption in agriculture per activity[109]. CO_2 emission estimates from fuel consumption in Agriculture, Forestry and Fisheries (liquid, solid, gaseous and biomass) are reported by Member States under the rubric ‘energy’. They are therefore included in the GHG emission inventories as part of the energy sector, but not disaggregated.

Recent research in this field has been mainly focused on the mitigation options derived by the use of bio-fuels in agriculture (Schneider, McCarl, 2003) which are not the objective of this study. The problem is that few data on technological application of machinery to different agricultural activities is available up to date at a regional level. In this modelling exercise, information on energy costs covered in the European Accounts of Agriculture (EUROSTAT) and engineering information on diesel consumption per crop activity (KTBL, 2002) are combined to estimate CO_2 emissions from machinery application on agricultural fields. Additional information on subsidised diesel costs for Member States is used to match both sources (Commission of the European Communities, 2003b). Moreover, an average technology for each phase of the cropping system is assumed for all European countries and differences in emissions per hectare across regions are explained by different subsidisation policies and land use.

From the methodological point of view, a cross entropy approach is used to consistently calculate agricultural fuel consumption by including support points based on information on diesel consumption per activity and percentage of diesel costs on total energy costs This information is directly used to calculate regional diesel consumption and CO_2 emission units (KBA, 2000).

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[109] The EEA does not provide any information in its online data service on CO_2 emissions for the agricultural sector but some data on CO_2 from agricultural soils for Finland (http://dataservice.eea.eu.int/dataservice/, accessed on June 2004)

$$(9.1) \qquad CO2Die_r = \sum_i \left[EG_{r,i} / DP_r * Cg * X_{r,i} \right]$$

Where:
CO2Die = carbon dioxide emissions from diesel burning on machinery (in tonnes).
EG = fuel costs per activity (in € per hectare or head)
DP = agricultural fuel price (in € per litter)
Cg = carbon dioxide emission factor (in kg CO_2 per litter of diesel consumed)

This analysis presents a highly valuable pressure indicator which can be used, as previously indicated, for other research objectives. Its principal weakness refers to the lack of national data on cropping technologies (tillage, harvesting, etc). It should be considered as a reference point for the rest of emission sources calculated in the model (it is subject to the same assumptions and data sources: energy costs, land management variables, etc).

App. 6.2. Carbon dioxide and nitrous oxide emissions from fertiliser production

An important indirect source of GHG emissions in European agriculture are production processes of mineral fertilisers. Based on the work done by Molina (Molina, 2004), carbon dioxide and nitrous oxide emissions factors are estimated for the three main types of mineral fertilisers applied in Europe: *nitrogenous*, *phosphate* and *potash fertilisers*.

The structure of the fertiliser sector in Europe is characterised by an increasing dependency of foreign production. Fertiliser consumption has changed during the last years forcing the fertiliser industry to adapt itself not only due to market fluctuations but also to new environmental policies. In 1985, the EU-15 imported 9.8 Mio tonnes of fertilisers and exported 11.4 Mio tonnes. Step by step this trend has been changing over time and from 1989 onwards Europe became a net importer of fertilisers (3.4 million tonnes in 2001).

Technical progress in agriculture has been coupled to the wide-spread use of anorganic fertilisers. They have contributed to an increasing improvement on yields but at the same time have raised some health and environmental concerns. From an environmental perspective, the main negative externalities attached to its production are *carbon dioxide* and *nitrous oxide emissions*. Both these pollutants are classified by the IPCC as climate relevant gases and, therefore, will be the centre of this analysis. For simplicity, no distinction is made regarding domestically produced or imported fertiliser and uniform emission factors matching current European production technology are assumed. For the purpose of this modelling exercise, consumption is assumed to be equal to production, reference emissions being calculated based on FAO consumption statistics (demand side of the problem) and emission factors on production ones. In this analysis, farmers are 'charged' with the environmental burden of their own consumption pattern.

In the following equations carbon dioxide and nitrous oxide emissions are calculated based on total mineral fertiliser application, which takes into account demand of nutrients by crops ($ND_{r,k,f}$), correction for N losses through ammonia volatilisation from mineral fertiliser application ($AmmMF_r$) and for observed over-fertilisation practices ($NutCorr_{r,f}$)

$$(9.2) \qquad CO2\,\mathrm{Pr}\,d_r = \sum_k \left[\sum_f \left(ND_{r,k,f} * NutCorr_{r,f} * MF_{r,k} / (1 - AmmMF_r) * Ch_f \right) * X_{r,k} \right]$$

$$(9.3) \qquad N2O\,\mathrm{Pr}\,d_r = \sum_k \left[\sum_f \left(ND_{r,k,f} * NutCorr_{r,f} * MF_{r,k} / (1 - AmmMF_r) * Ci_f \right) * X_{r,k} \right]$$

Where:

CO2Prd = nitrous oxide emissions from mineral fertiliser production (in tonnes)

N2OPrd = nitrous oxide emissions from mineral fertiliser production (in tonnes)

Ch = carbon dioxide emission factor for mineral fertiliser produced (in kg per ton of fertiliser produced)

Ci = nitrous oxide emission factor for mineral fertiliser produced (in kg per ton of fertiliser produced)

In table (33) balanced average emission factors for nitrogenous, phosphate and potash fertiliser production are reported. This table shows emission data, including CO_2^{eq} from N_2O, of fertilisers production processes (tonnes of CO_2^{eq} per tonne of nutrient). It make sense to calculate emissions per nutrient and not per manufactured products since many regional statistics about fertilisers consumption are not ordered by specific fertiliser types but by nutrients.

Table (33) Emission factors for average and modern technology production of nitrogenous, phosphate and potash fertilisers and fertiliser production data (average for the EU-15)

	CO_2^{eq} average technology	CO_2^{eq} modern technology	Production
Ammonium Nitrate	6.80	3.00	1359
Ammonium Phosphate (N)	3.34	0*	21
Ammonium Sulphate	3.10	1.28	760
Ammonium SulphateNitrate	7.51	3.28	12
Calcium Ammonium Nitrate	6.87	3.02	2698
Other Complex Fert (N)	9.61	3.80	1734
Other Nitrogenous Fert	4.76	2.23	762
Urea	1.33	0.91	1288
Nitrogenous Fertilisers	**6.06**	**2.62**	**8634**
Concent Superphosphate (TSP)	0.27	0*	177
Ground Rock Phosphate (triple)	0.17	0*	134
Single Superphosphate	0.18	0*	145
Oth Complex Fert (P2o5)	2.84	0*	1795
Other Phosphate Fertil	2.84	0*	35
Basic Slag	0.27	0*	5
Phosphate Fertilisers	**2.32**	**0***	**2289**
Muriate Over 45% K2o (MOP)	0.33	0*	5086
Potash Fertilisers	**0.33**	**0***	**5086**

Source: Molina, 2004; 0.057 tonnes of CO_2 per Giga-Joule for natural gas combustion assumed (currently used by 85 % of European factories); 2001 three year average.

Measurement units: tonnes of CO_2^{eq} per tonne of nutrient for emission factors and 1000 tonnes of nutrient for production data.

* Note: zero and even negative values are due to reductions in emissions by energy recycling (mainly achieved in other sectors, e.g. heating). For the current 'sectoral' analysis, only a positive data set is used.

According to Jenssen and Kongshaug (Jenssen, Kongshaug, 2003), 58 % of total GHG emissions from fertiliser production are N_2O and the rest CO_2. In order to calculate *N_2O emission factors* for nitrogenous, phosphate and potash fertiliser production, the previous coefficients are multiplied by 0.58 and divided by 310 (global warming potential). *CO_2 emission factors* are just obtained by multiplying by 0.42 (see table (34)).

Table (34) Average carbon dioxide and nitrous oxide emission factors for nitrogenous, phosphate and potash fertilisers (average for the EU-15)

	Nitrogenous Fertiliser		Phosphate Fertiliser		Potash Fertiliser	
	Average technology	Modern technology	Average Technology	Modern Technology	Average Technology	Modern Technology
Carbon dioxide	2543.65	1101.42	970.36	0*	0.14	0.07
Nitrous oxide	11.33	4.91	4.32	0*	0.62	0.31

Source: Molina, 2004; 2001 three year average calibration year.

Measurement units: kg per tonne of nutrient.

Nitrogenous fertilisers' production is the main source of emissions, being at the same time the most applied fertiliser type in agriculture. A ton of nutrient produced implies a loss of 2.5 tonnes of CO_2 and 11 kg of N_2O considering the current average technology used in Europe.

Appendix 7 Estimated greenhouse gas emissions from agricultural sources and comparison with reported emission inventories at Member State level

App. 7.1. Methane Emissions

	EU-15	Austria	Belgium+Lux	Denmark	Finland	France	Germany	Greece
4. CH$_4$ Agriculture	**7658.83**	**169.99**	**220.31**	**183.98**	**87.47**	**1903.56**	**1190.33**	**158.09**
A. Enteric Fermentation (Tier 2)	**5820.88**	143.76	180.71	140.88	74.44	1267.46	997.34	131.01
B. Manure Management (Tier 2)	**1758.15**	26.23	39.60	43.10	13.03	632.27	192.99	22.96
C. Rice Cultivation	**79.80**	0.00	0.00	0.00	0.00	3.84	0.00	4.11
D. Agricultural Soils	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E. Prescribed Burning of Savannas	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Field Burning of Agricultural Residues	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G. Other	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other CH$_4$ Indicators in CAPRI (endogenous)								
A. Enteric Fermentation (Tier 1)	**5741.87**	141.23	187.12	123.18	64.44	1335.98	866.66	133.79
B. Manure Management (Tier 1)	**1518.48**	23.23	35.36	38.75	10.85	542.69	162.13	20.90

	EU-15	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom
4. CH4 Agriculture	**7658.83**	**433.00**	**701.31**	**390.40**	**172.74**	**876.07**	**129.33**	**1042.26**
A. Enteric Fermentation (Tier 2)	**5820.88**	382.94	568.82	324.03	112.36	637.47	110.29	749.39
B. Manure Management (Tier 2)	**1758.15**	50.06	88.72	66.37	55.45	215.45	19.04	292.87
C. Rice Cultivation	**79.80**	0.00	43.77	0.00	4.93	23.15	0.00	0.00
D. Agricultural Soils	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
E. Prescribed Burning of Savannas	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Field Burning of Agricultural Residues	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G. Other	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other CH4 Indicators in CAPRI (endogenous)								
A. Enteric Fermentation (Tier 1)	**5741.87**	406.32	538.85	273.55	119.66	686.21	99.59	765.30
B. Manure Management (Tier 1)	**1518.48**	43.01	77.60	56.33	48.74	196.58	15.60	246.71

Source: own calculations, 2001 three year average calibration year for CAPRI and NGHGIs for year 2001.

