

CARBON OFFSET PROJECTS IN THE AGRICULTURAL SECTOR

Claudine Foucherot¹ and Valentin Bellassen²

The agricultural sector accounts for 14% of global anthropogenic greenhouse gas emissions. If we also take into account carbon emissions and sequestration from upstream – production of fertilisers, deforestation, etc. – and downstream – bio-energies, etc. – the share rises to 30%. Many practices and technologies enable agriculture's impact on climate change to be reduced. According to a number of estimates that are summarised in this research, the agricultural sector's mitigation potential is of the same order of magnitude as its emissions over a period of 30 years. However, changing agricultural practices comes at a cost, and in most cases such changes are not made without economic incentives.

Carbon offsetting projects are one of the economic tools available to reduce agricultural emissions by paying for metric tons of avoided CO₂e emissions. A summary of the emission reductions enabled by agricultural projects to date is provided in this report. It covers most projects certified by quality assurance standards, including those set up by the Kyoto Protocol (Clean Development Mechanism and Joint Implementation) and those in the voluntary market (Verified Carbon Standard, Climate Action Reserve, Gold Standard, Chicago Climate Exchange, and American Carbon Registry). The assessment drawn up on this basis shows that emission reductions enabled through carbon offsetting are thousand times lower than actual emissions and their potential mitigation. Agricultural projects have reduced emissions by 14 MtCO₂e in 2010, i.e. 7% of the reductions generated by all carbon offset projects across all sectors for this year.

Initiatives focus on three technologies: bio-energies (crop residues), methanisation of livestock waste, and soil carbon sequestration using no-till practices. This is very little compared with the large number of mitigation technologies that could be used in this sector. The diffuse nature of agricultural emissions and the cost of the abatement measures are the main obstacles to developing agricultural projects. However, the introduction of multi-farm aggregators enables to share costs. Moreover, research on new techniques for measuring emissions more efficiently and less costly is a mean to overcome these obstacles and release the mitigation potential.

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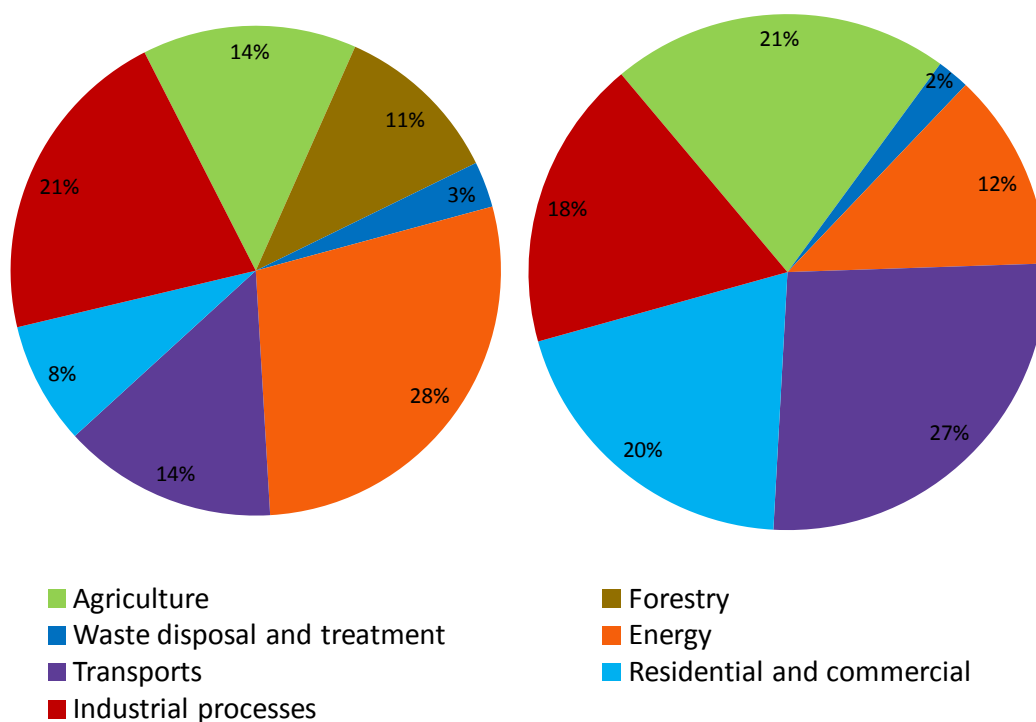
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INTRODUCTION

Agriculture is the fourth largest sector in terms of global anthropogenic greenhouse gas (GHG) emissions. It accounts for 14% of global emissions, i.e. 6.6 GtCO₂e/year (see Figure 1, IPCC 2007). Three types of gas are involved: nitrous oxide (N₂O), methane (CH₄), and to a lesser extent carbon dioxide (CO₂). In fact, agriculture is the largest sector when it comes to emitting gases other than carbon dioxide, and accounts for 60% and 50% of global N₂O and CH₄ emissions respectively (Smith, Martino, *and al.* 2007).

In France, the agricultural sector has the second highest emissions after the transportation sector (CITEPA 2011). Its share of emissions in France is higher than at global level, as it accounts for 21% of all domestic emissions (i.e. 105 MtCO₂e out of 496 MtCO₂e in 2009). This situation is explained by two factors. Firstly, France is the largest agricultural producer in Europe. Secondly, the French electricity sector emits less greenhouse gas than in other countries, due to the importance of nuclear and hydroelectric power, which account for 76% and 11% of electricity generation respectively (MEEDDM 2010). Meanwhile, the French forestry sector does not actually emit any greenhouse gas, as it is a net carbon sink that sequestered 80 MtCO₂e in 2009 (CITEPA 2011).

Figure 1 – Breakdown of greenhouse gas emissions by sector in 2009



Note: The breakdown of French greenhouse gas emissions by sector is for Metropolitan France only. The forestry sector is not shown, as it is a net sink in Metropolitan France, while emissions for the energy sector correspond to national energy generation and transformation, and international traffic is not taken into account for the transportation sector.

World source: IPCC (2007) reviewed according to Van der Werf et al. (2009). French source: CITEPA (2011).

The IPCC sector breakdown used in Figure 1 does not show all the emissions over which farmers have an effective lever: “upstream” emissions, which correspond to the production of fertilisers, pesticides, animal feeds and agricultural machinery, and emissions caused by deforestation intended to increase agricultural land are not classified as agricultural emissions, neither are emissions linked to the consumption of fossil fuels on farms. If we factor in all these sources of emissions, agriculture’s share of total global GHG emissions amounts to around 30%, both on a global scale (World Bank 2009) and in France.

Agricultural emissions are therefore substantial, but the sector’s potential to play a role in mitigating climate change is just as significant. That potential includes implementing certain practices and technologies, which enable:

- **A reduction in emissions from agricultural activities:** in this case, changes in practices have a direct impact on the sources of emissions. This is the case, for instance, when farmers reduce their use of nitrogen fertilisers, which reduces nitrous oxide (N₂O) emissions from cropland and pasture;
- **An increase in carbon storage:** agricultural soils can be a carbon source or a carbon sink depending on farming practices. For instance, low tillage or the sowing of intermediate crops enables more carbon to be sequestered in the soil;
- **The replacement of fossil fuels by biomass energy:** biomass intended for energy generation comes from crop residues – rice husks, bagasse, etc. – or from dedicated crops like miscanthus or sugar cane. It can be burned directly or turned into bio-fuels. There are a lot of discussions regarding the environmental benefits of bio-energies at the present time, particularly on the issue of land-use change. These considerations will be detailed in the following section.

The first section of this Climate Report reviews the agricultural sector’s emissions and mitigation potential, and extends its limits to the sector’s upstream and downstream activities. The aim is to describe the sub-sector and regional breakdown of the emissions and mitigation potential attributed to agricultural activities. The second section sets out agriculture’s role in carbon markets. The third section draws lessons from the 733 projects surveyed. This section primarily explains the reasons behind the success of certain kinds of projects, and the difficulties involved in implementing others due to the specific features of the agricultural sector.

I. THE AGRICULTURAL SECTOR: A MITIGATION POTENTIAL THAT MATCHES ITS EMISSIONS

A. Classification of sources of emissions and mitigation

For the purpose of this report, the agricultural sector's sources of emissions and mitigation are taken in their broadest sense: all emissions that are directly affected by choices made by a farmer and any projects likely to generate carbon credits for a farmer are taken into account, to the extent that their impact on emissions is significant.

Therefore, in addition to the agricultural emissions defined by the IPCC (enteric fermentation, waste management, rice fields, cropland and pasture, and burning of savannahs and crop residues), other sub-sectors are taken into account. This includes farms’ energy consumption, which is usually classified under the energy sector. Some upstream emissions have also been included, like those from fertiliser production, which are generally included in the industrial sector, and the conversion of forests into agricultural land, which is usually found in the forestry sector. Likewise, where downstream emissions are concerned, we will also be looking at decisions to turn biomass into bio-energy.

Conversely, emissions linked to food-processing or transportation are not affected by changes in farming practices, and will therefore not be taken into account. Moreover, since emission reductions linked to greater efficiency in the fertiliser production process do not depend on farmers, they will not be included in this report either.

Finally, some minor sources of emissions, like the production of pesticides³ or the manufacture of agricultural machinery, will be left out.

Emissions sources and their mitigation potential are therefore classified under nine major sub-sectors themselves classified under three groups depending on whether the emission sources or their mitigation potential are upstream of the agricultural sector, from the farm or downstream of it. Each of these sub-sectors is described below using the same process: the first paragraph reminds the type of emissions involved and the second one developed some techniques that can be implemented to mitigate these emissions.

Upstream

- **Fertiliser production**, which includes emissions from processing CO₂ and N₂O at the production plant site.

In the context of this report, the mitigation potential linked to fertiliser production corresponds to a simple decrease in production due to the reduced consumption of fertilizers by farmers.

- **Land conversion**, which includes CO₂ emissions linked to converting forests and wetlands into agricultural land.

Reducing these emissions may involve three kinds of measures: (i) avoiding converting forests and wetlands into agricultural land; (ii) reforesting degraded agricultural land that has become less productive; and (iii) setting up an agro-forestry system by planting widely spaced trees among crops, or by cultivating plots where the tree coverage has been thinned. Only agro-forestry projects have been included in this report, as the others are considered solely as forestry projects.

