

## Indicators Monitoring the Contribution of Agriculture to Climate Change in the EU

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Climate change is among the greatest environmental, social and economic risks to the Earth. It is evident that the climate system has a higher temperature now than it had in the pre-industrial age. The average temperature of the air and the waters increases, which results in the melting of snow and ice, the rising of sea levels and a need for the adaptation of human life including agricultural production. Reliable information is essential on the driving forces and pressures on the climate in order that the impacts could be assessed and a proper mitigation strategy could be developed.

This study describes the relations between agricultural production and climate change. The different driving forces and environmental pressures are explained in detail. The paper presents the indicators monitoring the contribution of agriculture to climate change and the linkages and interactions between them. It aims at providing useful information for policymakers for the formulation of adequate mitigation and adaptation policy.

KEYWORDS:

Agriculture.

Climate.

Sustainable development.

The concept of sustainable development was defined by the Brundtland report (*Our Common future* [1987]), in 1987 as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. There are three components of sustainable development (economic development, social development and environmental protection), which are interdependent and mutually reinforcing pillars (*UN* [2005]).

The European Council of June 2006 adopted a renewed Sustainable Development Strategy for the enlarged EU that is based on the Gothenburg strategy of 2001. The renewed strategy sets overall objectives and targets for seven key challenges for the time period until 2010 (*Council of the European Union* [2006]):

- climate change and clean energy,
- sustainable transport,
- sustainable production and consumption,
- public health threats,
- better management of natural resources,
- social inclusion, demography and migration,
- fighting global poverty.

Climate change is the field within sustainable development that deserves most of the attention of researchers, policy makers and the general public nowadays. Policy makers recognized the importance of tackling the problem of climate change decades ago. The UN Framework Convention on Climate Change (UNFCCC) was adopted in 1992. It was followed by the Kyoto Protocol in 1997. In the EU, measures have been taken in order to reduce the emissions of greenhouse gases since the beginning of the 1990s. In 2000, the European Commission launched the first European Climate Change Programme (ECCP), which stimulated the adoption of several measures in this field including a proposal for emission trading of greenhouse gases and a proposal for regulating certain fluorinated gases. The Second European Climate Change Programme was launched in October, 2005. It explores further cost-effective options for reducing greenhouse gas emissions in synergy with the EU’s “Lisbon strategy” for increasing economic growth and job creation. The objectives of the second ECCP include (*ECCP* [2008]):

- increased use of renewable energy (wind, solar, biomass) and combined heat and power installations,
- improvements in energy efficiency in buildings, household appliances and in industry,

- reduction of carbon dioxide emissions from new passenger cars,
- abatement measures in manufacturing industry,
- measures to reduce methane emissions from landfills,
- integration of climate change into the EU's Rural Development Policy,
- support scheme for energy crops,
- reduction of N<sub>2</sub>O in soils,
- integration of climate change into the EU's Structural and Cohesion Funds.

In order that proper steps could be taken to reduce the emissions of greenhouse gases, statistical information on the driving forces and pressures related to climate change is essential for policy makers so that a strategy for mitigation could be worked out. Mitigation strategy includes measures that contribute to the change of economic activities for the sake of reduction in greenhouse gas emissions.

The adaptation strategy consists of measures that enable mankind to change their life and activities so that they would be adapted to the different climatic conditions. The effects of climate change should be estimated and assessed in order that an adequate adaptation strategy could be elaborated.

Statisticians have a role in the development of both the mitigation and adaptation strategies. While they have a crucial responsibility in the measurement of the contribution of the different economic activities in the emissions of greenhouse gases, they have a less important role in formulating the adaptation strategy.

As a result of previous research, a set of indicators on sustainable development in agriculture was presented (*Fekete-Farkas-Molnár-Szűcs* [2004]; *Fekete-Farkas et al.* [2007]; *Valkó-Fekete-Farkas* [2007], [2008]). The indicators are organized according to the four (economic, social, environmental and institutional) dimensions of sustainable development. A database has been set up and the indicators are being tested in terms of their capability in describing the sustainability of agriculture. In this paper, climate change related indicators are used.