App. 7.2. Nitrous Oxide Emissions

	EU-15	Austria	Belgium+Lux	Denmark	Finland	France	Germany	Greece
4. N_2O Agriculture (corrected)	**717.72**	**12.93**	**26.97**	**22.18**	**12.26**	**187.10**	**131.78**	**10.45**
4. N_2O Agriculture	**519.71**	**9.89**	**11.71**	**14.39**	**7.05**	**132.60**	**101.05**	**10.45**
A. Enteric Fermentation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B. Manure Management	43.20	1.08	1.37	2.06	0.53	9.43	9.63	0.24
C. Rice Cultivation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Agricultural Soils	476.51	8.8	10.3	12.3	6.5	123.2	91.4	10.2
--- Atmospheric Deposition (ammonia vol.)	50.30	1.01	1.23	1.67	0.50	11.75	10.01	0.72
--- Animal Production (N excretion on pasture)	61.79	1.43	1.50	1.09	0.65	18.05	11.57	0.34
--- Crop Residues	30.92	0.69	0.39	1.14	0.58	10.03	8.18	0.48
--- N fixation	7.67	0.15	0.18	0.16	0.13	1.97	1.17	0.16
--- Org fertiliser (Animal Waste)	151.82	3.11	3.87	4.15	1.44	37.00	26.02	3.41
--- Syn fertiliser (application)	174.02	2.42	3.17	4.13	3.22	44.38	34.46	5.10
--- Histosols (EXOGENOUS)	18.04	0.00	0.00	0.23	3.75	0.00	10.59	0.00
--- Nitrate Leaching (EXOGENOUS)	148.17	3.04	0.00	7.41	1.45	50.94	20.14	0.00
--- Other (EXOGENOUS)	31.80	0.00	15.26	0.15	0.01	3.55	0.00	0.00
E. Prescribed Burning of Savannas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Field Burning of Agricultural Residues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G. Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other N_2O Indicators in CAPRI (endogenous)								
--- Application of fertilizer (incl. overfertilisation)	214.70	3.07	4.63	5.81	3.82	56.27	43.19	5.73
--- Fertilizer Production	119.46	1.65	2.10	2.64	2.14	30.77	22.25	3.55
--- Atmospheric Deposition (rainfall)	18.52	0.71	0.52	0.53	0.15	4.64	4.86	0.30

	EU-15	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom
4. N_2O Agriculture (corrected)	**717.72**	**24.26**	**77.16**	**27.83**	**12.45**	**64.68**	**17.36**	**90.31**
4. N_2O Agriculture	**519.71**	**20.80**	**52.30**	**23.12**	**8.03**	**52.70**	**9.49**	**66.13**
A. Enteric Fermentation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B. Manure Management	43.20	1.34	4.81	3.01	0.75	3.94	0.76	4.23
C. Rice Cultivation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D. Agricultural Soils	476.51	19.5	47.5	20.1	7.3	48.8	8.7	61.9
--- Atmospheric Deposition (ammonia vol.)	50.30	1.56	6.96	2.61	0.89	5.32	0.76	5.31
--- Animal Production (N excretion on pasture)	61.79	3.53	6.43	2.86	0.93	4.42	1.00	7.99
--- Crop Residues	30.92	0.23	2.25	0.45	0.19	2.24	0.78	3.30
--- N fixation	7.67	0.42	0.78	0.37	0.12	0.75	0.18	1.13
--- Org fertiliser (Animal Waste)	151.82	6.89	16.06	8.18	2.98	15.33	2.15	21.22
--- Syn fertiliser (application)	174.02	6.82	15.00	5.63	2.18	20.70	3.86	22.95
--- Histosols (EXOGENOUS)	18.04	0.00	0.11	0.00	0.00	0.00	3.05	0.31
--- Nitrate Leaching (EXOGENOUS)	148.17	3.47	19.98	0.00	4.41	11.56	2.43	23.33
--- Other (EXOGENOUS)	31.80	0.00	4.77	4.71	0.00	0.43	2.39	0.53
E. Prescribed Burning of Savannas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F. Field Burning of Agricultural Residues	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G. Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other N_2O Indicators in CAPRI (endogenous)								
--- Application of fertilizer (incl. overfertilisation)	214.70	7.48	19.82	7.44	2.87	24.89	4.71	24.98
--- Fertilizer Production	119.46	4.53	11.70	3.59	1.63	15.45	2.44	15.00
--- Atmospheric Deposition (rainfall)	18.52	0.50	1.46	0.75	0.10	1.25	0.15	2.60

Source: own calculations, 2001 three year average calibration year for CAPRI and NGHGIs for year 2001.

App. 7.3. Comparison with reported greenhouse gas emission inventories for Member States

	% of total emissions	EU-15	Austria	Belgium+Lux	Denmark	Finland	France	Germany	Greece
4. N_2O Agriculture (corrected)		**2%**	**13%**	**60%**	**-13%**	**2%**	**6%**	**3%**	**-49%**
4. N_2O Agriculture	**100.0%**	**-26%**	**-13%**	**-30%**	**-44%**	**-42%**	**-25%**	**-21%**	**-49%**
B. Manure Management	9.9%	-38%	-53%	-12%	45%	-59%	-1%	-54%	-74%
D. Agricultural Soils(2)	90.0%	-25%	-3%	-32%	-49%	-39%	-26%	-15%	-48%
--- Atmospheric Deposition (ammonia vol.)	5.3%	35%	169%	---	45%	22%	18%	32%	---
--- Animal Production (N excretion on pasture)	12.7%	-31%	111%	---	17%	21%	-5%	98%	-97%
--- Crop Residues	5.1%	-15%	40%	---	-80%	13%	5%	114%	-73%
--- N fixation	2.0%	-47%	-58%	---	-78%	634%	-74%	14170%	501%
--- Org fertiliser (Animal Waste)	13.2%	64%	68%	---	25%	71%	48%	8%	351%
--- Syn fertiliser (application)	23.6%	5%	4%	---	-6%	0%	8%	-3%	-8%
4. CH_4 Agriculture	**100.0%**	**-10%**	**-12%**	**-36%**	**6%**	**4%**	**-9%**	**-2%**	**-10%**
A. Enteric Fermentation (Tier 2)	73.3%	-7%	-4%	-16%	8%	0%	-9%	0%	-8%
B. Manure Management (Tier 2)	25.2%	-18%	-39%	-68%	2%	34%	-7%	-9%	-2%
C. Rice Cultivation	1.3%	-28%	---	---	---	---	-55%	---	-34%

	% of total emissions	EU-15	Ireland	Italy	Netherlands	Portugal	Spain	Sweden	United Kingdom
4. N_2O Agriculture (corrected)		**2%**	**-7%**	**-1%**	**20%**	**-34%**	**3%**	**-4%**	**3%**
4. N_2O Agriculture	**100.0%**	**-26%**	**-20%**	**-33%**	**0%**	**-58%**	**-16%**	**-47%**	**-25%**
B. Manure Management	9.9%	-38%	-39%	-65%	394%	-81%	-24%	-57%	-5%
D. Agricultural Soils(2)	90.0%	-25%	-19%	-26%	-11%	-51%	-14%	-46%	-26%
--- Atmospheric Deposition (ammonia vol.)	5.3%	35%	2%	70%	---	60%	-5%	26%	-2%
--- Animal Production (N excretion on pasture)	12.7%	-31%	-63%	-9%	13%	-82%	-58%	-29%	-47%
--- Crop Residues	5.1%	-15%	-38%	-17%	---	-67%	5%	-40%	-54%
--- N fixation	2.0%	-47%	2508%	-78%	87%	22%	-14%	69%	18%
--- Org fertiliser (Animal Waste)	13.2%	64%	391%	94%	-13%	65%	168%	-13%	166%
--- Syn fertiliser (application)	23.6%	5%	-11%	7%	-1%	-5%	5%	58%	3%
4. CH_4 Agriculture	**100.0%**	**-10%**	**-18%**	**-19%**	**-5%**	**-38%**	**-22%**	**-17%**	**14%**
A. Enteric Fermentation (Tier 2)	73.3%	-7%	-17%	-7%	1%	-9%	-8%	-19%	-8%
B. Manure Management (Tier 2)	25.2%	-18%	-25%	-53%	-25%	-62%	-47%	-3%	190%
C. Rice Cultivation	1.3%	-28%	---	-41%	---	-43%	65%	---	---

Source: own calculations; 2001 three year average calibration year for CAPRI and NGHGIs for year 2001; comparison of CAPRI estimations with NGHGIs.