We also may mention other upstream emissions which are due to animal feed production. In the same way as for the production of fertilizers, the emissions reductions can be achieved by two distinct ways of which only the second is related to a change in agricultural practice: the first way is a technical improvement of production efficiency and the second corresponds to a production decrease resulting from a consumption reduction of concentrates. One of the levers for the second way is to favour polyculture-breaching.

At farm level

- **Cropland and pasture**, which corresponds to the N₂O emissions linked to the use of organic and mineral nitrogen fertilisers, to the open-air waste emissions and to legumes. The mechanisms involved are detailed in Appendix 1.

One way of reducing nitrous oxide emissions is to limit the use of nitrogen fertilisers (sustainable use of fertilisers, planting legumes, avoiding leaving the soil bare, changing the kinds of nitrogen fertilisers used, etc.). Water management also has an impact on the denitrification process, which can be defined as an alternative breathing mechanism. For example, soil drainage enables improved aeration, and therefore a less intensive denitrification process. However, this effect is harder to understand, and therefore has not been taken into account in our calculations.

- **Livestock farming**, which breaks down into two sources of emissions: enteric fermentation and waste management. Enteric fermentation emits methane (CH₄), which is formed when cellulose is digested by ruminants (cattle, sheep, goats and members of the camel family) through the microbial fermentation process. Animal waste emits CH₄ when organic matter breaks down in an anaerobic environment, as well as N₂O, especially if the ventilation is poor.

Where waste management is concerned, the choice of its form, i.e. liquid waste (slurry), or solid waste (manure) has an impact on CH₄ and N₂O emissions. According to the Canadian Ministry for Agriculture and Agri-Food, slurry emits between four and six times more gas than compost manure (which is raked to improve aeration), while a heap of manure emits 1.3 times more gas than compost. Another technique to

³ In volume terms, the consumption of pesticides accounts for 0.5% of fertiliser consumption (FAOSTAT 2011).

reduce emissions is to methanise livestock waste⁴. This reduces emissions by 80% at the storage stage, and enables heat and electricity to be generated, while preserving the waste's fertilising properties. Where enteric fermentation is concerned, there are currently few measures to reduce emissions without decreasing production. The methods envisaged amount to changing the cattle feed (higher proportion of concentrates, feed with a high polyunsaturated fatty acid content, etc.), and to improving productivity in order to reduce herd numbers.

- **Rice-growing:** the flooding of cultivated areas, and therefore the absence of oxygen, encourages the growth of anaerobic bacteria, and therefore the production of CH₄ via fermentation. Emissions can be reduced by drying out the soil between growing periods, although this may increase N₂O emissions.
- **Burning organic matter for non-energy generation purposes**, which mostly includes slash-and-burn farming and setting fire to sugar cane crops to make harvesting them easier. The gases in question are CH₄ and to a lesser extent N₂O; CO₂ emissions are not generally included in inventories, as the gas was captured at an earlier stage, while the plants were growing. New agricultural machinery enables sugar cane to be harvested without setting fire to the field beforehand, while the intensification of agricultural production is expected to reduce the use of slash-and-burn farming.
- **Energy consumption**, which is mainly linked to heating greenhouses and livestock barns, preserving milk stocks, and even operating tractors. Better tuned machinery and less use of agricultural machinery as a result of simplifying the way the land is farmed enable CO₂ emissions reduction.
- **Carbon flows between the soil and the atmosphere**, which can result in a zero balance, either in terms of storing carbon in the soil or releasing it into the atmosphere, depending on changes to the soil's carbon stores. This situation involves a specific mitigation mechanism, as the process may involve both reducing emissions and increasing carbon sequestration. The process poses two major challenges:
 - *reversibility*: any carbon stored in the ground may return to the atmosphere, if the practice is abandoned, or if the climate becomes unfavourable. Furthermore, the kinetics of retrieval is faster than the kinetics of storage, hence the importance of maintaining soil carbon stocks (Arrouays *et al.*, and Stengel, 2002).
 - *saturation*: once the soil is saturated, usually after one hundred years or so, the level of carbon sequestered no longer rises, even if the practices (no-till, intermediate crops, etc.) continue.

The main techniques for increasing the quantity of carbon in the soil are simplifying farming methods (superficial cultivation, no-till, etc.), converting cropland to pasture, agro-forestry, increasing soil return of crop residues or dung and unharvested crops (green manure) ... These techniques can increase the provision of organic carbon and protect the soil against erosion and carbon mineralization leading to CO₂ emissions.

Downstream

- **Bio-energies**, which replace fossil fuels. At first sight, bio-energies seem like a real catalyst for reducing emissions; they do, however, have their limits. For instance, they pose a problem in terms of competing land use. In fact, dedicated energy crops may generate high CO₂ emissions, if it is necessary to clear a forest to plant them. They may also create tensions in agricultural prices when they replace food crops. This competition effect may be direct or indirect. The indirect effect appears, for instance, when agro-fuels are grown on land to the detriment of farming, which is then moved to another area, to the detriment of a tropical forest. The use of crop residues as bio-fuels – almost the only type of bio-fuel offset project allowed so far – enables the competition issue to be avoided, but may lead to a decrease in the soil's fertility and carbon stores: returning crop residues to the soil enables it to be enriched, because they represent added organic matter.

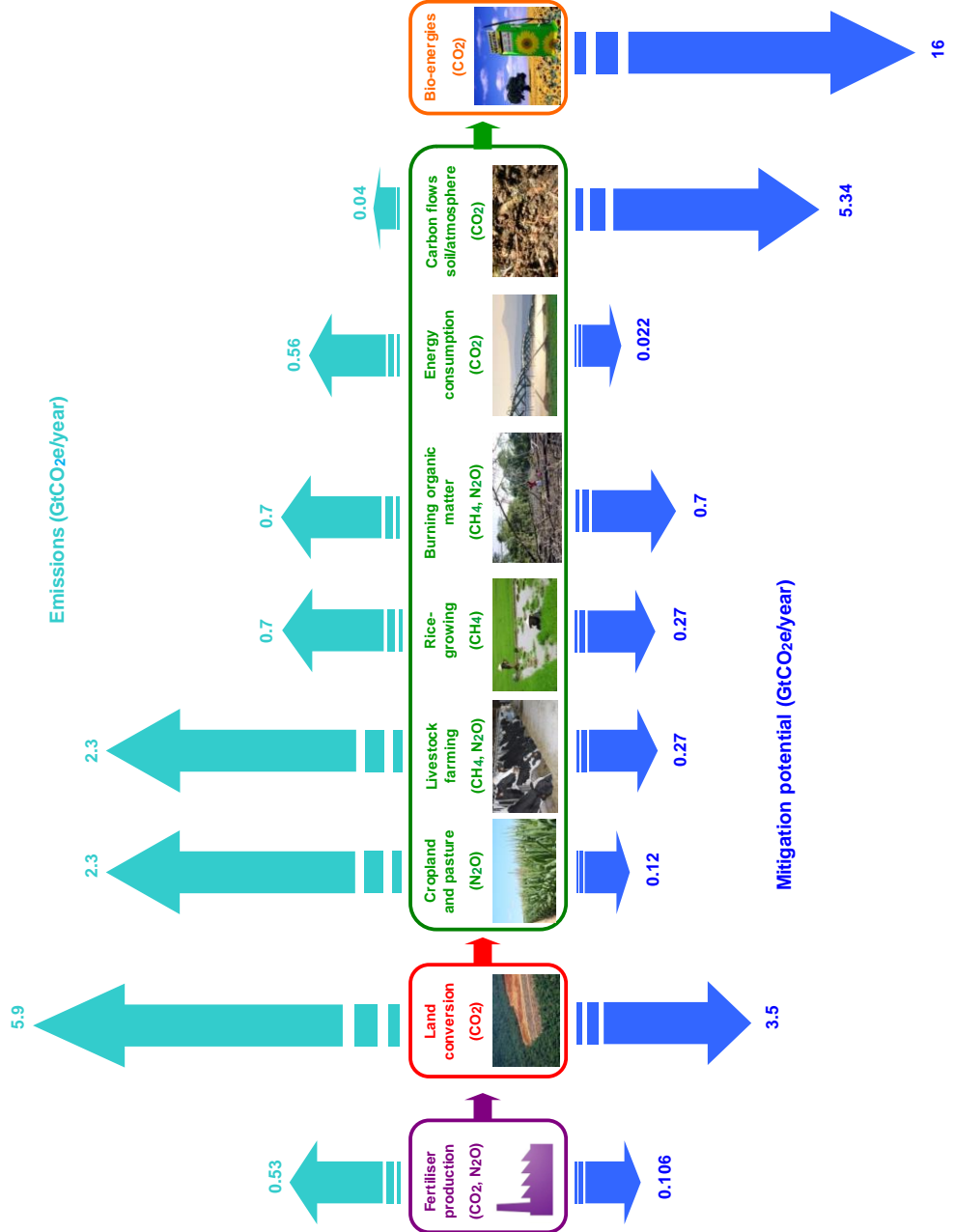
Bio-products, by replacing energy-intensive raw materials, are also a way to mitigate greenhouse gas emissions.

⁴ Methanisation of liquid livestock waste corresponds to its anaerobic fermentation in a digester, which results in the formation of biogases (50-75% of CH₄ and 25-45% of CO₂); these can be used as a source of heat, electricity or both (cogeneration). In addition to biogas, methanisation also enables the production of digestate, which has a high fertiliser value.

B. Estimating emissions and mitigation potential by sub-sector at global level

It is important to determine what the main sources of emissions are, in order to introduce suitable techniques for reducing emissions. However, the areas with the highest mitigation potential are not always where emissions are the highest. This is for example the case of CO₂ fluxes between soil and atmosphere where the potential for carbon sequestration in soil is more than 100 times higher than current emissions. Emissions and mitigation potentials for the different sub-sectors defined above are summarized in Figure 2.

Figure 2 – Global emissions and mitigation potential



Note: mitigation potentials correspond here to the maximum technical potential per year by 2030 which reflect the expected increase in demand for food.

Source: CDC Climat based on the US-EPA (2006) for the maximum emission estimates and on Smith et al. (2007) for the mitigation potential. Details of calculations and sources are provided in Appendices 2 and 3.