## 1. Climate change and its relation with agriculture

In the last two centuries, the concentrations of carbon dioxide, methane and nitrous oxide have significantly risen as a result of human activities. The atmospheric concentration of carbon dioxide has increased from a pre-industrial value of about 280 ppm to 379 ppm<sup>1</sup> in 2005 (*IPCC* [2007]). As a consequence, global mean sur-

<sup>1</sup> ppm (parts per million) is the ratio of the number of greenhouse gas molecules to the total number of molecules of dry air.

face temperatures have risen by  $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$  when estimated by a linear trend over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years ( $0.13^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$  vs.  $0.07^{\circ}\text{C} \pm 0.02^{\circ}\text{C}$  per decade) (*Trenberth et al.* [2007]).

The main direct impacts of climate change are as follows:

- frequent extreme weather patterns,
- changes in temperature patterns,
- changes in rainfall patterns,
- rising of the sea level because of melting of ice.

The indirect impacts include the change of territory or the extinction of species, increased frequency and volume of floods, reduced snow cover, worsened water availability in dry areas, changes in crop productivity, changes in tourist destinations, etc.

Carbon dioxide ( $\text{CO}_2$ ) is the most important contributor to climate change with 82 percent of the total in terms of global warming potential (GWP).<sup>2</sup> Methane ( $\text{CH}_4$ ) has a GWP 21 times that of carbon dioxide, while nitrous oxide ( $\text{N}_2\text{O}$ ) has a GWP of 310. Methane emissions accounts for 9.7 percent of the greenhouse gas (GHG) emissions and nitrous oxide is responsible for 6.6 percent of it (*OECD* [2002]).

There is a two-way relation between agricultural production and climate change. Agriculture has a significant role in the contribution to climate change. Agriculture was responsible for 9 percent of the emissions of greenhouse gases in 2003, while 53 percent of methane and 66 percent of nitrous oxide was emitted by agriculture in the EU 25 (*Eurostat* [2008]). Besides, climate has a crucial impact on agricultural production especially on the production of crops. Therefore the adaptation of agricultural production to the different climatic conditions and to the effects of climate change is inevitable.

### 1.1. Effects of agriculture on the climate

Agriculture contributes to the climate change in the following ways:

- emissions of carbon dioxide,
- emissions of methane,

<sup>2</sup> Global warming potential (GWP): The ratio of the warming caused by a substance to the warming induced by a similar mass of carbon dioxide.

- emissions of nitrous oxide,
- land use, land-use change and forestry.

### 1.1.1. Emissions of carbon dioxide

Carbon dioxide is a greenhouse gas that is emitted in the largest volume as a result of human activities. Agriculture is a minor source of carbon dioxide emissions. In Hungary, 10 percent of the total carbon dioxide was emitted by agricultural production (*Bálint* [2006]). The majority of carbon dioxide emissions from agricultural sources originate from:

- use of fossil fuels for heating buildings and operating machinery,
- natural respiration of livestock,
- land-clearing methods such as burning,
- decomposition of soil organic matter (*Kirchmann–Thorvaldsson* [2000]).

### 1.1.2. Emissions of methane

In the European Union, the main sources of methane emissions in agriculture are the enteric fermentation of ruminant livestock and manure management. In Europe, 72 percent was the share of enteric fermentation, while 27 percent was the share of manure management among the sources of methane emissions from agriculture in 2006. (See Table 1.)