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Appendix 8 Estimated shadow values for the construction of regional marginal abatement cost curves

App. 8.1. For the EU-15 and Member States

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
European Union	**EU000**	12.0	24.0	36.1	48.2	60.3	72.5	84.6	96.5	108.3	119.5	130.0	140.5	150.9	161.1	171.3
Austria	**AT000**	13.6	27.9	42.2	56.7	71.1	85.5	100.1	114.7	129.4	144.0	158.6	173.0	187.1	201.2	215.4
Belgium	**BL000**	13.9	27.9	42.0	56.2	70.4	84.6	99.0	113.4	128.0	142.5	156.6	170.1	183.5	196.7	209.9
Germany	**DE000**	14.8	29.7	44.7	60.0	75.2	90.2	104.6	118.1	130.6	141.6	152.2	162.7	173.4	184.2	195.0
Denmark	**DK000**	15.9	32.0	48.1	64.6	81.2	98.0	114.8	132.3	156.2	173.6	191.2	208.6	225.9	243.2	260.5
Greece	**EL000**	8.9	18.0	27.1	36.3	45.4	54.5	63.7	73.1	82.7	92.5	102.8	113.2	124.5	136.6	149.0
Spain	**ES000**	8.2	16.0	24.2	32.2	40.2	48.2	56.3	64.6	72.9	81.4	89.3	97.3	105.1	112.9	120.8
Finland	**FI000**	20.2	38.7	53.2	67.1	82.6	98.4	114.5	130.7	147.0	163.3	179.6	195.9	212.4	228.9	245.6
France	**FR000**	12.2	24.5	36.8	49.3	61.9	74.6	87.4	100.2	113.2	125.1	135.8	146.3	156.4	166.3	175.7
Ireland	**IR000**	7.1	14.1	21.1	28.2	35.3	42.6	49.9	57.2	64.5	71.9	78.9	85.6	92.4	99.1	105.9
Italy	**IT000**	15.0	30.6	46.1	61.8	77.6	93.5	109.2	123.4	136.7	150.0	163.2	176.3	189.4	202.4	215.2
Netherlands	**NL000**	17.3	35.1	52.7	70.4	88.1	105.9	123.7	141.7	159.6	177.6	194.2	210.3	226.5	242.8	259.0
Portugal	**PT000**	8.7	17.2	26.0	34.8	43.9	53.0	62.4	71.9	81.3	89.5	97.6	105.5	113.6	121.9	130.5
Sweden	**SE000**	13.7	27.2	40.1	50.1	59.9	69.5	79.2	88.9	98.7	108.6	118.6	128.7	138.9	149.2	159.9
United Kingdom	**UK000**	7.4	14.6	22.0	29.4	36.8	44.2	51.6	59.0	66.5	73.8	80.8	87.8	94.7	101.4	108.0

Source: own calculations; year 2001; Luxembourg is modelled together with Belgium; emission reduction standards for CO_2^{eq} emissions from 1 % to 15 %.

App. 8.2. For Nuts 2 regional units (Nuts 1 if not further disaggregated)

	Code	**1%**	**2%**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**	**11%**	**12%**	**13%**	**14%**	**15%**
BURGENLAND	**AT110**	20.1	40.4	60.6	80.8	101.0	121.2	141.4	161.6	181.8	201.9	222.0	237.9	246.3	254.8	263.2
NIEDEROESTERREICH	**AT120**	14.7	30.3	46.2	61.7	76.5	91.4	106.3	121.2	136.1	150.8	165.6	180.4	195.2	210.0	224.8
KAERNTEN	**AT210**	11.5	23.4	35.4	47.6	60.0	72.3	84.8	97.6	110.7	123.7	136.7	149.7	162.8	175.9	188.9
STEIERMARK	**AT220**	12.8	26.3	39.9	53.7	67.7	81.8	96.3	110.8	125.4	139.9	154.5	169.0	183.5	198.0	212.5
OBEROESTERREICH	**AT310**	12.2	24.9	37.8	51.3	64.8	78.4	92.0	105.6	119.3	132.8	146.3	159.8	173.4	186.9	200.5
SALZBURG	**AT320**	13.6	28.1	42.6	57.5	72.4	87.4	102.4	117.5	132.5	147.5	162.5	177.4	192.4	207.4	222.4
TIROL	**AT330**	14.1	28.3	42.7	57.0	71.5	86.2	100.9	116.2	131.4	146.7	162.0	177.7	193.5	209.2	225.0
VORARLBERG	**AT340**	15.2	30.8	46.3	61.7	77.3	93.1	109.0	125.3	141.9	158.5	175.2	192.2	209.3	226.4	243.6
ANTWERPEN	**BL210**	14.2	28.8	43.3	57.9	72.4	86.9	101.4	116.0	130.5	144.9	159.8	175.3	190.9	206.6	222.2
LIMBURG (B)	**BL220**	16.0	32.3	48.6	64.9	81.2	97.7	114.5	131.6	149.3	166.8	184.3	201.8	219.5	237.2	255.5
OOST-VLAANDEREN	**BL230**	14.1	28.5	43.1	58.2	73.5	89.3	105.2	121.2	137.3	153.4	169.4	185.4	201.5	217.5	233.6
VLAAMS BRABANT	**BL240**	14.9	29.9	44.9	60.1	75.1	90.2	105.4	120.6	136.0	151.3	166.6	182.1	197.6	213.2	228.9
WEST-VLAANDEREN	**BL250**	15.0	30.4	45.7	61.0	76.2	91.4	106.7	122.2	137.8	153.4	169.3	185.4	201.5	217.7	234.4
BRABANT WALLON	**BL310**	14.9	29.7	44.6	59.5	74.4	89.3	104.3	119.4	134.5	149.6	160.0	169.7	179.8	190.2	200.6
HAINAUT	**BL320**	13.2	26.3	39.5	52.8	65.9	79.1	92.4	105.7	119.0	132.4	145.7	156.3	165.8	175.4	184.9
LIEGE	**BL330**	13.9	27.7	41.6	55.6	69.5	83.4	97.4	111.5	125.7	139.8	153.8	163.4	173.0	182.6	192.2
LUXEMBOURG (B)	**BL340**	10.5	20.5	30.8	41.2	51.6	62.0	72.5	83.1	93.8	104.5	115.2	125.9	136.6	147.3	156.2
NAMUR	**BL350**	11.9	23.5	35.4	47.3	59.2	71.1	83.0	95.1	107.2	119.3	131.3	143.3	154.5	163.2	171.8
LUXEMBOURG (GRAND-DUCHE)	**BL400**	15.1	30.3	45.6	60.9	76.3	91.8	107.4	123.1	138.7	153.9	163.5	173.6	183.9	194.3	204.7
STUTTGART	**DE110**	16.2	33.4	50.6	67.1	83.3	99.2	115.0	130.7	142.6	154.0	165.3	176.7	188.0	199.4	210.8
KARLSRUHE	**DE120**	16.2	32.5	49.2	65.9	82.5	98.9	114.7	130.4	141.4	152.0	162.6	173.2	183.8	194.5	205.1
FREIBURG	**DE130**	13.6	27.0	40.7	54.6	68.7	82.8	96.7	110.8	124.9	136.8	146.8	156.8	166.8	176.8	186.8
TUEBINGEN	**DE140**	14.1	28.3	42.6	57.4	72.4	87.3	102.1	116.9	131.7	142.6	153.4	164.2	175.0	185.9	196.8
OBERBAYERN	**DE210**	14.5	28.9	43.7	58.5	73.3	88.1	102.8	117.5	130.9	141.5	152.3	163.0	173.8	184.6	195.3
NIEDERBAYERN	**DE220**	15.3	30.6	46.0	61.4	76.9	92.0	106.9	121.9	136.8	148.2	159.5	170.9	182.3	193.6	205.0
OBERPFALZ	**DE230**	15.5	31.1	46.8	62.6	78.4	94.1	109.7	125.4	139.9	151.1	162.3	173.5	184.7	195.9	207.2
OBERFRANKEN	**DE240**	15.2	30.6	46.3	62.1	77.9	93.6	108.9	124.4	138.3	149.1	159.9	170.6	181.4	192.2	202.9
MITTELFRANKEN	**DE250**	15.4	30.8	46.3	61.9	77.5	92.8	108.1	123.4	138.6	150.1	161.5	172.9	184.4	195.9	207.4
UNTERFRANKEN	**DE260**	16.2	32.6	49.3	66.0	82.6	99.0	114.7	130.3	142.0	153.0	164.0	175.0	186.0	197.0	208.1
SCHWABEN	**DE270**	12.9	26.0	39.2	52.7	66.1	79.4	92.5	107.4	123.5	138.7	149.9	161.2	172.5	183.7	195.1