Several sources of emissions led by land conversion

Demographic growth and changes in emerging countries' dietary habits (especially in China and India) are resulting in increased demand for foodstuffs at global level. In addition, competition from energy crops is growing. These two phenomena are leading to a rising trend in agricultural prices, which puts increasing pressure on land. The increase in agricultural land areas is therefore the main cause of deforestation. Deforestation accounts for 44% of agricultural emissions, i.e. 5.7 GtCO₂e per year.

Cropland/pasture and livestock farming are the two largest sources of emissions after deforestation. They account for 18% of agricultural emissions each. Emissions linked to livestock farming break down into two sub-categories: enteric fermentation, which accounts for 83% of emissions from livestock farming, and waste management, which includes the remaining 17%.

The border between the cropland/pasture and livestock farming categories, as defined by our estimates, does not take into account the real importance of livestock farming in terms of emissions. In fact, emissions in the field that are linked to fodder production are recognised under the cropland and pasture sector, even though they are intended as animal feed. Under "life-cycle analysis"-type accounting, direct and indirect emissions, excluding the conversion of land for livestock farming, have been estimated at 85% of European emissions from the agricultural sector, as defined by the UNFCCC (Joint Research Centre 2010). This percentage has to be treated with caution, in that it does not compare like with like: emissions from livestock farming have been calculated using a life-cycle analysis that takes imports into account, while the European agricultural emissions were surveyed according to UNFCCC guidelines.

Upstream of the agricultural sector, fertiliser production, which is dominated by nitrogen fertilisers, is also a significant source of emissions. It emits 0.53 GtCO₂e per year, i.e. 4% of agricultural emissions.

Other emission sources appear at global level, like those linked to rice-growing or the burning of organic matter. They emit 0.7 GtCO₂e, i.e. 5% of agricultural emissions, each. Rice-growing is the world's second largest source of methane emissions after enteric fermentation.

Lastly, changes in land use, agricultural practices and climate are also factors that affect agricultural land carbon stores. According to Smith *et al.* (2007), some regions of the world are net carbon sinks while others are net sources of carbon emissions. The net global amount of CO₂ emissions from agricultural soils is estimated to be 0.04 GtCO₂ per year, on a highly uncertain basis.

Bio-energies are the main mitigation catalyst

Bio-energies seem to be the main means of reducing emissions at global level. The very broad range of the estimate (between 4 and 16 GtCO₂e per year) is due to uncertainty regarding future yields and the areas available for dedicated crops. The higher the yields, the higher crop residues will be, and the more land will be available for energy crops. 12 GtCO₂e per year out of a mitigation potential of 16 GtCO₂e per year (which corresponds to a high estimate) could be mitigated through the use of dedicated crops (miscanthus and jatropha), while the remaining 4 GtCO₂e per year could be mitigated by crop residues like straw, bagasse (a sugar-cane by-product), or rice husks. However, these figures are highly contested, since they do not apprehend the problems of indirect effects mentioned above.

The second mitigation catalyst is carbon sequestration in the soil. P. Smith *et al.* (2007) estimate the mitigation potential of soil carbon storage to be 5.34 GtCO₂e per year.

Limiting the conversion of forest land into agricultural land is another important mitigation catalyst, with the emissions reduction potential of 3.5 GtCO₂e per year. The relative merits of the various means of doing so – more intensive farming, protected areas, planning land use, etc. – are still being actively discussed at international level through the REDD+⁵ mechanism (Pfaff *et al.* 2010).

The mitigation potential for the two main sources of emissions on farms, i.e. cropland and pasture and livestock farming, seems very low, as it amounts to 0.12 and 0.27 GtCO₂e per year respectively. Reducing the use of nitrogen fertilisers is achievable up to a certain limit, beyond which yields might be affected. As

⁵ Emission reductions linked to deforestation and to forest degradation, and increase in forest carbon stocks.

to livestock farming, the mitigation potential is higher, although it remains low compared with the level of emissions involved. The means to reduce emissions linked to enteric fermentation – which accounts for 83% of livestock farming emissions – are limited.

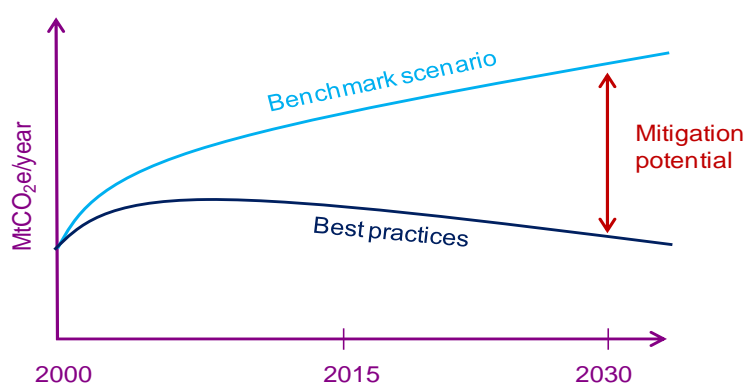
The mitigation potential of the rice-growing and organic matter combustion sectors is estimated to be 0.27 and 0.7 GtCO₂e per year respectively. Since the maximum technical potential is concerned, the assumption used for the combustion of organic matter corresponds to the complete stoppage of practices relating to this sub-sector.

Where the production of nitrogen fertilisers is concerned, the mitigation potential corresponds solely to the emissions reductions created by a fall in demand, not to any technical improvement in production, which would then fall under the industrial sector, as mentioned earlier. This sub-sector is therefore correlated with the cropland and pasture sub-sector. The mitigation potential is estimated to be 0.106 GtCO₂e per year, corresponding to a 20% decrease in fertiliser production (Appendix 3).

Uncertainty, technical potential and economic potential

Estimates of technical mitigation potential should be treated with caution. According to the IPCC report, the global mitigation potential (excluding upstream and/or downstream activities) is around 5.8 GtCO₂e per year, with a confidence interval of 95% within a range between 0.3 and 11.4 MtCO₂e. There are two main reasons for this uncertainty. Firstly, it is hard to estimate the mitigation factors linked to the implementation of a given practice or technology. Very often these factors depend on several parameters, such as climatic conditions, the nature of the soil, the type of crop, diet, age, the live weight of the animal, etc. The lack of data, particularly in developing countries, limits us to using factors that are inaccurate by default. Secondly, it is hard to estimate the future emissions for the agricultural sector that will determine the benchmark scenario. In fact, mitigation potential is calculated on a global scale⁶, based on a benchmark scenario forecast up until 2030⁷, as summarised in Figure 3.

Figure 3 – Calculating mitigation potential



Source: CDC Climat Research

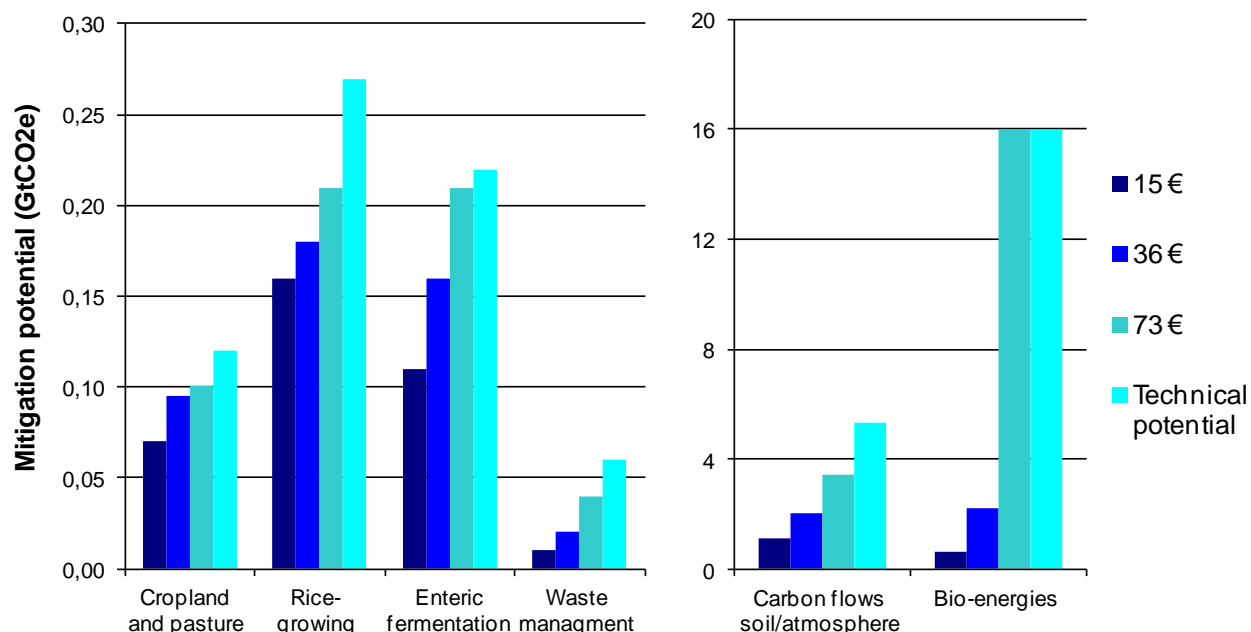
These uncertainties are compounded by the issue of incompatibility between various practices, which is not always taken into account. For example, the use of crop residues is included in both “soil carbon sequestration” and “bio-energies” sub-sectors, while one method of use excludes the second.

In addition, the technical potential does not take into account the economic limits: economic mitigation potentials are highly dependent on the carbon price for each sub-sectors (Figure 4).

⁶ The models used to draw up the benchmark scenario (including Image v. 2.2 for estimating future cropland and pasture areas, and the IMPACT model for estimating dedicated rice-growing areas) primarily take increased food demand and improved yields into account.

⁷ The benchmark scenario corresponds to the IPCC B2 scenario.

Figure 4 – Comparison of the economic and technical mitigation potential levels for each sub-sector (GtCO₂e per year)



Source: CDC Climat based on data in Smith et al. (2007).

Economic viability of strategies that can be implemented to reduce GHG emissions depends on the price of carbon. When prices are low, the strategies that can be implemented are those where production is maintained and where there is just a change in practices (no-till, decrease in fertiliser use, change of feed, etc.). When prices are higher, strategies that involve an initial investment without any changes in production can be envisaged. This is the case, for instance, with water management for cultivated plots (irrigation and/or drainage), or even the installation of a methaniser. In the latter case, the gain achieved thanks to electricity generation (where it exists) may make installing such a facility easier. Finally, when the prices are even higher, mitigation strategies that involve decrease in production become economically viable.