Table 1

*Emissions of methane from agricultural sources in the EU, 1990–2006*  
(metric tons)

Sources of emissions	1990.	1995.	2000.	2005.	2006.
	year				
Enteric fermentation	8 712.9	7 634.6	7 312.7	6 933.1	6 930.9
Manure management	2 678.2	2 544.3	2 520.2	2 496.0	2 542.1
Rice cultivation	118.7	106.2	103.9	111.4	113.9
Agricultural soils	–31.5	–30.3	–29.7	–29.6	–29.6
Field burning of agricultural residues	43.9	29.9	27.3	23.6	22.7
<i>Total emissions from agriculture</i>	<i>11 522.2</i>	<i>10 284.7</i>	<i>9 934.4</i>	<i>9 534.4</i>	<i>9 579.9</i>

Source: Eurostat [2008].

From 1990 to 2006, the emissions of methane from enteric fermentation dropped by 27 percent in the EU. The decrease can be explained by diminishing ruminant livestock. Simultaneously, the emissions from manure management have decreased by 5 percent.

### 1.1.3. Emissions of nitrous oxide

Nitrous oxide (N<sub>2</sub>O) is a potential greenhouse gas that is emitted from the soil through the processes of denitrification and nitrification. The use of nitrogen fertilizers is conducive to the emissions of nitrous oxide. Another source of nitrous oxide emissions is the solid waste of animals. The main sources of nitrous oxide emissions in agriculture are summarized in Table 2.

Table 2

*Emissions of nitrous oxide from agricultural sources in the EU, 1990–2006*  
(metric tons)

Sources of emissions	1990.	1995.	2000.	2005.	2006.
	year				
Manure management	142.32	120.22	112.92	107.35	107.27
Agricultural soils	984.21	836.27	830.17	775.2	768.67
Field burning of agricultural residues	1.00	0.69	0.56	0.46	0.44
Other	0.23	0.23	0.23	0.19	0.21
<i>Total emissions from agriculture</i>	<i>1127.76</i>	<i>957.41</i>	<i>943.88</i>	<i>883.19</i>	<i>876.58</i>

Source: Eurostat [2008].

In Europe, 88 percent of nitrous oxide emissions originated from agricultural soils, while 12 percent was the share of manure management in 2006.

Since detailed estimations for the emissions of nitrous oxide from agricultural sources are not available for the EU, estimations for the United States of America are presented. In the USA, 78 percent of emissions derived from agricultural soils and 21 percent from manure management in 2006. (See Table 3.) 22 percent of nitrous oxide was emitted because of the use of nitrogen fertilizers. Concerning the emissions from manure management, cattle livestock is responsible for the majority of emissions (20 percent of emissions originates from agricultural sources) (*Energy Information Administration* [2007]).

Table 3

*Nitrous oxide emissions from agricultural sources in the USA, 1990–2006*  
(million metric tons in carbon dioxide equivalent)

Sources of emissions	1990.	1995.	2000.	2005.	2006.*
	year				
Biological fixation in crops	58.6	62.1	67.9	70.7	71.2
Nitrogen fertilizers	53.1	51.2	45.6	57.9	63.0
Crop residues	28.2	28.1	34.6	37.3	36.9
Other	4.5	4.8	4.9	4.9	5.0
<i>Total direct emissions</i>	<i>144.4</i>	<i>146.2</i>	<i>152.9</i>	<i>170.9</i>	<i>176.2</i>
Soil leaching	36.3	35.2	31.3	39.5	43.0
Atmospheric deposition	6.5	6.3	5.6	7.0	7.6
<i>Total indirect emissions</i>	<i>42.8</i>	<i>41.4</i>	<i>36.9</i>	<i>46.5</i>	<i>50.6</i>
<i>Total agricultural soils</i>	<i>187.1</i>	<i>187.7</i>	<i>189.8</i>	<i>217.4</i>	<i>226.7</i>
Cattle	57.5	61.1	57.4	56.4	56.8
Swine	1.5	1.6	1.6	1.7	1.7
Poultry	0.9	1.2	1.3	1.4	1.4
Horses	0.7	0.7	0.7	0.7	0.7
Sheep	1.0	0.8	0.6	0.5	0.5
Goats	0.3	0.3	0.2	0.4	0.5
<i>Total solid waste of animals</i>	<i>61.9</i>	<i>65.6</i>	<i>61.8</i>	<i>61.2</i>	<i>61.7</i>
Crop residue burning	0.5	0.5	0.6	0.6	0.6
<i>Total agricultural sources</i>	<i>249.5</i>	<i>253.7</i>	<i>252.2</i>	<i>279.2</i>	<i>289.1</i>

\* Preliminary data.