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
BRANDENBURG	**DE400**	15.2	30.1	45.2	60.4	75.6	90.5	105.2	116.1	123.7	131.4	139.1	147.7	157.2	166.7	176.3
DARMSTADT	**DE710**	15.2	30.4	45.8	62.0	79.1	96.0	111.4	126.8	139.2	149.9	160.6	171.3	182.1	192.8	203.5
GIESSEN	**DE720**	13.7	27.3	41.2	55.7	70.3	84.9	99.1	113.4	127.6	139.5	149.8	160.0	170.3	180.6	190.9
KASSEL	**DE730**	14.6	29.1	43.8	59.0	74.4	89.7	104.6	119.5	133.4	143.9	154.5	165.1	175.6	186.2	196.7
MECKLENBURG-VORPOMMERN	**DE800**	16.2	32.3	48.5	64.9	81.2	97.4	112.4	122.2	132.0	141.8	151.3	161.0	170.8	180.6	190.5
BRAUNSCHWEIG	**DE910**	17.7	35.7	54.1	72.8	91.4	109.2	126.2	137.4	148.6	159.8	171.2	182.2	193.3	204.3	215.3
HANNOVER	**DE920**	16.1	32.1	48.3	64.5	80.7	96.7	112.3	128.0	140.2	151.3	162.5	173.6	184.8	195.9	207.1
LUENEBURG	**DE930**	12.2	24.3	37.4	51.5	65.6	79.6	93.7	107.8	121.9	134.3	144.9	155.6	166.3	177.0	187.7
WESER-EMS	**DE940**	14.9	30.2	45.2	60.6	75.9	91.1	106.1	121.1	134.8	146.8	158.9	170.8	182.7	194.7	206.8
DUESSELDORF	**DEA10**	15.1	30.5	46.0	61.6	77.2	92.6	108.0	123.4	138.8	151.3	163.3	175.2	187.2	199.2	211.2
KOELN	**DEA20**	14.4	28.9	43.8	58.9	74.0	89.0	103.8	118.6	133.4	146.7	157.6	168.5	179.4	190.3	201.2
MUENSTER	**DEA30**	15.5	31.6	47.6	63.7	79.7	95.3	110.8	126.4	140.4	153.1	165.8	178.5	191.1	203.8	216.5
DETMOLD	**DEA40**	15.2	30.5	45.9	61.4	76.8	91.9	106.8	121.7	136.5	148.2	159.8	171.3	182.9	194.4	206.0
ARNSBERG	**DEA50**	12.7	25.6	38.7	52.4	66.5	80.5	94.2	107.8	121.4	135.0	146.9	157.6	168.3	179.0	189.7
KOBLENZ	**DEB10**	13.8	27.6	41.7	55.9	70.3	84.8	99.2	113.5	127.8	139.3	149.5	159.9	170.4	180.8	191.3
TRIER	**DEB20**	11.3	22.7	34.1	45.7	58.1	71.2	84.4	97.6	111.1	124.4	134.4	144.6	155.1	165.6	176.2
RHEINHESSEN-PFALZ	**DEB30**	19.1	37.9	57.0	76.1	95.2	114.0	129.3	140.4	151.5	162.5	173.6	184.6	195.7	206.8	217.8
SAARLAND	**DEC00**	11.6	23.1	34.8	47.4	60.2	72.9	85.5	98.1	110.6	123.1	132.3	141.7	151.1	160.6	170.4
SACHSEN	**DED00**	14.6	28.7	43.2	57.9	72.7	87.2	101.1	113.7	122.6	130.9	139.2	148.4	158.2	167.9	177.8
DESSAU	**DEE10**	20.4	40.2	60.4	80.7	101.0	119.7	130.2	140.7	151.2	162.0	172.8	183.8	195.1	206.5	217.9
HALLE	**DEE20**	21.7	43.5	65.7	88.4	111.7	125.6	137.4	149.0	160.4	171.9	183.4	194.9	206.4	217.9	229.3
MAGDEBURG	**DEE30**	18.6	36.8	55.2	73.8	92.3	110.6	124.7	135.1	145.5	155.9	166.4	176.9	187.5	198.2	208.9
SCHLESWIG-HOLSTEIN	**DEF00**	10.9	21.7	32.6	43.5	54.4	65.1	75.5	86.5	97.7	108.8	118.1	126.7	135.5	145.1	155.1
THUERINGEN	**DEG00**	14.5	28.8	43.4	58.0	72.5	86.8	100.7	113.0	122.0	131.2	140.8	150.3	160.0	169.7	179.4
ANATOLIKI MAKEDONIA, THRAKI	**EL110**	8.2	16.7	25.2	33.8	42.9	52.7	63.4	75.9	88.6	101.2	114.0	126.9	139.8	152.6	165.5
KENTRIKI MAKEDONIA	**EL120**	12.1	24.5	36.9	49.4	60.1	71.2	82.4	93.6	104.9	116.2	127.6	139.1	150.7	164.1	177.6
DYTIKI MAKEDONIA	**EL130**	9.5	19.1	28.6	38.2	48.2	57.1	65.5	74.2	85.0	96.7	108.7	120.6	132.6	144.8	156.9
THESSALIA	**EL140**	9.2	18.6	27.9	37.5	47.3	56.7	66.1	75.7	85.2	95.0	105.0	115.1	128.2	143.4	158.6
IPEIROS	**EL210**	7.0	14.1	21.2	28.5	35.9	43.4	51.1	58.8	66.5	74.2	82.0	89.8	97.6	105.6	113.5
IONIA NISIA	**EL220**	8.9	18.0	27.0	36.1	45.2	54.4	63.0	71.8	80.5	89.3	98.2	107.2	119.2	132.5	145.7
DYTIKI ELLADA	**EL230**	7.4	14.8	22.3	29.9	37.8	45.8	53.9	61.9	69.9	77.9	86.0	94.1	102.3	110.5	118.9
STEREA ELLADA	**EL240**	8.9	18.0	27.1	36.3	45.6	55.0	64.3	73.7	83.1	92.6	107.2	122.2	137.2	152.2	167.3
PELOPONNISOS	**EL250**	8.7	17.4	26.1	35.0	43.9	52.9	61.8	70.7	79.7	88.7	97.8	106.9	116.0	125.2	136.5

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
ATTIKI	**EL300**	10.9	21.9	32.9	43.9	54.0	63.3	72.8	82.4	92.0	101.7	111.4	121.2	132.1	145.5	159.1
VOREIO AIGAIO	**EL410**	6.4	12.8	19.3	25.7	32.2	38.8	45.4	52.1	58.7	65.2	71.8	78.4	85.1	93.7	104.6
NOTIO AIGAIO	**EL420**	7.2	14.5	21.9	29.3	36.8	44.9	53.2	60.5	69.1	79.4	89.8	100.1	110.5	120.8	131.2
KRITI	**EL430**	6.7	13.4	20.1	26.9	33.8	40.7	47.6	54.5	61.5	68.4	75.4	82.5	94.0	106.4	118.8
GALICIA	**ES110**	9.6	19.0	28.6	38.2	47.8	57.6	67.4	77.9	88.5	99.5	106.6	113.8	121.0	128.1	135.2
ASTURIAS	**ES120**	7.0	13.7	20.6	27.4	34.3	41.2	48.2	55.3	62.3	69.5	76.5	83.6	90.7	96.9	102.0
CANTABRIA	**ES130**	8.4	16.6	25.0	33.2	41.5	49.9	58.2	66.7	75.1	83.6	92.1	98.1	103.4	108.7	113.9
PAIS VASCO	**ES210**	7.9	15.4	23.2	30.6	38.0	45.4	52.9	60.6	69.7	80.4	91.1	101.9	110.7	118.8	127.0
NAVARRA	**ES220**	7.3	14.3	21.5	28.2	34.8	41.5	48.2	55.1	62.1	69.2	76.3	83.5	90.8	99.3	108.5
RIOJA	**ES230**	7.7	14.9	22.5	29.5	36.3	43.3	50.2	57.3	66.3	77.4	88.6	100.0	111.7	122.9	133.9
ARAGON	**ES240**	8.4	16.1	24.3	31.4	38.2	45.3	52.7	61.2	69.9	78.6	87.4	96.1	104.9	113.7	122.2
MADRID	**ES300**	8.0	15.8	25.7	36.2	46.9	57.5	67.7	78.7	89.2	100.2	111.2	122.2	132.4	142.7	152.9
CASTILLA-LEON	**ES410**	7.0	13.7	20.6	27.1	33.5	40.0	46.5	53.0	59.6	66.2	72.9	79.6	86.4	93.3	100.3
CASTILLA-LA MANCHA	**ES420**	7.9	15.4	23.1	30.2	37.1	43.9	50.8	57.6	64.5	71.4	78.3	85.3	92.3	99.4	107.8
EXTREMADURA	**ES430**	5.6	10.7	16.2	21.1	25.9	30.8	35.7	40.6	45.6	50.6	55.6	60.5	65.5	70.5	75.3
CATALUNA	**ES510**	10.0	20.2	30.9	43.2	55.8	68.4	81.0	93.7	106.4	118.5	129.5	140.5	151.6	162.7	173.8
COMUNIDAD VALENCIANA	**ES520**	10.8	21.3	32.4	45.9	59.7	73.5	87.4	101.3	115.1	128.4	141.5	155.2	169.5	183.8	198.0
BALEARES	**ES530**	9.1	17.8	26.7	34.9	42.9	50.7	58.6	66.4	74.5	82.5	90.7	99.0	105.6	111.9	118.3
ANDALUCIA	**ES610**	9.0	17.6	26.5	34.6	42.6	50.6	58.6	66.7	74.7	82.8	90.9	99.2	107.3	115.1	122.9
MURCIA	**ES620**	9.3	18.3	27.6	36.3	45.1	55.4	67.1	79.3	91.5	103.7	115.9	127.9	139.9	151.9	163.9
CANARIAS	**ES700**	9.2	18.1	27.3	35.7	44.0	52.2	60.5	68.8	77.1	85.4	93.7	101.0	107.7	114.3	120.9
ITAE-SUOMI	**FI130**	15.6	31.2	46.9	60.1	73.3	86.7	101.1	115.4	129.6	144.1	158.5	172.9	187.4	201.8	216.4
VAELI-SUOMI	**FI140**	18.6	37.1	51.9	65.9	80.0	94.2	108.5	123.1	137.7	152.4	167.0	181.6	196.3	211.0	225.9
POHJOIS-SUOMI	**FI150**	16.3	32.7	47.6	60.9	74.2	87.7	101.6	115.6	129.6	143.8	158.0	172.3	186.5	200.8	215.2
UUSIMAA	**FI160**	23.1	42.7	56.7	71.0	88.2	105.7	123.6	141.6	159.6	177.6	195.7	213.7	232.1	250.5	268.9
AHVENANMAA/AALAND	**FI200**	20.6	41.0	55.7	71.2	87.0	103.4	120.1	136.7	153.4	170.2	186.9	203.7	220.6	237.7	254.7
ILE DE FRANCE	**FR100**	18.9	37.4	56.0	74.7	93.4	112.2	130.9	149.7	168.5	187.1	205.6	224.1	242.2	259.8	276.7
CHAMPAGNE-ARDENNE	**FR210**	16.2	32.4	48.7	65.0	81.4	97.8	114.2	130.6	147.1	162.1	174.7	186.3	197.9	209.5	220.9
PICARDIE	**FR220**	17.4	34.9	52.7	70.5	88.3	106.2	124.2	142.1	159.8	173.3	185.5	197.6	209.5	221.1	232.5
HAUTE-NORMANDIE	**FR230**	14.8	29.7	44.6	59.7	74.9	90.2	105.5	120.8	136.3	151.8	166.9	179.0	189.4	199.8	210.1
CENTRE	**FR240**	11.1	22.0	33.1	44.3	55.5	66.8	78.0	89.3	100.7	111.7	122.4	133.0	143.7	154.3	164.6
BASSE-NORMANDIE	**FR250**	14.4	29.3	44.4	59.5	74.7	89.8	105.0	120.2	135.4	150.4	165.1	179.3	188.7	198.1	207.4
BOURGOGNE	**FR260**	9.8	19.9	30.1	40.5	51.0	61.5	72.1	82.6	93.2	103.5	113.3	123.1	132.9	142.9	152.9