If we do not take the agricultural sector's upstream and downstream activities into consideration, the mitigation potential is estimated to be 1.5, 2.6 and 4.15 GtCO₂e per year, at prices of €15 per tCO₂e, €36 per tCO₂e and €73 per tCO₂e respectively⁸.

C. Estimating regional emissions and mitigation potential

This section seeks to describe the geographical breakdown of emissions and mitigation potential. The geographical breakdown corresponds to the one used by the World Meteorological Organisation (WMO): Africa, Asia (including the Eastern part of Russia beyond the Ural Mountains, but not including either Indonesia or Malaysia), South America, North America, Central America and the Caribbean, the South-West Pacific (including Indonesia and Malaysia) and Europe (including the Western part of Russia and Turkey).

Asia: half of global emissions

Asia, which accounts for 49% of global agricultural emissions, is the region with the highest emissions by far (Figure 5). This is not at all surprising, given that the region is the largest consumer of nitrogen

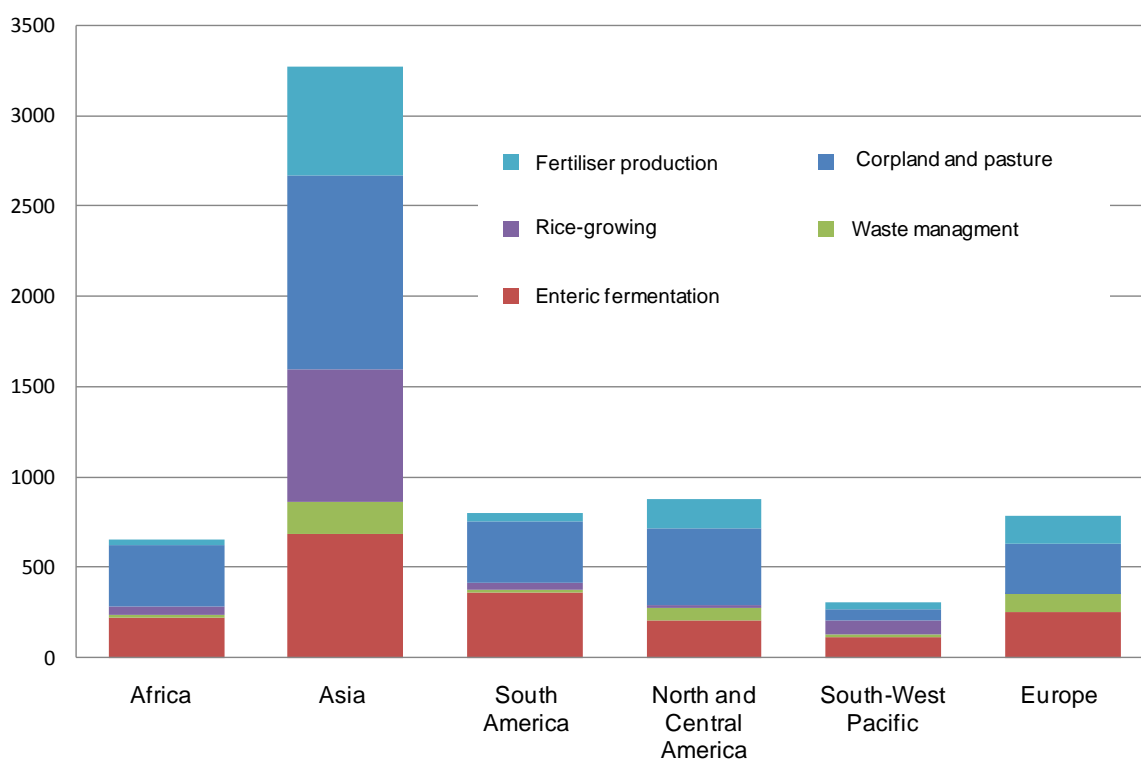
⁸ The carbon prices (US\$20, US\$50, and US\$100) have been converted into euros using the average 2007 exchange rate.

fertilisers (60% of global consumption), owns 31% of the world's cattle, 97% of buffaloes, and 42% of sheep (the species that emit the most methane), and is home to 82% of all areas where rice is harvested (FAOSTAT 2011).

In Africa and America, the proportion of emissions generated by waste management is relatively low compared with the proportion generated by enteric fermentation. This is probably due to the extensive (open-air) nature of livestock farming in these regions. Liquid agricultural waste only results in N₂O and CH₄ emissions when livestock are kept in barns, or their waste is recovered and stored before being spread over fields. Emissions caused by open-air animal waste are included in the “cropland and pasture” sub-sector.

Emissions caused by deforestation are mainly found in two regions of the world: in the Amazon Basin, where the conversion of forest land into agricultural land is primarily related to livestock farming and the expansion of soy crops intended for animal feed; and in Indonesia, mainly due to the cultivation of oil palm (Bellassen, *et al.* 2008).

Figure 5 – Regional breakdown of emissions from the agricultural sector in 2000 (MtCO₂e)



Note: The data for emissions caused by energy consumption and the combustion of organic matter are not sufficiently accurate to break them down for each of the six regions. 92% of emissions caused by the combustion of organic matter are generated in developing countries, mainly in Sub-Saharan Africa, America and the Caribbean, while energy consumption is higher in industrialised countries. Moreover, emissions relating to the conversion of forest land into agricultural land are mainly generated in South America and in the South-West Pacific (Indonesia).

Where fertiliser production is concerned, emissions correspond to the region's consumption level, not to its production level.

Source: Vergé, De Kimpe and Desjardins (2006).

The ranking of the continents changes radically when the carbon intensity of agricultural production in different regions is compared (Figure 6)⁹. Africa and South America are the two regions that generate the most emissions for each foodstuff produced. Although Asia has the highest emissions, it is relatively

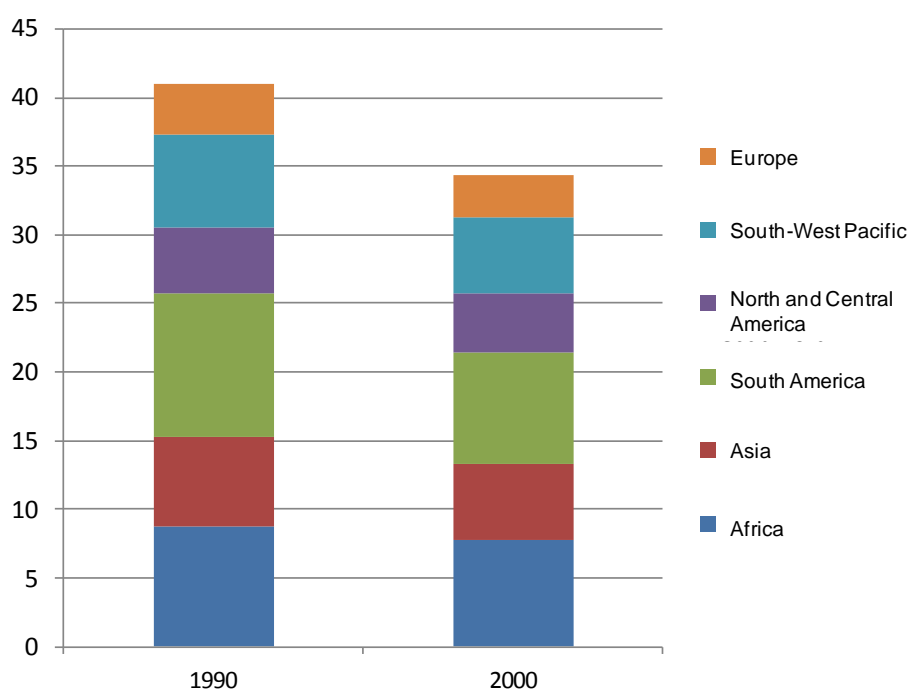
⁹ Net agricultural production has been calculated as follows: the quantity of each foodstuff (corn, rice, milk, eggs, etc.) produced for each region is weighted according to its benchmark price, which corresponds to the average price of that foodstuff in the period between 1999 and 2000. Therefore the price of the same foodstuff does not depend on the area where it was produced. Next, the various types of production for one year, weighted according to price, are added up to obtain the net agricultural production for a region. Produce intended for animal feed is not included.

efficient. The two regions with the fewest emissions per quantity produced are Europe, at the top of the list, followed by Central and North America. The regions where yields are highest therefore have the lowest emissions on an equal output basis.

Efficiency in terms of emissions according to output improved between 1990 and 2000, falling from €41 per tCO₂e to €34 per tCO₂e. The main reason is probably improved productivity. Generally speaking, high-intensity agriculture emits fewer emissions when emissions are measured against the quantities produced. For example, improving the yields for a given crop, which is linked to better fertilisation and to better water management, enables a reduction in emissions per quantity produced, and also enables soil carbon storage to be increased by increasing the crop residues that can be returned to the soil.

However, these numbers also need to be treated with caution, given that no distinction is made between the various kinds of production (cereals, meat, milk, etc.). In fact, some types of production cause more emissions than others. For example, this is the case with cattle farming when compared with poultry farming, or flooded rice cultivation when compared with wheat cultivation. It is therefore hard to compare regional emissions when they are reduced to net agricultural production, given that these regions do not have the same production profile.

Figure 6 – Regional emissions reduced to production levels (tCO₂e per €)



Source: FAOSTAT (2011); Vergé, De Kimpe and Desjardins (2006).