Source: Energy Information Administration [2007].

#### 1.1.4. Land use, land-use change and forestry (LULUCF)

The change in land use has a significant impact on the contribution of agriculture to climate change. The most important land use changes that affect the carbon dioxide emissions or captures are (IPCC [2000]):

- changes in forest and other woody biomass stocks including commercial management, harvest of industrial roundwood (logs) and fuelwood, production and use of wood commodities, and establishment and operation of forest plantations, as well as planting of trees in non-forest locations,

- conversion of forests and grasslands to pasture, cropland, or other managed uses,
- abandonment of croplands, pastures, plantation forests, or other managed lands that regrow into their prior natural grassland, or forest conditions,
- changes in soil carbon.

The major potential possibilities for reduction of greenhouse gas emissions by land-use change are as follows (*Schlamadinger et al.* [2007]):

- provision of renewable energy,
- substitution for more fossil carbon-intensive products,
- reduction of emissions of non-carbon dioxide gases (for example from agriculture),
- sequestration of carbon through enhancement of terrestrial C stocks,
- conservation of existing carbon stocks (for example through reduced deforestation, devegetation, forest degradation, and land degradation).

## **2. The contribution of agriculture to climate change**

In this part, the driving forces and pressures of the contribution of agriculture to climate change are presented. It is followed by the analysis of the linkages between related indicators.

### **2.1. Driving forces**

The driving forces of the contribution of agriculture to climate change are:

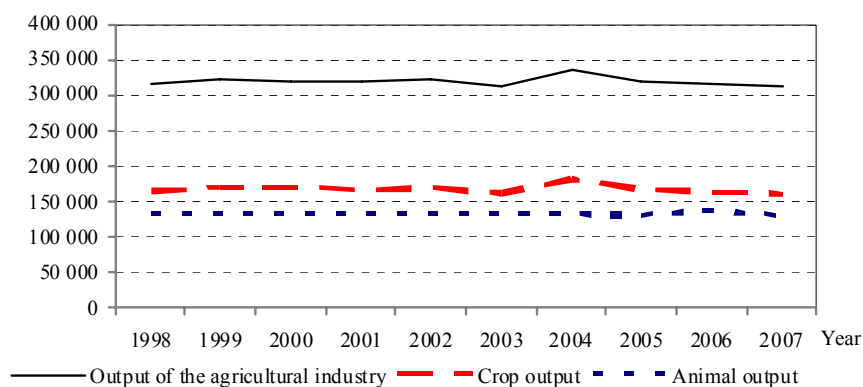
- volume of agricultural production (the output of agriculture),
- structure of agricultural production (the ratio of animal and crop production),
- land use, land-use change and forestry,
- size of livestock,
- use of fertilizers,
- use of fossil fuels and energy.

The production of crops and that of animals and animal products contribute to the climate change since they can be characterised by the combustion of fossil fuels, a major contributor to the global warming. As already mentioned, the major sources of greenhouse gases are the respiration of animals, the enteric fermentation of ruminant livestock and the management of manure in animal husbandry, and the use of fertilizers in crop production in the EU.

### 2.1.1. The output of agriculture

Figure 1 shows that neither the animal nor the crop outputs show significant changes at EU level in the last decade. The only change that can be detected is a peak in the crop output in 2004 because of the favourable weather for cereals in Europe in that year.

Figure 1. The output of agriculture at constant basic prices in the EU 27, 1998–2007 (EUR million)



Source: Eurostat [2008].