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
NORD-PAS-DE-CALAIS	**FR300**	14.2	28.5	42.8	57.0	71.4	86.1	100.7	115.4	130.2	145.1	155.8	164.9	174.0	183.4	192.7
LORRAINE	**FR410**	12.9	25.9	39.0	52.3	65.6	78.9	92.3	105.7	119.2	132.4	145.2	158.0	170.8	181.9	190.8
ALSACE	**FR420**	16.3	32.6	49.0	65.3	81.7	98.2	115.0	132.0	149.2	166.1	178.0	188.6	199.1	209.8	220.6
FRANCHE-COMTE	**FR430**	15.3	31.0	46.8	62.5	78.3	94.1	109.9	125.8	141.6	157.3	170.2	179.2	188.2	197.3	206.3
PAYS DE LA LOIRE	**FR510**	10.8	21.6	32.5	44.0	55.4	66.9	78.8	90.2	102.3	113.4	124.1	134.8	146.1	157.5	166.6
BRETAGNE	**FR520**	15.8	32.2	48.4	64.6	80.8	97.0	113.3	129.5	145.8	157.1	165.7	174.3	182.8	191.5	200.0
POITOU-CHARENTES	**FR530**	9.9	19.5	29.1	38.7	48.3	57.9	67.8	77.6	87.5	97.1	106.3	115.5	124.6	133.8	142.9
AQUITAINE	**FR610**	9.9	19.7	29.5	39.3	49.2	59.2	69.2	79.4	90.0	100.3	110.3	120.4	131.3	142.2	152.9
MIDI-PYRENEES	**FR620**	7.8	15.3	22.7	30.0	37.3	44.7	52.8	61.1	69.5	77.6	85.2	92.8	100.7	108.5	116.3
LIMOUSIN	**FR630**	6.4	12.5	19.2	26.1	33.1	40.2	47.4	54.6	62.1	69.1	75.5	82.0	88.7	95.3	102.0
RHONE-ALPES	**FR710**	12.5	25.5	38.7	51.8	64.9	78.1	91.3	104.8	119.0	133.0	146.6	160.2	173.8	183.1	191.7
AUVERGNE	**FR720**	8.2	16.3	24.3	33.1	42.7	52.8	63.2	73.7	84.4	94.6	104.7	115.1	125.4	135.8	146.2
LANGUEDOC-ROUSSILLON	**FR810**	8.2	16.1	24.0	31.6	39.4	47.9	56.6	65.4	74.2	82.7	91.0	99.2	107.5	115.7	123.9
PROVENCE-ALPES-COTE D'AZUR	**FR820**	8.4	16.7	25.6	34.7	43.7	52.8	61.9	71.0	80.2	89.2	98.1	107.0	115.9	124.9	133.9
CORSE	**FR830**	6.8	13.3	19.8	26.2	32.8	39.4	46.2	53.1	60.2	68.1	75.2	82.3	89.5	96.6	103.9
Border, Midlands and Western	**IR010**	6.8	13.3	19.9	26.6	33.4	40.4	47.3	54.3	61.3	68.4	75.1	81.4	87.8	94.2	100.6
Southern and Eastern	**IR020**	7.4	14.6	22.0	29.4	36.8	44.3	51.8	59.3	66.9	74.5	81.8	88.8	95.8	102.9	109.9
PIEMONTE	**IT110**	12.8	26.0	39.2	52.5	65.9	79.2	92.6	105.9	119.0	132.1	145.1	158.1	171.1	182.6	194.0
VALLE D'AOSTA	**IT120**	17.5	35.3	52.9	70.5	88.2	105.9	123.6	135.4	146.0	156.7	167.3	178.0	188.7	199.4	210.2
LIGURIA	**IT130**	11.6	23.5	35.5	47.7	59.9	72.1	84.4	96.7	108.8	120.8	132.8	144.8	156.9	168.9	179.8
LOMBARDIA	**IT200**	18.2	36.9	55.6	74.3	93.0	111.7	130.4	146.9	159.7	172.5	185.3	198.2	211.1	224.1	237.0
TRENTINO-ALTO ADIGE	**IT310**	14.5	29.2	44.4	59.8	76.7	99.8	122.9	137.0	148.1	159.2	170.4	181.6	192.9	204.3	215.8
VENETO	**IT320**	21.3	43.4	65.3	87.2	109.8	132.0	154.2	172.0	188.8	205.5	222.2	238.9	255.6	272.3	289.1
FRIULI-VENEZIA GIULIA	**IT330**	26.5	53.7	80.6	107.5	134.5	152.1	169.0	186.0	203.0	220.0	237.0	253.9	270.9	287.9	304.9
EMILIA-ROMAGNA	**IT400**	17.3	35.1	52.6	70.2	87.7	105.3	120.2	132.1	144.0	156.0	168.0	179.9	191.9	203.9	216.0
TOSCANA	**IT510**	10.8	22.6	35.1	47.6	60.1	72.7	85.2	97.8	110.2	122.6	135.0	147.4	160.0	173.2	185.2
UMBRIA	**IT520**	13.9	28.2	42.6	57.0	71.4	85.8	100.2	114.6	128.9	143.0	157.2	171.4	185.8	200.4	214.8
MARCHE	**IT530**	18.7	38.1	57.8	77.7	97.6	117.6	137.6	157.6	177.3	196.8	216.0	233.9	251.8	269.7	287.6
LAZIO	**IT600**	12.6	25.4	38.2	51.0	64.0	77.0	90.1	103.1	116.0	129.0	142.9	156.6	170.2	183.7	196.4
ABRUZZO	**IT710**	10.0	20.8	31.7	42.8	53.8	65.0	76.1	87.3	99.0	110.3	121.7	133.1	144.9	157.3	169.6
MOLISE	**IT720**	14.2	28.5	42.9	57.2	71.6	86.1	100.8	115.4	130.4	145.8	162.0	178.0	193.4	208.7	224.0
CAMPANIA	**IT800**	13.5	27.6	41.7	55.8	70.0	84.2	98.4	112.6	126.7	140.7	154.7	167.6	179.1	190.6	202.0
PUGLIA	**IT910**	12.9	25.9	38.9	52.4	66.8	83.3	100.4	117.8	135.4	153.0	167.7	182.5	197.3	212.0	226.8

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
BASILICATA	**IT920**	9.1	19.3	28.0	38.3	48.7	59.3	70.3	81.6	92.8	104.0	115.2	126.5	137.8	149.1	160.3
CALABRIA	**IT930**	10.2	21.1	32.0	42.9	53.9	65.2	76.6	88.0	99.4	110.7	122.0	133.3	144.8	156.2	167.5
SICILIA	**ITA00**	9.1	18.1	27.2	36.3	45.6	55.8	67.3	79.1	91.0	102.7	114.5	126.4	138.3	150.2	162.3
SARDEGNA	**ITB00**	7.1	14.8	23.6	32.4	41.6	51.2	60.9	70.5	80.0	89.6	99.1	108.7	118.3	128.1	137.8
GRONINGEN	**NL110**	22.8	45.8	68.7	91.7	114.7	137.7	160.7	184.4	208.7	233.0	257.2	281.6	306.0	330.5	354.7
FRIESLAND	**NL120**	14.1	28.3	42.6	56.9	71.2	85.5	99.9	114.2	128.5	142.8	157.1	171.5	185.9	200.3	214.8
DRENTHE	**NL130**	21.1	42.7	64.0	85.4	106.7	128.1	149.5	170.9	192.4	213.8	235.3	256.8	278.3	299.9	321.5
OVERIJSSEL	**NL210**	13.9	28.1	42.1	56.2	70.2	84.3	98.4	112.5	126.6	140.8	155.0	169.1	183.4	197.6	211.9
GELDERLAND	**NL220**	13.2	26.7	40.1	53.5	66.9	80.4	93.9	107.6	121.2	134.9	148.6	162.3	176.0	189.8	203.6
FLEVOLAND	**NL230**	34.4	69.0	103.6	138.6	173.8	209.3	245.2	281.3	317.3	353.4	371.4	381.9	392.3	402.9	413.4
UTRECHT	**NL310**	13.9	28.0	42.1	56.1	70.2	84.3	98.4	112.5	126.6	140.8	155.0	169.2	183.4	197.6	211.9
NOORD-HOLLAND	**NL320**	18.2	36.6	55.1	73.6	92.0	110.5	129.1	147.6	166.2	184.6	203.1	221.7	240.2	258.8	277.5
ZUID-HOLLAND	**NL330**	18.3	36.9	55.6	74.3	93.0	111.9	131.3	151.0	170.6	190.3	210.0	229.7	249.4	269.3	289.2
ZEELAND	**NL340**	33.8	68.2	102.9	138.0	173.6	209.6	245.6	281.7	317.9	354.2	371.5	381.8	395.5	409.1	419.4
NOORD-BRABANT	**NL410**	15.1	31.0	46.6	62.1	77.6	93.2	108.8	124.4	140.0	155.5	170.9	186.4	201.9	217.5	233.1
LIMBURG (NL)	**NL420**	18.5	37.9	57.2	76.5	95.7	115.0	134.4	153.7	173.1	192.4	211.7	231.0	250.4	269.8	289.3
LISBOA E VALE DO TEJO	**PT130**	9.0	18.2	28.3	39.1	50.8	62.6	74.4	86.3	98.1	109.9	121.3	131.3	141.2	151.1	161.1
ALENTEJO	**PT140**	6.1	11.9	17.9	23.7	29.5	35.4	41.4	47.5	55.5	64.0	71.9	79.8	87.7	95.7	103.6
ALGARVE	**PT150**	7.5	14.9	22.5	29.7	36.9	44.4	52.9	62.5	72.3	81.8	90.9	100.0	109.3	118.4	127.0
ENTRE DOURO E MINHO	**PT160**	10.2	20.0	30.1	40.0	50.0	60.2	70.6	81.3	91.4	97.1	103.0	109.9	117.8	125.8	133.8
TRAS-OS-MONTES	**PT170**	7.2	14.1	21.4	28.3	35.2	42.4	50.3	58.7	67.3	76.4	85.0	93.7	102.5	111.3	120.9
BEIRA LITORAL	**PT180**	10.2	20.3	30.8	41.0	51.3	61.7	72.1	82.6	92.7	99.0	106.2	112.8	118.4	124.1	132.4
BEIRA INTERIEUR	**PT190**	7.9	15.6	23.5	31.0	38.6	46.9	56.4	67.0	78.5	89.8	100.7	111.6	120.0	128.4	136.8
ACORES	**PT200**	11.7	23.5	35.4	47.2	59.2	71.2	83.2	93.6	99.3	104.9	110.3	116.1	123.8	133.3	142.9
MADEIRA	**PT300**	10.9	21.5	32.4	42.7	53.1	63.5	73.9	84.3	93.1	98.8	104.5	110.1	115.8	121.6	127.3
STOCKHOLM	**SE010**	14.0	27.5	41.5	54.4	65.9	77.5	89.2	100.8	112.5	124.3	136.0	147.8	159.5	171.0	182.5
OESTRA MELLANSVERIGE	**SE020**	12.8	25.3	38.1	48.1	58.0	67.9	77.9	88.0	98.2	108.5	118.9	129.3	139.6	149.8	160.0
SYDSVERIGE	**SE040**	13.0	25.7	38.0	47.3	56.6	65.9	75.3	84.7	94.2	103.7	113.4	123.6	134.6	145.5	156.9
NORRA MELLANSVERIGE	**SE060**	15.5	30.7	44.8	55.4	66.0	76.6	87.2	97.9	108.6	119.3	130.1	141.0	151.8	162.6	173.3
MELLERSTA NORRLAND	**SE070**	15.5	31.0	47.1	63.0	78.9	88.8	98.7	108.7	118.7	128.8	138.9	149.1	159.2	169.5	179.7
OEVRE NORRLAND	**SE080**	17.9	35.7	53.9	72.0	84.1	94.2	104.4	114.6	124.9	135.4	146.0	156.6	167.2	177.8	188.5
SMAALAND MED OEARNA	**SE090**	14.0	27.5	39.4	47.5	55.7	63.9	72.1	80.4	88.7	97.1	105.6	114.3	123.0	132.8	143.7
VAESTSVERIGE	**SE0A0**	13.6	26.9	39.5	49.0	58.9	69.0	79.3	89.6	100.0	110.4	120.9	131.3	141.7	151.9	162.3