The greatest mitigation potential is thus... in Asia

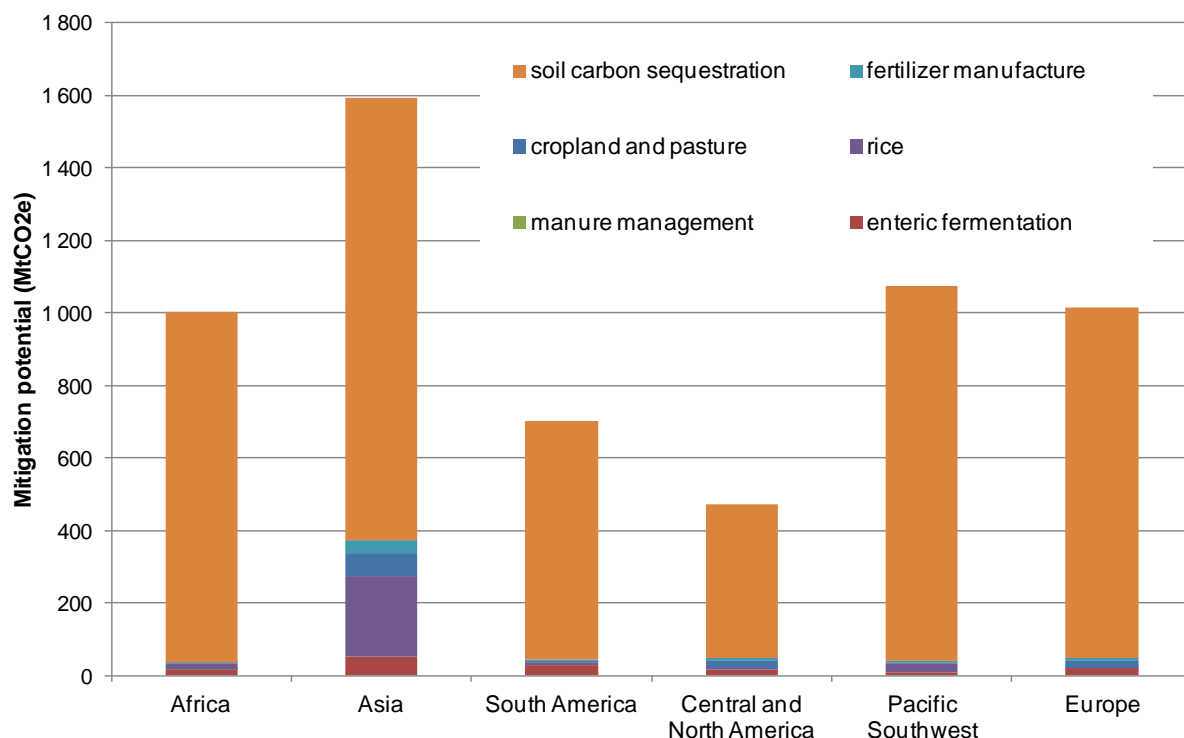
Asia has the greatest mitigation potential (Figure 7). If we exclude soil carbon storage, its main mitigation catalyst is better management of its rice crop. Among other issues, this better management involves keeping the soil dry between two crops, better management of organic matter additions, which should preferably be made during drying-out periods, and the use of varieties that give out fewer emissions.

Soil carbon storage capacity is unequally distributed throughout the world. Soil use, the nature of the soil and climate are the three main factors to take into account when determining carbon storage potential in soil. In the same way as a corn crop stores less carbon in the soil than a meadow, a vertisol (which is rich in clay) will have less storage capacity than a podzol (which is rich in organic matter, and is found mainly in Europe), while an area in a hot, dry climate will store less carbon than a cold, wet area. The soil use and agricultural practices implemented determine short-term variations in carbon levels, while the nature of the soil and the climate explain long-term storage capacity. We also need to take the actual state of the

soil into account. Africa and Asia are the two areas where soil degradation is highest, primarily due to erosion.

Where bio-energies are concerned, the IPCC report estimates that the most promising regions are Latin America, Sub-Saharan Africa and Eastern Europe, followed by Oceania and Northern and Eastern Asia in the longer term.

Figure 7 – Breakdown of mitigation potential by region (MtCO₂e per year)



See Appendix 6 for details of the calculations.

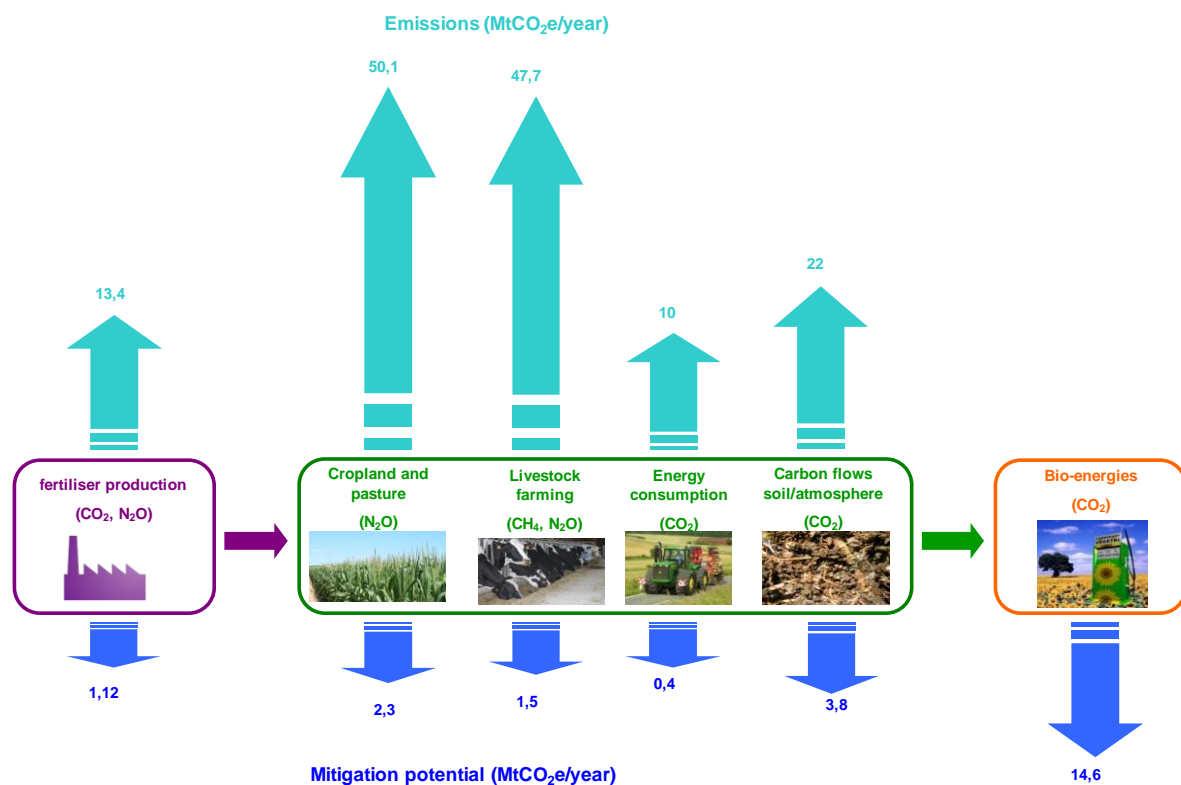
Source: X.P.C. Vergé, C. De Kimpe, and R. L. Desjardins (2006); P. Smith et al. (2007)

D. The French example

There are fewer sources of emissions in France than at global level. This is because the forestry sector is a net carbon sink at French level. In addition, since rice-growing is negligible, it has not been taken into account in this report; nor has the combustion of organic matter.

Mitigation potentials estimate for the various sub-sectors have not been calculated in the same way for French and global level. For the French example, the only mitigation potentials which have been considered result from changes in practices relatively easy to set up whereas, the global figures correspond to the maximum technical potential. Thus, the French mitigation potentials are underestimated compared to global figures. The other differences of calculation are highlighted in Appendix 7. Emissions and mitigation potentials are given by sub-sector in Figure 8.

Figure 8 – Emissions and technical mitigation potential in France



Note: The 13.4 MtCO₂e emitted during the fertiliser production process were calculated in relation to the consumption of fertilisers in France, not to their production. In fact, only 40% of the fertilisers consumed are produced in France.

Source: CDC Climat, based on data from the UNFCCC emission survey, and on data in Leseur (2006) for the mitigation potential. For details of emission and mitigation potential calculations, see Appendix 4 and Appendix 5.

Sources of emissions that are less diversified than at global level

The cropland and pasture category single-handedly accounts for 39% of agricultural emissions (excluding upstream and/or downstream activities). The 50.1 MtCO₂e per year shown in Figure 8 take into account both direct and indirect N₂O emissions caused by the use of nitrogen fertilisers. The sub-sector's strong contribution to GHG emissions is explained both by the substantial use of mineral nitrogen fertilisers (France is the largest consumer of nitrogen fertilisers in Europe¹⁰) and by a significant livestock farming industry, which involves the spreading of large quantities of animal waste.

Livestock farming is responsible for 37% of emissions (excluding upstream and/or downstream activities). Within this sub-sector, enteric fermentation accounts for 59% of the total, and waste management for 41%. The smaller gap than the one observed at global level is explained by the relative importance of enclosed breeding in France¹¹.

Upstream of the agricultural sector, fertiliser production, which is dominated by nitrogen fertilisers, is also a significant source of emissions. Every metric ton of nitrogen spread in the form of fertiliser is responsible for 10.5 tCO₂e of emissions in the field (67%) and 5.1 tCO₂e during its production (33%).

Energy consumption on French farms emits 10 MtCO₂e per year. This is a relatively high figure compared with the global level, but is comparable to that of industrialised countries.

Lastly, IFEN (the French Environment Agency) estimates that the carbon stored in agricultural soils is declining by 6 MtC per year; in other words, French agricultural soils could be emitting 22 MtCO₂e per year. Proportionally, this figure is much higher than at global level (40 MtCO₂ per year). This situation is

¹⁰ France accounts for 20% of European consumption (<http://bitagro.imist.ma/spip.php?article112>).

¹¹ Waste emitted directly in the open air is only included in the "cropland and pasture" sub-category.

primarily explained by the fact that some countries, like France, are sources of CO₂, while others are carbon sinks. Thus, the net global balance of CO₂ emissions from agricultural soils is relatively low.

Bio-energies are the prime mitigation catalyst, both in France and the World

A major portion of the mitigation potential comes from bio-energies, half of which is accounted for by bio-fuels. This estimate, which reflects the targets of the French Climate Plan adopted in 2004, probably underestimates the mitigation potential of bio-fuels. This is because Leseur (2006) takes into account the targets set by the 2003 European Directive, which aimed to include 5.75% of bio-fuels in the fuel mix by 2010. In fact, this target was broadly met, and the new target is to include 10% of bio-fuels between now and 2020. The other half of the mitigation potential corresponds to the use of crop residues, such as straw, and to growing dedicated crops like miscanthus, in order to produce heat or electricity.