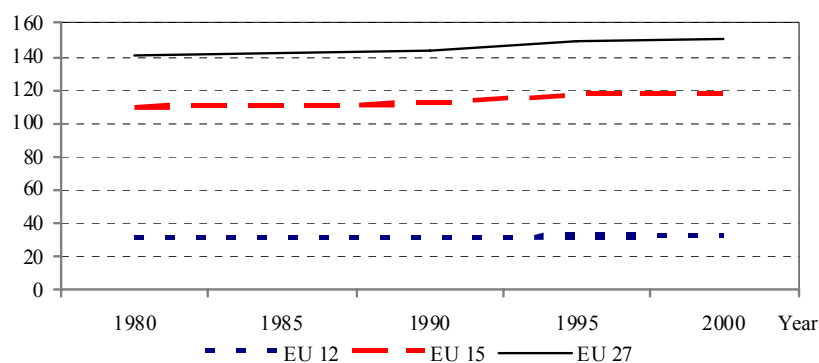
### 2.1.2. Land use, land-use change and forestry

The size of the utilized agricultural area does not show any significant change from 1980 to 2000 in Europe (Eurostat [2008]). In the EU 15<sup>3</sup>, the size of the forest area increased by 8 percent from 1980 to 2000, while its growth was only 4 percent in the EU 12<sup>4</sup>. (See Figure 2.) The increment of the forest area in the EU 15 is the consequence of the EU policy for afforestation.

<sup>3</sup> EU 15 refers to Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom.

<sup>4</sup> EU 12 refers to Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia and Slovenia.

Figure 2. Total land under forest, 1980–2000  
(million ha)

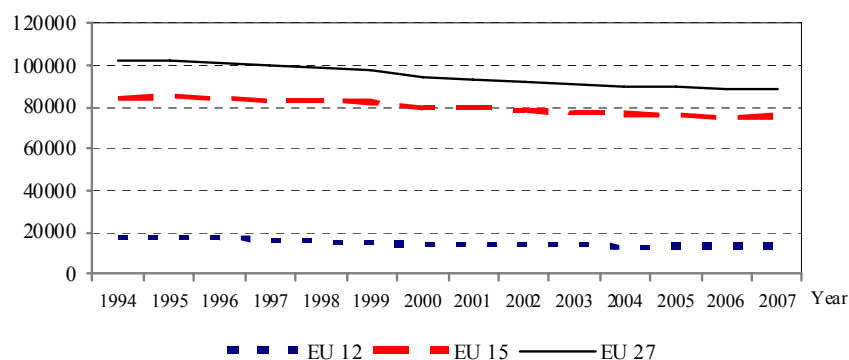


Source: Eurostat [2008].

### 2.1.3. Livestock

Livestock management (especially cattle livestock) is an important source of methane emissions and it partly contributes to the emissions of nitrous oxide, too. Enteric fermentation of ruminant livestock and manure management are major sources of greenhouse gas emissions. In the EU, the number of cattle livestock decreased by 13 percent from 1994 to 2007. (See Figure 3.)

Figure 3. The size of cattle livestock, 1994–2007\*  
(thousand heads)



\* Data of months of December.

Source: Eurostat [2008].

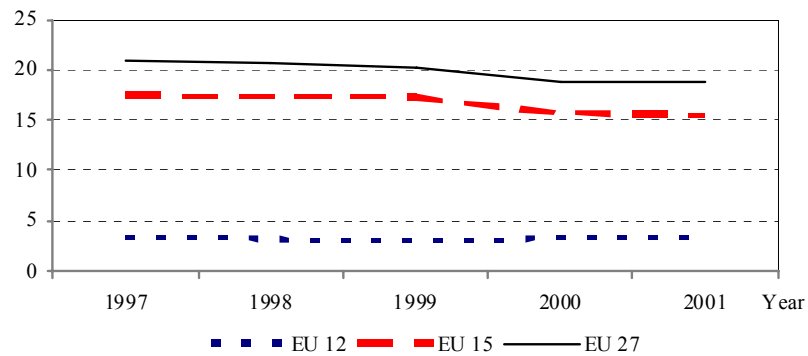
In the Central and Eastern European countries, there was also a significant drop in cattle livestock in the transition period of the early 1990s. From 1989 to 1995 the