	Code	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
North East	**UKC00**	6.1	12.1	18.1	24.2	30.3	36.4	42.5	48.6	54.7	60.8	66.5	72.2	77.9	83.6	89.3
North West (including Merseyside)	**UKD00**	6.0	11.9	17.9	23.9	29.9	35.9	41.9	47.9	53.9	59.9	65.6	71.4	77.1	82.8	88.6
Yorkshire and The Humber	**UKE00**	7.6	15.1	22.8	30.4	38.0	45.7	53.4	61.1	68.7	76.4	83.7	91.0	98.3	105.6	112.9
East Midlands	**UKF00**	8.6	17.1	25.7	34.3	42.9	51.5	60.1	68.7	77.4	85.9	94.2	102.4	110.6	118.9	127.1
West Midlands	**UKG00**	6.8	13.6	20.3	27.2	34.0	40.8	47.6	54.5	61.3	68.1	74.6	81.1	87.6	94.0	100.5
Eastern	**UKH00**	13.4	26.5	39.8	53.1	66.5	79.8	93.1	106.5	119.9	133.2	146.1	158.8	169.8	176.1	182.5
South East	**UKJ00**	8.1	16.0	24.1	32.2	40.3	48.5	56.6	64.8	73.0	81.1	88.9	96.7	104.5	112.3	120.0
South West	**UKK00**	6.9	13.8	20.7	27.6	34.5	41.5	48.4	55.4	62.4	69.3	75.9	82.4	89.0	95.5	102.1
Wales	**UKL00**	5.3	10.6	15.9	21.3	26.6	31.9	37.3	42.7	48.0	53.3	58.4	63.5	68.6	73.7	78.8
Scotland	**UKM00**	7.8	15.7	23.6	31.5	39.5	47.4	55.4	63.4	71.5	79.4	86.9	94.4	101.9	109.4	116.8
Northern Ireland	**UKN00**	6.3	12.5	18.7	25.0	31.3	37.6	43.9	50.3	56.6	62.9	68.7	74.4	80.2	86.0	91.8

Source: own calculations; year 2001; emission reduction standards for CO_2^{eq} emissions from 1 % to 15 %.

Appendix 9 Permit transactions from emission trading at regional level (without price effects)

App. 9.1. For the EU-15 and Member States

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
European Union	**EU000**	**171.3**	**157.6**	**271393.1**	**952.1**	**5984.0**	**5984.0**	**6936.1**	**6936.1**
Austria	**AT000**	215.3	161.2	5714.3	0.0	239.7	0.0	239.7	0.0
Belgium	**BL000**	210.0	160.8	7118.7	3.7	275.6	0.0	279.3	3.7
Germany	**DE000**	195.0	160.8	48495.7	4.8	1704.2	0.0	1709.0	4.8
Denmark	**DK000**	260.4	161.2	7448.1	0.0	469.3	0.0	469.3	0.0
Greece	**EL000**	149.0	154.2	5998.7	32.9	0.0	52.2	32.9	85.1
Spain	**ES000**	120.8	151.8	28357.9	89.8	0.0	1681.5	89.8	1771.3
Finland	**FI000**	245.6	161.2	3546.5	0.0	198.0	0.0	198.0	0.0
France	**FR000**	175.7	159.5	68820.9	690.4	1101.7	0.0	1792.1	690.4
Ireland	**IR000**	105.9	150.9	11819.0	0.0	0.0	1106.1	0.0	1106.1
Italy	**IT000**	215.2	160.9	27573.3	37.2	1204.8	0.0	1242.1	37.2
Netherlands	**NL000**	259.0	161.2	13553.6	0.0	785.7	0.0	785.7	0.0
Portugal	**PT000**	130.5	151.9	5091.3	5.4	0.0	162.7	5.4	168.1
Sweden	**SE000**	159.9	159.1	4714.0	11.9	4.9	0.0	16.8	11.9
United Kingdom	**UK000**	108.0	151.2	33141.1	76.0	0.0	2981.6	76.0	3057.5

Source: own calculations; simulation scenario 85 % emission standard and emission trade; year 2001; Luxembourg is modelled together with Belgium.

* Initial permit prices are in line with the $MAC_{15\%}$ results in App. 8.1.

** Purchases inland are equal to sales inland for a Member State.

App. 9.2. For Nuts 2 regional units (Nuts 1 if not further disaggregated)

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
BURGENLAND	**AT110**	263.2	161.2	270.4	0.0	20.6	0.0	20.6	0.0
NIEDEROESTERREICH	**AT120**	224.7	161.2	1661.1	0.0	80.0	0.0	80.0	0.0
KAERNTEN	**AT210**	188.9	161.2	540.6	0.0	13.1	0.0	13.1	0.0
STEIERMARK	**AT220**	212.5	161.2	979.2	0.0	39.1	0.0	39.1	0.0
OBEROESTERREICH	**AT310**	200.4	161.2	1373.2	0.0	45.2	0.0	45.2	0.0
SALZBURG	**AT320**	222.4	161.2	332.2	0.0	15.2	0.0	15.2	0.0
TIROL	**AT330**	225.0	161.2	434.9	0.0	19.8	0.0	19.8	0.0
VORARLBERG	**AT340**	243.5	161.2	122.8	0.0	6.6	0.0	6.6	0.0
ANTWERPEN	**BL210**	222.2	161.2	609.9	0.0	27.0	0.0	27.0	0.0
LIMBURG (B)	**BL220**	255.5	161.2	403.8	0.1	24.1	0.0	24.2	0.0
OOST-VLAANDEREN	**BL230**	233.6	161.2	919.2	0.1	47.1	0.0	47.1	0.0
VLAAMS BRABANT	**BL240**	228.9	161.2	339.4	0.1	16.8	0.0	16.9	0.0
WEST-VLAANDEREN	**BL250**	234.4	161.2	1605.2	0.1	82.2	0.0	82.3	0.0
BRABANT WALLON	**BL310**	200.6	161.2	214.9	0.4	9.1	0.0	9.6	0.0
HAINAUT	**BL320**	184.9	161.2	932.9	0.1	26.1	0.0	26.2	0.0
LIEGE	**BL330**	192.3	161.2	549.9	0.2	20.2	0.0	20.3	0.0
LUXEMBOURG (B)	**BL340**	156.3	155.9	573.6	0.0	0.0	0.0	0.0	3.7
NAMUR	**BL350**	171.8	161.2	566.9	2.5	4.2	0.0	6.6	0.0
LUXEMBOURG (GRAND-DUCHE)	**BL400**	204.7	161.2	403.0	0.2	19.0	0.0	19.1	0.0
STUTTGART	**DE110**	210.8	161.2	1511.7	0.0	74.0	0.0	74.0	0.0
KARLSRUHE	**DE120**	205.1	161.2	510.0	0.0	23.7	0.0	23.7	0.0
FREIBURG	**DE130**	186.8	161.2	887.0	0.0	25.8	0.0	25.8	0.0
TUEBINGEN	**DE140**	196.8	161.2	1276.1	0.0	47.4	0.0	47.4	0.0
OBERBAYERN	**DE210**	195.3	161.2	2381.2	0.0	85.7	0.0	85.7	0.0
NIEDERBAYERN	**DE220**	205.0	161.2	1770.7	0.0	77.0	0.0	77.0	0.0
OBERPFALZ	**DE230**	207.2	161.2	1186.9	0.0	54.7	0.0	54.7	0.0
OBERFRANKEN	**DE240**	202.9	161.2	865.7	0.0	37.8	0.0	37.8	0.0
MITTELFRANKEN	**DE250**	207.4	161.2	1074.7	0.0	48.7	0.0	48.7	0.0