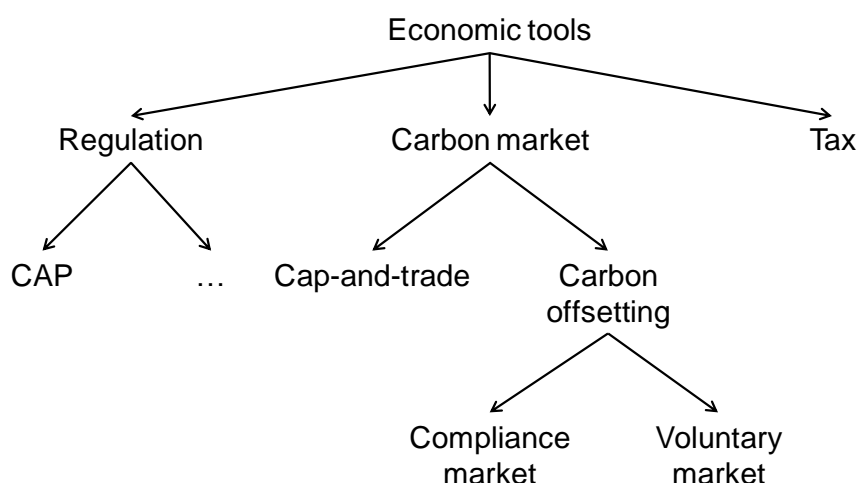
Where soil carbon sequestration is concerned, the mitigation potential is proportionately much lower than at global scale. In fact, it amounts to 14.6 MtCO₂e per year in France compared with 5,340 MtCO₂e per year at global level, which corresponds to 0.1 tCO₂ per hectare¹² per year and 1.1 tCO₂ per hectare¹³ per year respectively. This situation can be explained in two ways. On the one hand, tropical regions have a very significant carbon sequestration potential because of their climate. On the other, the areas with the most degraded soil are in developing countries (Sub-Saharan Africa, Central and Southern Asia, the Caribbean, Central America and the Andes). The greater the degradation of the soil, the higher that soil's capacity for capturing carbon will be.

II. CARBON OFFSET PROJECTS: A MEANS OF MONETISING EMISSION REDUCTIONS

A. Compensation makes agriculture an integral part of carbon markets

Carbon markets are one of the three major economic tools that enable emissions to be reduced, the other two being regulation and taxation. They come in two forms: “cap-and-trade” schemes and carbon offset mechanisms, which generate credits (Figure 9).

Figure 9 – Economic tools for reducing emissions



Source: CDC Climat Research.

Cap-and-trade schemes include whole sectors of the economy, where every installation must surrender the same amount of allowances as the amount of GHG it has emitted. To achieve that goal, installations that have excess allowances relative to their emissions can sell them to installations with an allowance

¹² Total agricultural areas according to FAOSTAT (2011).

¹³ Idem.

deficit. None of the current cap-and-trade schemes actually includes agriculture. Only the New Zealand scheme plans to include agriculture, starting in 2015 (Box 1).

Box 1 – New Zealand’s Emission Trading Scheme – NZ ETS

The agricultural sector is expected to enter the NZ ETS in January 2015. New Zealand is planning to include the two following sub-sectors:

- livestock farming (including enteric fermentation and manure management);
- cropland and pasture (including direct and indirect N₂O emissions resulting from the use of nitrogen fertilisers).

The challenge resides in working out whether compliance obligations will be set at farm level, at industry level, upstream and downstream (food processors for the “livestock farming” sub-sector, and nitrogen fertiliser manufacturers for the “cropland and pasture” sub-sector), or whether to combine both levels.

Setting the obligations at the level of meat and dairy processors would require them to surrender allowances (NZUs) equivalent to the emissions generated by the products they process. Processors could then use the total amount of the emissions relating to the current NZU price to determine the price they offer the farmer. Where emissions relating to fertilisers are concerned, the manufacturer, the importer or the supplier would also face equivalent obligations.

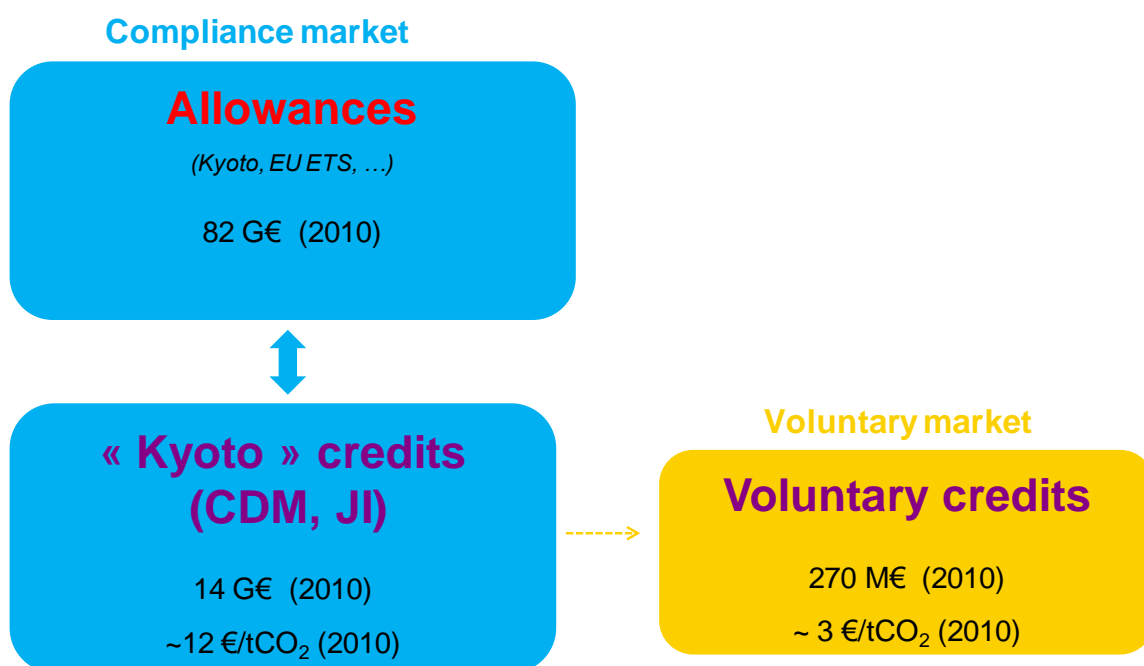
The choice of setting obligations at processor level has the advantage of being simpler to implement and less expensive. Moreover, setting the obligations at farm level poses a major problem: herd owners and land owners are not always the same people. Who would be responsible in this case? However, an obligation set at farm level offers a wider range of emission reduction opportunities. This is because assessment is more accurate (use of factors specific to the farm, not factors common to all farms), and enables the factoring in of emission reductions linked to practices such as optimising the timing of fertiliser application or changing cattle feed.

Source: CDC Climat Research. For further details, see Climate Study No 26 – The inclusion of forestry and agricultural emissions in New Zealand’s new carbon market.

Offsetting is the second way of gaining a foothold in the carbon markets. The process consists of drawing up an appropriate emission reduction project perimeter. The emissions within the perimeter are compared with a benchmark scenario, and the difference can be monetised in the form of carbon credits. This process enables operators in a sector that is not included in cap-and-trade scheme to monetise their emission reductions if they wish to do so. Emission reductions in the agricultural sector are usually monetised in this way.

The standard used to certify emission reductions, and therefore carbon credits, determines the market in which these reductions are monetised. The Clean Development Mechanism (CDM) and Joint Implementation (JI) are the compliance market’s two traditional standards. The European Emission Trading Scheme (EU-ETS) is by far the largest compliance market. The Climate Action Reserve (CAR) was recognised in 2010 by the Californian authorities as an offset standard for California’s emission trading scheme, which should start up in 2013. Its status should therefore change from “voluntary” to “compliant” in the near future. The compliance markets are credit trading schemes where the regulator, which allocates credits to installations operating under constraints, authorises polluters to a certain degree to use carbon credits to ensure that they are compliant. These markets are larger and more liquid, and their prices are higher than those of the voluntary markets (Figure 10).

Figure 10 - Compliance and voluntary markets



Source: CDC Climat Research, based on data from the World Bank (2011).

All other standards are only recognised by voluntary markets, where various entities – companies, public institutions, private individuals, etc. – purchase credits in order to meet a voluntary emissions reductions target. This variety of standards makes voluntary markets a framework that is more flexible, responsive and innovative than compliance markets.

B. Carbon offset standards

All these standards are seeking to guarantee five quality criteria: (i) additionality, which corresponds to the fact that the emission reductions could not have occurred without being monetised on the carbon market; (ii) verification of the emissions reductions according to specifications drawn up beforehand; (iii) the permanence of the emission reductions; (iv) the offset timetable, i.e. ensuring that the credits can only be issued once the emissions have actually been reduced; (v) transparency, which makes it possible to guarantee that the same ton of CO₂ cannot be resold several times.

Eight offset standards are considered in this section: the Clean Development Mechanism (CDM), Joint Implementation (JI), the Verified Carbon Standard (VCS), the Climate Action Reserve (CAR), the Gold Standard (GS), the Chicago Climate Exchange (CCX), and the American Carbon Registry (ACR). The CDM and JI standards cover 100% of the credits traded on the compliance markets, and all these standards cover 78% of those traded on the voluntary markets¹⁴.

CDM and JI for compliance markets

Clean Development Mechanism (CDM)

CDM projects are approved by the United Nations, and implemented in developing countries that have no emission reduction targets under the Kyoto Protocol. No type of agricultural project is excluded *per se*, except projects for the sequestration of carbon in agricultural soils.

Joint Implementation (JI)

JI projects are those that have been implemented in industrialised countries that have quantified emissions reductions targets under the Kyoto Protocol (Annex B countries). These countries are required

¹⁴ According to the data in Peters-Stanley *et al.* (2011), excluding the CCB, which is most often added to another standard.

to provide national inventories of their emissions. Agricultural emissions are included in those inventories on the same basis as those of other sectors (energy, industry, transportation, etc.).