livestock fell by 64 percent in Latvia, by 60 percent in Bulgaria, by 54 percent in Estonia, by 44 percent in Romania and by 42 percent in Hungary (*Eurostat* [2008]).

#### 2.1.4. Fertilizer use

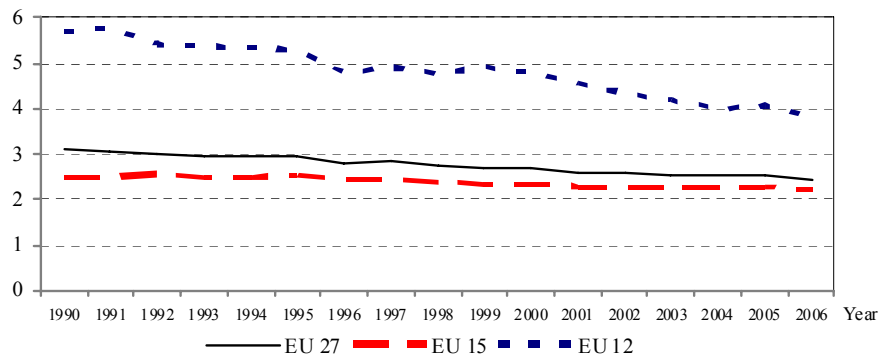
The use of nitrogen fertilizers is an important driving force of emissions of greenhouse gases. As a result, nitrous oxide is emitted to the environment. Data on fertilizer consumption in the EU, which are only available for the period of 1997–2001, show a ten percent decrease.<sup>5</sup> (See Figure 4.)

Figure 4. Fertilizer consumption, 1997–2001  
(million metric tons of active ingredients)



Source: *Eurostat* [2008].

Figure 5. The ratio of agriculture in the total consumption of energy, 1990–2006  
(percent)



Source: *Eurostat* [2008].

<sup>5</sup> The time series is short compared to the other data sets analyzed in this article. Therefore only limited analysis is possible.

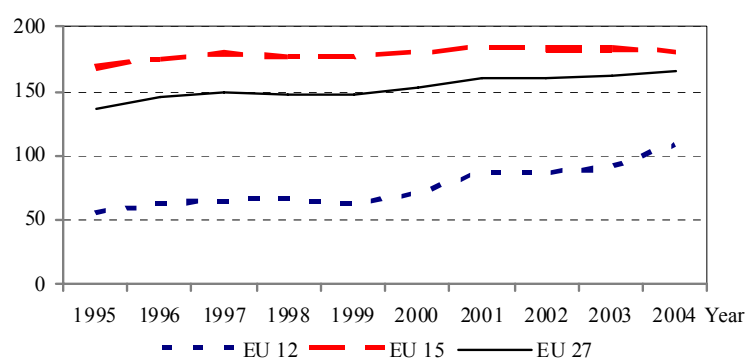
### 2.1.5. The use of fossil fuels

An important contributor to the climate change is the combustion of fossil fuels for heating and for the operation of machines used for agricultural production. The energy consumption of agriculture dropped by 45 percent in the new member states (EU 12) from 1990 to 2006, while it increased by 4 percent in the EU 15 in the same comparison. Compared to the total energy consumption of the economy, the ratio of agriculture decreased from 3.1 percent to 2.4 percent in the EU. (See Figure 5.)