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
UNTERFRANKEN	**DE260**	208.1	161.2	983.1	0.0	47.0	0.0	47.0	0.0
SCHWABEN	**DE270**	195.1	161.2	1607.1	0.0	54.7	0.0	54.7	0.0
BRANDENBURG	**DE400**	176.3	161.2	2910.1	0.0	51.9	0.0	51.9	0.0
DARMSTADT	**DE710**	203.5	161.2	612.7	0.0	27.3	0.0	27.3	0.0
GIESSEN	**DE720**	190.9	161.2	543.7	0.0	17.8	0.0	17.8	0.0
KASSEL	**DE730**	196.8	161.2	946.5	0.0	36.1	0.0	36.1	0.0
MECKLENBURG-VORPOMMERN	**DE800**	190.5	161.2	2970.8	0.0	100.6	0.0	100.6	0.0
BRAUNSCHWEIG	**DE910**	215.3	161.2	986.1	0.0	53.6	0.0	53.6	0.0
HANNOVER	**DE920**	207.1	161.2	1519.2	0.0	70.3	0.0	70.3	0.0
LUENEBURG	**DE930**	187.7	161.2	2583.1	0.0	72.9	0.0	72.9	0.0
WESER-EMS	**DE940**	206.8	161.2	3941.7	0.0	169.1	0.0	169.1	0.0
DUESSELDORF	**DEA10**	211.2	161.2	809.7	0.0	38.0	0.0	38.0	0.0
KOELN	**DEA20**	201.2	161.2	833.1	0.0	34.6	0.0	34.6	0.0
MUENSTER	**DEA30**	216.4	161.2	1951.7	0.0	95.4	0.0	95.4	0.0
DETMOLD	**DEA40**	206.0	161.2	1245.5	0.0	54.4	0.0	54.4	0.0
ARNSBERG	**DEA50**	189.7	161.2	836.0	4.7	20.6	0.0	25.4	0.0
KOBLENZ	**DEB10**	191.3	161.2	679.6	0.0	22.2	0.0	22.2	0.0
TRIER	**DEB20**	176.2	161.2	488.0	0.0	7.7	0.0	7.7	0.0
RHEINHESSEN-PFALZ	**DEB30**	217.8	161.2	607.2	0.0	34.7	0.0	34.7	0.0
SAARLAND	**DEC00**	170.4	161.2	187.6	0.1	1.8	0.0	1.9	0.0
SACHSEN	**DED00**	177.8	161.2	2094.7	0.0	40.4	0.0	40.4	0.0
DESSAU	**DEE10**	217.9	161.2	471.7	0.0	26.7	0.0	26.7	0.0
HALLE	**DEE20**	229.2	161.2	602.4	0.0	39.4	0.0	39.4	0.0
MAGDEBURG	**DEE30**	208.9	161.2	1422.9	0.0	71.7	0.0	71.7	0.0
SCHLESWIG-HOLSTEIN	**DEF00**	155.1	155.9	3322.0	0.0	0.0	0.0	0.0	4.8
THUERINGEN	**DEG00**	179.4	161.2	1875.6	0.0	40.1	0.0	40.1	0.0
DANMARK	**DK000**	260.4	161.2	7448.1	0.0	469.3	0.0	469.3	0.0
ANATOLIKI MAKEDONIA	**EL110**	165.5	156.2	663.7	5.6	0.0	0.0	5.6	0.0
KENTRIKI MAKEDONIA	**EL120**	177.6	156.2	1106.3	20.3	0.0	0.0	20.3	0.0
DYTIKI MAKEDONIA	**EL130**	156.9	156.2	355.6	0.3	0.0	0.0	0.3	0.0
THESSALIA	**EL140**	158.6	156.2	898.6	1.7	0.0	0.0	1.7	0.0

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
IPEIROS	**EL210**	113.5	150.9	452.4	0.0	0.0	21.8	0.0	25.9
IONIA NISIA	**EL220**	145.7	150.9	81.4	0.0	0.0	0.0	0.0	0.4
DYTIKI ELLADA	**EL230**	118.9	150.9	624.7	0.0	0.0	18.3	0.0	29.2
STEREA ELLADA	**EL240**	167.2	156.2	552.3	4.7	0.0	0.0	4.7	0.0
PELOPONNISOS	**EL250**	136.5	150.9	422.2	0.0	0.0	0.0	0.0	5.4
ATTIKI	**EL300**	159.1	156.2	125.2	0.3	0.0	0.0	0.3	0.0
VOREIO AIGAIO	**EL410**	104.6	150.9	156.6	0.0	0.0	0.0	0.0	8.2
NOTIO AIGAIO	**EL420**	131.2	150.9	175.8	0.0	0.0	0.0	0.0	4.0
KRITI	**EL430**	118.8	150.9	383.8	0.0	0.0	12.0	0.0	12.0
GALICIA	**ES110**	135.2	150.9	2768.1	0.0	0.0	53.3	0.0	80.2
ASTURIAS	**ES120**	101.9	150.9	1103.0	0.0	0.0	175.3	0.0	175.3
CANTABRIA	**ES130**	113.9	150.9	859.7	0.0	0.0	90.9	0.0	90.9
PAIS VASCO	**ES210**	126.9	150.9	607.6	0.0	0.0	23.4	0.0	23.4
NAVARRA	**ES220**	108.5	150.9	588.1	0.0	0.0	34.8	0.0	34.8
RIOJA	**ES230**	133.9	150.9	281.1	0.0	0.0	1.9	0.0	5.4
ARAGON	**ES240**	122.2	150.9	1604.0	0.0	0.0	44.0	0.0	63.9
MADRID	**ES300**	152.9	153.3	500.9	0.0	0.0	0.0	0.0	0.0
CASTILLA-LEON	**ES410**	100.3	150.9	6116.7	0.0	0.0	527.5	0.0	527.5
CASTILLA-LA MANCHA	**ES420**	107.8	150.9	2666.7	0.0	0.0	164.9	0.0	164.9
EXTREMADURA	**ES430**	75.3	150.9	2026.3	0.0	0.0	402.9	0.0	402.9
CATALUNA	**ES510**	173.8	156.2	3060.5	58.1	0.0	0.0	58.1	0.0
COMUNIDAD VALENCIANA	**ES520**	198.0	156.2	773.7	26.3	0.0	0.0	26.3	0.0
BALEARES	**ES530**	118.3	150.9	240.9	0.0	0.0	15.4	0.0	15.4
ANDALUCIA	**ES610**	122.9	150.9	4293.6	0.0	0.0	138.6	0.0	176.6
MURCIA	**ES620**	163.9	156.2	694.5	5.4	0.0	0.0	5.4	0.0
CANARIAS	**ES700**	120.9	150.9	172.6	0.0	0.0	8.5	0.0	9.9
ITAE-SUOMI	**FI130**	216.4	161.2	527.7	0.0	22.5	0.0	22.5	0.0
VAELI-SUOMI	**FI140**	225.9	161.2	805.4	0.0	39.5	0.0	39.5	0.0
POHJOIS-SUOMI	**FI150**	215.2	161.2	358.1	0.0	15.1	0.0	15.1	0.0
UUSIMAA	**FI160**	268.9	161.2	1835.3	0.0	119.6	0.0	119.6	0.0
AHVENANMAA/AALAND	**FI200**	254.7	161.2	19.9	0.0	1.2	0.0	1.2	0.0

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
ILE DE FRANCE	**FR100**	276.7	161.2	714.8	51.6	0.0	0.0	51.6	0.0
CHAMPAGNE-ARDENNE	**FR210**	220.9	161.2	2848.0	0.0	162.1	0.0	162.1	0.0
PICARDIE	**FR220**	232.5	161.2	2726.1	50.1	130.0	0.0	180.1	0.0
HAUTE-NORMANDIE	**FR230**	210.1	161.2	2397.4	118.5	0.0	0.0	118.5	0.0
CENTRE	**FR240**	164.6	161.2	3262.9	0.0	11.8	0.0	11.8	0.0
BASSE-NORMANDIE	**FR250**	207.4	161.2	5277.4	253.1	0.0	0.0	253.1	0.0
BOURGOGNE	**FR260**	152.9	155.9	3796.5	0.0	0.0	0.0	0.0	13.9
NORD-PAS-DE-CALAIS	**FR300**	192.7	161.2	2728.8	0.0	105.6	0.0	105.6	0.0
LORRAINE	**FR410**	190.8	161.2	3089.2	0.0	97.1	0.0	97.1	0.0
ALSACE	**FR420**	220.5	161.2	805.2	47.9	0.0	0.0	47.9	0.0
FRANCHE-COMTE	**FR430**	206.3	161.2	2078.8	110.3	0.0	0.0	110.3	0.0
PAYS DE LA LOIRE	**FR510**	166.6	161.2	7586.6	58.9	0.0	0.0	58.9	0.0
BRETAGNE	**FR520**	200.0	161.2	9272.6	0.0	470.5	0.0	470.5	0.0
POITOU-CHARENTES	**FR530**	142.9	155.9	3081.0	0.0	0.0	0.0	0.0	53.3
AQUITAINE	**FR610**	152.9	155.9	3156.4	0.0	0.0	0.0	0.0	11.0
MIDI-PYRENEES	**FR620**	116.3	155.9	4334.8	0.0	0.0	0.0	0.0	263.0
LIMOUSIN	**FR630**	102.0	155.9	2325.1	0.0	0.0	0.0	0.0	238.7
RHONE-ALPES	**FR710**	191.7	161.2	3718.8	0.0	124.5	0.0	124.5	0.0
AUVERGNE	**FR720**	146.2	155.9	4240.7	0.0	0.0	0.0	0.0	47.1
LANGUEDOC-ROUSSILLON	**FR810**	123.9	155.9	727.5	0.0	0.0	0.0	0.0	35.1
PROVENCE-ALPES-COTE D'AZUR	**FR820**	133.9	155.9	491.8	0.0	0.0	0.0	0.0	14.2
CORSE	**FR830**	103.9	155.9	160.4	0.0	0.0	0.0	0.0	14.1
Border	**IR010**	100.6	150.9	5021.3	0.0	0.0	545.1	0.0	545.1
Southern and Eastern	**IR020**	109.9	150.9	6797.7	0.0	0.0	560.9	0.0	560.9
PIEMONTE	**IT110**	193.9	161.2	3399.7	12.6	94.0	0.0	106.6	0.0
VALLE D'AOSTA	**IT120**	210.1	161.2	84.2	3.2	1.1	0.0	4.3	0.0
LIGURIA	**IT130**	179.8	161.2	143.9	0.0	2.6	0.0	2.6	0.0
LOMBARDIA	**IT200**	237.0	161.2	5772.0	0.0	373.5	0.0	373.5	0.0
TRENTINO-ALTO ADIGE	**IT310**	215.7	161.2	551.9	0.0	29.6	0.0	29.6	0.0
VENETO	**IT320**	289.0	161.2	3071.3	0.0	255.8	0.0	255.8	0.0
FRIULI-VENEZIA GIULIA	**IT330**	304.9	161.2	610.5	0.0	55.6	0.0	55.6	0.0