Under JI, types of agricultural projects are only authorised if the emissions they reduce are accounted for in the national inventory. This process *de facto* excludes carbon sequestration in agricultural soils for country such as France, as the emissions resulting from changes in soil carbon storage are not included. In addition, the emission factors used in the inventories are not always sufficiently accurate to account for emission reductions due to a change in practice. For example, a change of feed at a cattle farm, designed to reduce methane emissions from enteric fermentation, will have no impact on the inventory if the emission factor used does not take this change of feed into account¹⁵. The IPCC guidelines on emission inventories give countries some latitude in the choice of methods and emission factors. The types of possible JI projects may therefore vary slightly from one country to another, depending on the national inventory's level of accuracy.

Voluntary markets: VCS, CAR, GS, CCX, and ACR

Historically, voluntary standards have based their procedures on the CDM, while gradually introducing innovations to (i) reduce the costs and delays associated with certification, and (ii) broaden the range of projects authorised. Then, they are less restrictive than the Kyoto standards leading to a lower carbon price.

Verified Carbon Standard (VCS)

The Climate Group, the International Emissions Trading Association and the World Economic Forum Global Greenhouse Register have been developing the VCS since March 2006. The standard has created a carbon credit unit: the Verified Carbon Unit (VCU). 42%¹⁶ of the voluntary credits traded in 2010 were VCUs. All types of agricultural projects are in principle authorised by the VCS.

Climate Action Reserve (CAR)

The CAR succeeded the California Climate Action Registry (CCAR), which was created by the State of California in 2001. The CAR certifies projects implemented in North America, and has also created its own carbon credit unit: Climate Reserve Tonnes (CRTs). 16% of the voluntary credits traded in 2010 were CRTs. The only methodologies available for the agricultural sector are for the methanisation of liquid agricultural waste.

Gold Standard (GS)

The Gold Standard was set up in 2003 by the WWF and several other non-governmental organisations, and has now been approved by 70 NGOs world-wide. This standard accounted for 10% of the voluntary credits traded in 2010. The projects certified by this standard are renewable energy and energy-efficiency projects.

Chicago Climate Exchange (CCX)

The Chicago Climate Exchange, which was founded in 2003, was first and foremost an innovative voluntary cap-and-trade scheme up until 2010. The scheme shut down in 2010, but its "offset" compartment continues in the form of the Chicago Climate Exchange Offset Registry Program. In this case, the carbon credit used is the Carbon Financial Instrument (CFI), which is the equivalent of 100 tCO₂e. CFI offset credits accounted for 4% of the voluntary credits traded in 2010. Compared to all the other standards, the CCX protocols are original in that they granted credits on the basis of a certified practice – which was allocated a certain amount of emissions reductions by default –, and not on the basis of an assessment specific to each project. The CCX allows two types of agricultural projects: livestock liquid waste methanisation projects and soil carbon sequestration projects, which primarily involve stopping tillage and converting cropland into meadows.

¹⁵ To achieve this, the accuracy of the inventory must extend to the representative nature of the systems and their development (feeding and waste management systems, and status of emission reduction practices).

¹⁶ According to the data in Peters-Stanley *et al.* (2011), excluding the CCB, which is most often added to another standard. The same source is used for the other standards.

American Carbon Registry (ACR)

The ACR was founded in 1997 by two environmental organisations: the Environmental Resource Trust and the Environmental Defense Fund. The carbon credit unit created by this standard is the Emission Reduction Ton (ERT). Not many agricultural projects are currently registered under this standard; however, several innovative methodologies for the agricultural sector were approved in 2010, including better management of the fertilisation process and improved rice-growing systems. 2% of the voluntary credits traded in 2010 were ERTs.

We can also note that a new standard exists in Australia, certifying agricultural and forestry projects: the Carbon Farming Initiative (CFI).

C. Three examples of agricultural projects

Project involving the replacement of fossil fuel with bagasse in India¹⁷

In 2005, the “Rajshree Sugar and Chemicals” sugar production plant launched a cogeneration project based on burning bagasse. The project was registered under the CDM standard on January 15th 2006. The installation of a high-pressure steam turbine, which is powered by burning bagasse, enables the plant to export carbon-neutral electricity within its local area, in addition to the electricity generated for its own use. The bagasse used is a sugar cane by-product, which is supplied by 20,000 local farmers, and involves an area covering 10,000 hectares and 655 villages. One of the aims of the cogeneration project is to ensure a reliable electricity supply for villages in the area. The project expects to reduce emissions by 80 ktCO₂ per year. During the first accounting period, which ran from February 20th 2007 to October 27th 2010, 408 ktCO₂e were avoided, i.e. more than 100% of the planned amount.

Methanisation projects developed by AgCert in Mexico¹⁸

AgCert¹⁹, the project development organisation, has implemented 88 projects to methanise liquid waste from livestock (pigs and/or cattle) in several Mexican regions, under the CDM standard. Digesters were installed to increase anaerobic fermentation. The methane generated in this way is then captured and burned in order to generate electricity. These projects have been implemented in an environment where emissions from animal waste are increasing sharply, as Mexico’s pork production has risen by 28% over the past 10 years. Moreover, the projects are in line with the agricultural targets set by the Mexican Government as part of the *2001-2006 National Development Plan*.

27 out of the 88 projects registered have begun to issue credits. The first project was registered on December 5th 2005, and single-handedly covers five locations. The SDP expects to reduce emissions by 122 ktCO₂e per year. In its first accounting period, which ran from March 31st 2006 to October 31st 2009, it issued 172,000 CERs, i.e. 32% of the amount expected.

¹⁷ Title: RSCL cogeneration expansion project.

¹⁸ Title: AWMS GHG Mitigation Project, MX05-B-02, Sonora, Mexico.

¹⁹ AgCert is now a subsidiary of the power firm AES

No-till farming projects

In the United States and Canada, aggregators, specialist companies, “Farm Bureaus”, and other organisations are bringing several farmers together to set up soil carbon sequestration projects, under the CCX standard. Any area under contract, where undertakings to stop or reduce tilling are complied with, enables a predefined amount of CFIs to be generated. In Canada, the first aggregator was C-Green Carbon Management Solutions Inc., which began operating in 2006, and now involves 2.2 million hectares of cultivated land where minimum tillage is used, grouped under three projects. The accounting process for emission reductions is retroactive; therefore, even though the projects were registered in October 2006, January 2007 and May 2008, the accounting period began in 2003. The three projects have enabled reductions of 7 700 ktCO₂. There are 13 aggregators of this kind in the United States.

III. LESSONS DRAWN FROM THE 733 AGRICULTURAL PROJECTS

A. The importance of accurate measurements when implementing agricultural projects

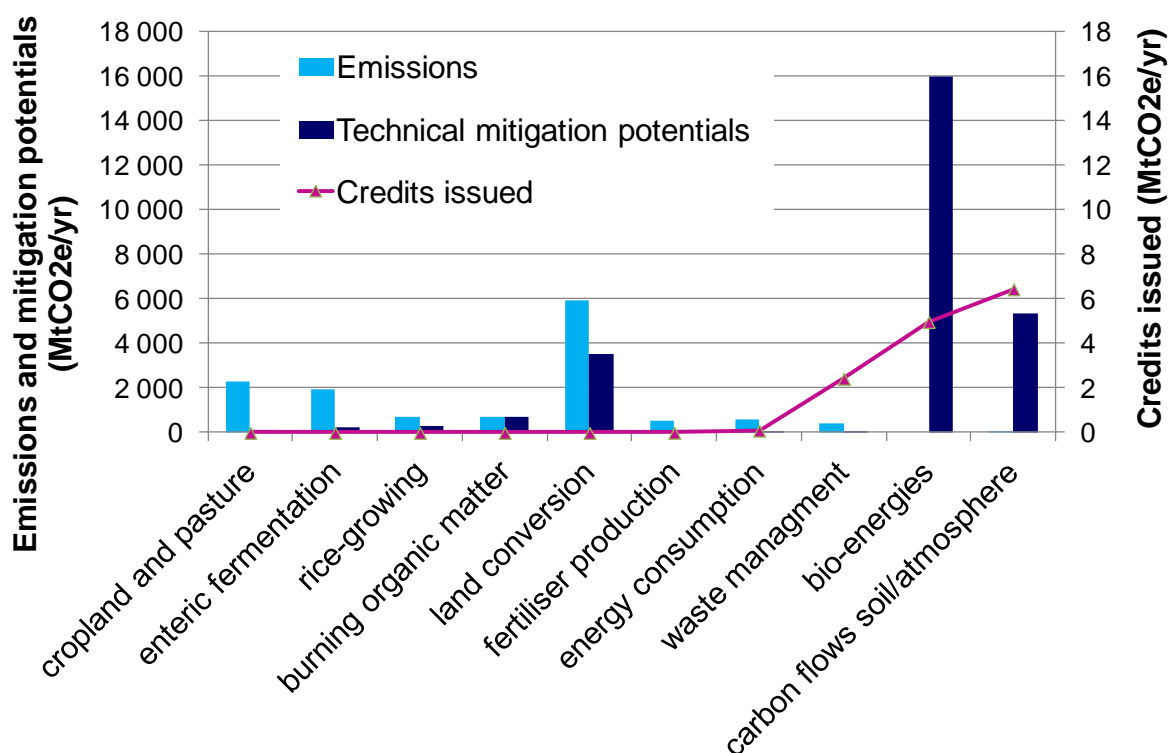
A small reduction in agricultural emissions; only three sub-sectors involved

733 projects affecting the agricultural sector had been registered under a carbon offset standard as of July 1st 2011, i.e. 14% of the projects across all sectors. However, their share of the credits issued every year²⁰ is lower: 14 MtCO₂e, i.e. 7% of the total.

Of greater concern is the fact that a factor of 1,000 separates the emissions and the mitigation potential of the emissions reductions generated by offset projects. Only three sub-sectors are involved: soil carbon sequestration, bio-energies, and livestock farming through the methanisation of liquid waste (Figure 11). Moreover, the implementation of carbon projects in a sub-sector does not appear to be related either to the volume of emissions in the sub-sector or to the size of its reduction “reserves”, i.e. the mitigation potential.

²⁰ The credits issued for each projects have been reduced to a period of one year, and then added up.

Figure 11 – Breakdown of emissions, mitigation potential and credits issued per sub-sector (MtCO₂e per year)



Notes: The emission and mitigation potential values are shown on the left axis and the values for the credits issued on the right axis.