Figure 6 describes the changes in energy efficiency of agriculture in the EU. In the new member states (EU 12), there was a considerable increase in energy efficiency from 1995 to 2004; though the gross value added (GVA) of agriculture per one unit of energy in the new member states still lags behind that of the EU 15. From 1995 to 2001, there was an increase in the energy efficiency in the EU 15, while a slight decrease can be detected between 2001 and 2004.

In addition to the energy consumption of agriculture, another aspect related to energy is the production of biofuels. Ethanol can be produced from maize or sugar cane, and biodiesel can be produced from plants that contain high amounts of vegetable oil. The production of biofuels is a controversial issue. On the one hand, biofuels are said to have an important role in the fight against greenhouse gas emissions, and they can have a favourable impact on fuel prices, on the other hand the support of fuel production against food production is debated. From the environmental point of view, further research is needed on the balance of greenhouse gas captures and emissions related to the production and use of crops for energy purposes.

Figure 6. Gross value added per unit of energy consumption, 1995–2004  
(EUR thousand/terajoules)

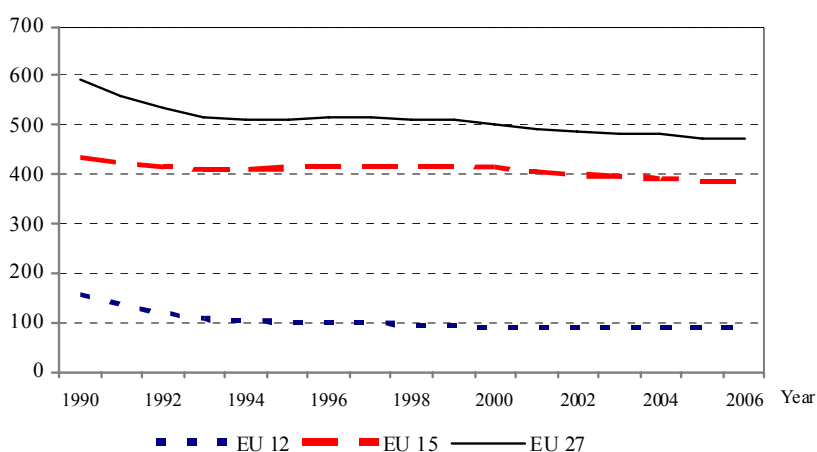


Source: Eurostat [2008].

## 2.2. Pressures – Emissions of greenhouse gases

The emissions of greenhouse gases – carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), methane (CH<sub>4</sub>), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF<sub>6</sub>) – have crucial impact on the climate (*UNFCCC* [2008]). The emissions from farms decreased by 44 percent in the new member states (EU 12), while it decreased by 11 percent in the EU 15 from 1990 to 2006. (See Figure 7.) Concerning EU 12, a sudden fall can be detected in the transition period due to the restructuring of agricultural production. The reason for this latter process is that radical political and economic changes occurred in the Central and Eastern European countries at the beginning of the 1990s, which led to a sharp economic decline. In the meanwhile, a new agricultural policy was initiated and a new, private ownership based agricultural structure was developed (*Fekete-Farkas et al.* [2008]).

Figure 7. Emissions of greenhouse gases in agriculture, 1990–2006  
(thousand metric tons in carbon dioxide equivalent)



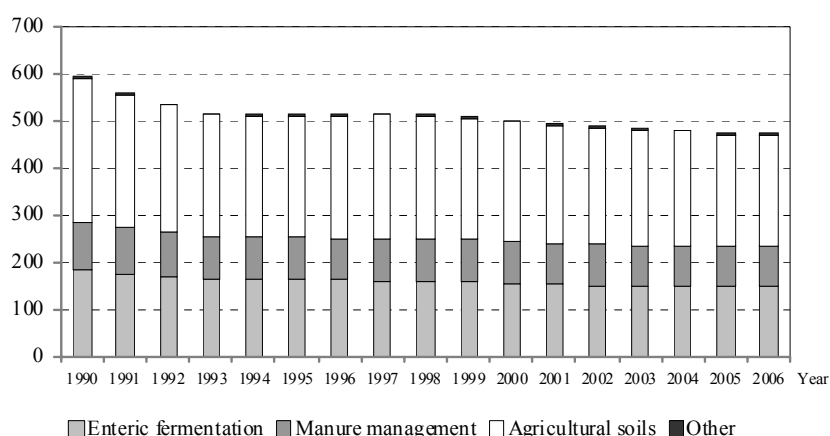
Source: Eurostat [2008].