	Code	Initial Permit Price*	Final Permit Price	Total amount of permits	Purchases inland**	Purchases abroad	Sales abroad	Total purchases	Total Sales
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
EMILIA-ROMAGNA	**IT400**	215.9	161.2	3315.1	0.0	168.8	0.0	168.8	0.0
TOSCANA	**IT510**	185.2	161.2	951.6	20.7	0.0	0.0	20.7	0.0
UMBRIA	**IT520**	214.8	161.2	474.9	0.0	19.9	0.0	19.9	0.0
MARCHE	**IT530**	287.6	161.2	633.0	0.0	47.1	0.0	47.1	0.0
LAZIO	**IT600**	196.3	161.2	1307.7	0.0	39.7	0.0	39.7	0.0
ABRUZZO	**IT710**	169.6	161.2	550.8	0.0	4.3	0.0	4.3	0.0
MOLISE	**IT720**	224.0	161.2	259.8	0.0	11.8	0.0	11.8	0.0
CAMPANIA	**IT800**	202.0	161.2	1148.2	0.0	45.8	0.0	45.8	0.0
PUGLIA	**IT910**	226.8	161.2	1017.3	0.0	50.5	0.0	50.5	0.0
BASILICATA	**IT920**	160.3	160.2	465.1	0.0	0.0	0.0	0.0	0.0
CALABRIA	**IT930**	167.5	161.2	655.3	0.0	4.1	0.0	4.1	0.0
SICILIA	**ITA00**	162.3	161.2	1513.8	0.7	0.7	0.0	1.4	0.0
SARDEGNA	**ITB00**	137.8	155.9	1647.4	0.0	0.0	0.0	0.0	37.2
GRONINGEN	**NL110**	354.7	161.2	861.6	0.0	74.1	0.0	74.1	0.0
FRIESLAND	**NL120**	214.8	161.2	1314.5	0.0	54.6	0.0	54.6	0.0
DRENTHE	**NL130**	321.5	161.2	894.2	0.0	72.3	0.0	72.3	0.0
OVERIJSSEL	**NL210**	211.9	161.2	1541.8	0.0	61.4	0.0	61.4	0.0
GELDERLAND	**NL220**	203.6	161.2	2344.2	0.0	81.1	0.0	81.1	0.0
FLEVOLAND	**NL230**	413.4	161.2	455.8	0.0	49.7	0.0	49.7	0.0
UTRECHT	**NL310**	211.9	161.2	469.7	0.0	18.7	0.0	18.7	0.0
NOORD-HOLLAND	**NL320**	277.5	161.2	737.9	0.0	50.7	0.0	50.7	0.0
ZUID-HOLLAND	**NL330**	289.2	161.2	809.2	0.0	57.4	0.0	57.4	0.0
ZEELAND	**NL340**	419.4	161.2	604.8	0.0	66.0	0.0	66.0	0.0
NOORD-BRABANT	**NL410**	233.0	161.2	2623.9	0.0	135.0	0.0	135.0	0.0
LIMBURG (NL)	**NL420**	289.3	161.2	895.9	0.0	64.7	0.0	64.7	0.0
LISBOA E VALE DO TEJO	**PT130**	161.0	156.2	925.0	5.4	0.0	0.0	5.4	0.0
ALENTEJO	**PT140**	103.6	150.9	1305.0	0.0	0.0	100.2	0.0	100.2
ALGARVE	**PT150**	127.0	150.9	89.8	0.0	0.0	2.8	0.0	3.1
ENTRE DOURO E MINHO	**PT160**	133.8	150.9	984.5	0.0	0.0	20.4	0.0	25.5
TRAS-OS-MONTES	**PT170**	120.9	150.9	297.8	0.0	0.0	11.8	0.0	11.8
BEIRA LITORAL	**PT180**	132.4	150.9	617.8	0.0	0.0	14.5	0.0	14.5

	Code	**Initial Permit Price***	**Final Permit Price**	**Total amount of permits**	**Purchases inland****	**Purchases abroad**	**Sales abroad**	**Total purchases**	**Total Sales**
		Euro	Euro	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units	1000 Units
BEIRA INTERIEUR	**PT190**	136.8	150.9	343.4	0.0	0.0	6.9	0.0	6.9
ACORES	**PT200**	142.9	150.9	498.0	0.0	0.0	4.9	0.0	4.9
MADEIRA	**PT300**	127.3	150.9	29.9	0.0	0.0	1.2	0.0	1.2
STOCKHOLM	**SE010**	182.5	161.2	92.4	2.0	0.0	0.0	2.0	0.0
OESTRA MELLANSVERIGE	**SE020**	160.0	159.9	1002.3	0.0	0.0	0.0	0.0	0.0
SYDSVERIGE	**SE040**	156.9	156.8	898.1	0.0	0.0	0.0	0.0	0.0
NORRA MELLANSVERIGE	**SE060**	173.3	161.2	334.1	4.4	0.0	0.0	4.4	0.0
MELLERSTA NORRLAND	**SE070**	179.7	161.2	169.1	0.0	3.6	0.0	3.6	0.0
OEVRE NORRLAND	**SE080**	188.5	161.2	182.4	5.4	0.0	0.0	5.5	0.0
SMAALAND MED OEARNA	**SE090**	143.7	155.9	905.5	0.0	0.0	0.0	0.0	11.9
VAESTSVERIGE	**SE0A0**	162.3	161.2	1130.1	0.1	1.3	0.0	1.3	0.0
North East	**UKC00**	89.3	150.9	1218.2	0.0	0.0	177.5	0.0	177.5
North West (incl. Merseyside)	**UKD00**	88.5	150.9	2139.0	0.0	0.0	309.5	0.0	313.6
Yorkshire and The Humber	**UKE00**	112.9	150.9	2380.5	0.0	0.0	155.5	0.0	155.5
East Midlands	**UKF00**	127.1	150.9	2088.2	0.0	0.0	73.0	0.0	73.0
West Midlands	**UKG00**	100.5	150.9	2051.5	0.0	0.0	206.9	0.0	206.9
Eastern	**UKH00**	182.4	156.2	2086.5	76.0	0.0	0.0	76.0	0.0
South East	**UKJ00**	120.0	150.9	1917.7	0.0	0.0	93.9	0.0	93.9
South West	**UKK00**	102.1	150.9	3920.6	0.0	0.0	376.0	0.0	376.0
Wales	**UKL00**	78.8	150.9	3862.6	0.0	0.0	703.5	0.0	770.4
Scotland	**UKM00**	116.8	150.9	8473.2	0.0	0.0	480.4	0.0	480.4
Northern Ireland	**UKN00**	91.8	150.9	3003.2	0.0	0.0	405.5	0.0	410.3

Source: own calculations; simulation scenario 85 % emission standard and emission trade; year 2001.

* Initial permit prices are in line with the $\text{MAC}_{15\%}$ results in App. 8.2.

** Purchases inland are equal to sales inland for a Member State.

Appendix 10 Impact of transaction costs on emission trading (sensitivity analysis)

TCin/TCout	0 €	5 €	10 €	50 €
0 €	0.743	1.077	2.872	2.203
5 €	0.000	0.693	0.952	1.859
10 €	0.000	0.000	0.688	1.332
50 €	0.000	0.000	0.000	0.274

TCin/TCout	0 €	5 €	10 €	50 €
0 €	6.899	6.288	5.440	4.004
5 €	7.664	6.555	5.984	3.318
10 €	7.645	7.248	6.169	4.876
50 €	7.645	7.248	6.857	3.658

%transaction costs / transaction value

TCin/TCout	0 €	5 €	10 €	50 €
0 €	0.0%	3.1%	6.4%	29.4%
5 €	0.0%	3.1%	6.4%	28.4%
10 €	0.0%	3.1%	6.2%	29.7%
50 €	0.0%	3.1%	6.2%	27.4%

Total transaction Costs (Mio €)

TCin/TCout	0 €	5 €	10 €	50 €
0 €	0.000	31.449	54.406	200.202
5 €	0.008	36.241	66.600	175.245
10 €	0.008	36.241	68.569	257.169
50 €	0.008	36.241	68.569	196.600

Source: own calculations (repeated simulations for year 2001 with a 15% emission standard and trading of emission permits).

TCin = Unitary transaction costs for trade within national borders (rows).

TCout = Unitary transaction costs for trade with foreign regions (columns).