Data on the source of emissions of greenhouse gases in agriculture are available in the database of Eurostat, though they do not cover the combustion of fossil fuels related to agriculture. Half of the emissions originate from the soil, mainly as a result of fertilizer use. 31 percent was the share of enteric fermentation of ruminant livestock, while 18 percent was that of manure management in 2006. In the EU member states, the emissions of greenhouse gases decreased by 20 percent from 1990 to 2006. (See Figure 8.)

The reason for the decrease of emissions from agricultural soil can be related to the fall of fertilizer use. In the EU, both figures show a 5 percent decrease from 1997

to 2001. The abatement of emissions from manure management and enteric fermentation can be related to diminishing ruminant livestock.

Figure 8. Emissions of greenhouse gases in agriculture of the EU by source of emissions, 1990–2006 (thousand metric tons in carbon dioxide equivalent)



Source: Eurostat [2008].

### 2.3. Analysis of the relation between driving forces and pressures in the EU

In order to present the relations among the different indicators, the correlations of selected indicators of the environmental and economic dimension related to climate change were calculated as a first step in the research. Each indicator was expressed as per unit of agricultural area, thus the obvious correlating factors (for example the size of the country) could be eliminated. Data of the EU 27 countries for the year 2000 were used for calculations. (See Table 4.)

A large correlation was detected in the case of the relation between the gross value added of agriculture and the use of energy by agriculture. The energy efficiency of agriculture does not show significant differences within the EU member states.

The relation between the use of fertilizers and the emissions of nitrous oxide seems to be significant, which may be the result of the estimation method used for the calculation of emissions of nitrous oxide.

The gross value added and the emissions of greenhouse gases also show a large correlation in Europe for the year 2000. According to this result, the “green efficiency” of agricultural production is similar in the EU member states.

Table 4

*The correlation of selected indicators for the EU 27, 2000*

Indicators examined	Correlation index
Use of energy in agriculture / agricultural area – gross value added of agriculture / agricultural area	0.90
Use of fertilizers / agricultural area – emissions of nitrous oxide / agricultural area	0.89
Gross value added of agriculture / agricultural area – emissions of greenhouse gases / agricultural area	0.87
Use of energy in agriculture / agricultural area – emissions of greenhouse gases / agricultural area	0.72
Use of fertilizers / agricultural area – crop output / agricultural area	0.45

*Source:* The author's own calculations.

The correlation between energy consumption and emissions of greenhouse gases is large. The reason why this correlation index is still large but slightly weaker than the former ones can be that besides the use of fossil fuels there are also other factors affecting the emissions of greenhouse gases (the use of fertilizers, the size of livestock, etc).

The correlation is medium in the case of fertilizer use and crop output. The medium correlation can be explained by dissimilarities in the structure of crop products and the difference in the fertilizer demand of crop species, the differing climatic and soil conditions in the member states, price differences, etc. Further research should be devoted to this area.

### 3. Conclusion

According to data presented in the paper, relative decoupling characterizes the European agriculture. While the output of agriculture did not change significantly over the last decade, the area of forests increased; the use of fertilizers, the relative and absolute use of energy, the cattle livestock and, as a result of all these, the emissions of greenhouse gases decreased.

Given the importance of climate change, priority should be placed on the related indicators. Reliable data on the driving forces and pressures of climate change will

enable us to make temporal and spatial comparisons, thus the policy makers can develop proper strategies for the mitigation of agricultural production.

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