Source: CDC Climat Research based on P. Smith et al. (2007); FAOSTAT; and UNEP RISOE (2011).

The most frequent type of emissions reductions projects involves soil carbon sequestration, solely under the CCX standard. These are no-till projects and those for converting cropland into meadows, which represent the agricultural sector's second largest mitigation potential. The number of credits awarded for each certified hectare varies according to the region where the project is located, with no measurement of carbon stocks before and after the project is implemented. For no-till projects, the amount of credits issued ranges between 0.5 and 1.5 tCO₂e per hectare per year. For projects aimed at converting land into meadows, it ranges between 1 to 2.5 tCO₂e per hectare per year. A soil carbon sequestration project is currently being approved by the VCS: this time, the methodology requires the measurement of carbon stock in the soil on a case-by-case basis for each project. The practice under consideration here is the management of meadows, and includes the limitation of over-grazing.

The bio-energies sub-sector comes a close second, with an average of 5 MtCO₂e emission reductions generated every year²¹, mainly by CDM projects (4.1 MtCO₂e per year). This sub-sector primarily includes the use of crop residues like bagasse (a sugar cane by-product), rice husks, and mustard-seed crop residues, as well as palm oil by-products. There is also a CDM project involving dedicated bio-fuel crops in Paraguay, but it is still marginal. This type of project involves a risk of carbon leakage, inasmuch as the crops planted – sunflowers, jatropha, etc. – to produce the bio-fuels may compete with food crops, and result in the displacement of pre-existing crops. In the worst case, the displacement of crops may lead to the deforestation of other land, and therefore generate a substantial amount of GHG. These leaks must be taken into account when calculating the project's emissions²².

²¹ The credits issued for each project have been reduced to a period of one year, and then added up.

²² According to the *General Guidance on Leakage in Biomass Project Activities (Version 3)*, if there is any displacement of activities that existed before the initiative, the initiative backer must supply the following two indicators:

- the percentage of people involved by the displacement of the pre-existing activity caused by the initiative;
- the percentage of pre-existing production (e.g. meat, corn, etc.) displaced because of the initiative.

Where the award of carbon credits is concerned, the last significant sub-sector to be featured is waste management. The credits issued are shared between the MDP, CCX, CAR and VCS standards, which account for 76%, 16%, 5% and 3% of the total respectively. The projects involved are mainly animal waste methanisation projects. There are also a few manure composting projects.

Two projects aimed at reducing energy consumption have been registered to date, but have not yet issued any credits (Table 1). One of these projects is under the *JI* standard, and the other is under the *VCS* standard. The *JI* project is a French one, aimed at pre-wilting alfalfa in the field which has generated 75 ktCO₂e up to now (Box 2). The *VCS* project, meanwhile, is a micro-irrigation project that involves moving from a diesel pump to a mechanical pump. We have also come across an agro-forestry project registered under the *CDM*. Lastly, there are two emission reduction projects for producing fertilisers under the *GS* standard. These projects involve replacing mineral fertilisers by vermicompost produced directly on site. The resulting emission reductions correspond to the emissions avoided by not producing mineral fertilisers on an industrial basis.

Not all sub-categories are represented. This is the case with cropland and pasture, enteric fermentation, rice-growing and the combustion of organic matter. However, methodologies that apply to these sub-sectors do exist. Some of them appear to have been developed for projects that will never see the light of day. This is the case, for instance, with the *CDM AMS-III-A* methodology, which is based on the principle of introducing inoculants²³ into the legume/grass rotation process during the legume phase by replacing synthetic nitrogen fertilisers; and also with the *JI* methodology in France aimed at reducing methane emissions by adding linseed to cattle feed. Other methodologies anticipate future projects, like the ones involving sustainable fertilisation under the *ACR* standard.

Table 1 – Average credits generated per year, and number of agricultural projects registered for each sub-sector and standard as of July 1st 2011

	Fertiliser production	Waste management	Bio-energies	Agroforestry	Energy consumption	Carbon flows soil/ atmosphere	Total
CDM		1836 ktCO ₂ e (215)	4067 ktCO ₂ e (310)	0 ktCO ₂ e (1)			5903 ktCO ₂ e (526)
JI		0 ktCO ₂ e (2)	24 ktCO ₂ e (4)		75 ktCO ₂ e (1)		99 ktCO ₂ e (7)
CCX		388 ktCO ₂ e (58)	245 ktCO ₂ e (15)			6455 ktCO ₂ e (65)	7087 ktCO ₂ e (138)
VCS		75 ktCO ₂ e (19)	651 ktCO ₂ e (20)		27 ktCO ₂ e (1)		752 ktCO ₂ e (15)
CAR		127 ktCO ₂ e (15)					127 ktCO ₂ e (15)
ACR		5 ktCO ₂ e (1)					5 ktCO ₂ e (1)
GS	5 ktCO ₂ e (2)	0 ktCO ₂ e (2)	0 ktCO ₂ e (2)				5 ktCO ₂ e (6)
Total	5 ktCO ₂ e (2)	2431 ktCO ₂ e (312)	4987 ktCO ₂ e (351)	0 ktCO ₂ e (1)	102 ktCO ₂ e (2)	6455 ktCO ₂ e (65)	13979 ktCO ₂ e (733)

Note: the figures in brackets correspond to the number of registered projects. Information about the number of projects currently under approval by the *CCX* and *VCS* standards is not available.

If both these indicators are below 10%, then the leakage is ignored. If one of the two indicators falls in a range of between 10% and 50%, then the leakage is assumed to amount to 15% of the difference between the emissions in the benchmark scenario and the initiative's emissions. If one of the two indicators is above 50%, then the initiative is turned down.

²³ The inoculation process involves applying rhizobium bacteria on legume seeds or in the soil where legumes will be planted. The presence of rhizobia is required for legumes to be able to convert nitrogen in the atmosphere into a form that the plant can absorb. This process is commonly known as "nitrogen fixation".

Source: CDC Climat Research based on the UNEP RISOE, the CCX Registry, the VCS Registry, the ACR Registry, the CAR Registry, and the GS (Gold Standard) Registry.

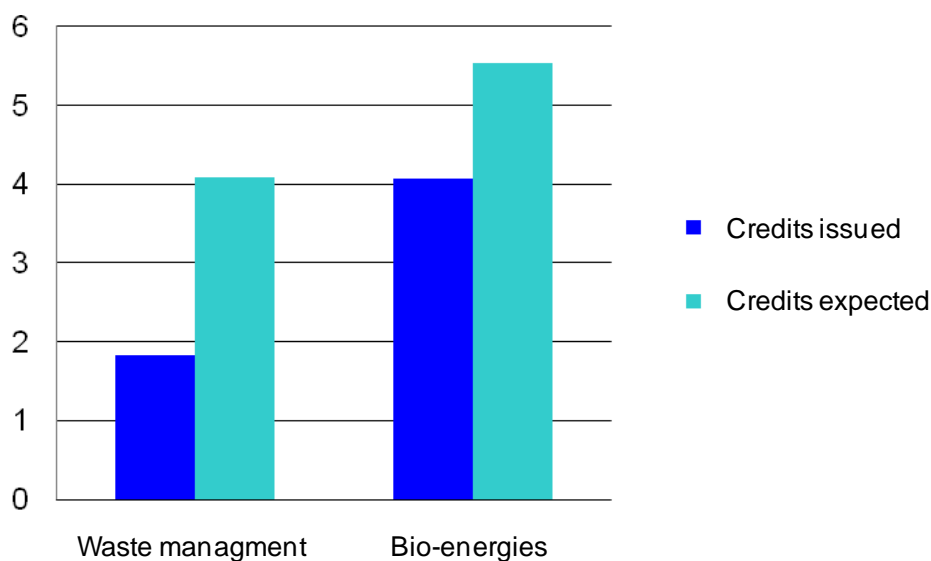
Projects involve sub-sectors where monitoring is easy

With the notable exception of the CCX, which certifies the practice, a carbon offset standard can only monetise emission reductions where the carbon emissions or the sequestration can be measured. However, the agricultural sector's emissions are usually hard to measure. The bio-chemical mechanisms behind these emissions are not all properly understood yet, and depend on several parameters (feed, breed, age, and weight of the animals; humidity, temperature, soil texture, etc.). In addition, a change in agricultural practices may affect several gases (N₂O, CH₄, and CO₂), and involve different mechanisms in opposite ways. For instance, irrigating a crop increases its yield, and therefore the return of residues to the soil. This means that carbon is stored in the soil. Conversely, water promotes the formation of nitrous oxide (N₂O) and methane (CH₄) by seeping into the gaps in the soil. This process is compounded by the CO₂ emissions linked to the energy consumed by the irrigation process.

Fortunately, not all sources of emissions present the same problems. It is possible to calculate the reduction in CH₄ and N₂O emissions for an agricultural liquid waste methanisation project fairly accurately: the emissions avoided correspond to the quantity of gas captured by the methaniser. There is also relatively low uncertainty when it comes to calculating CO₂ emission reductions resulting from the replacement of fossil fuels by biomass: one just needs to know what type of fuel was used beforehand, and measure what amount of that fuel was required to produce the energy generated by biomass combustion. The same goes for projects aimed at reducing energy consumption on farms. In contrast, it is far more complicated to measure the carbon stored in the soil as a result of stopping tillage, or even the N₂O emissions generated by using nitrogen fertilisers. The levels of uncertainty regarding the sequestration and emission factors for these processes amount to 50% and 200% respectively (Source: CITEPA).

It was possible to implement offset projects where the calculation of emissions for the benchmark scenario did not involve too much uncertainty. When the Project Design Document (PDD) describing the project is being drawn up, estimating the emissions for the benchmark scenario and for the project should highlight any uncertainties. These uncertainties must be explained for each parameter and a 95% confidence interval should be supplied as far as possible. In addition, the benchmark scenario must be calculated on a conservative basis. The project developer must make sure that project's emissions reductions are not overestimated. In the event of doubt, the values resulting in the lowest benchmark must be used. The greater the uncertainty, the more the project backer will have to reduce its right to credits in order to comply with the conservative estimation principle. This explains why there is not much variety in agricultural projects. In fact, we only come across "liquid livestock waste methanisation" and "bio-energy" projects under the CDM, JI and VCS standards. In practice, however, the amount of credits issued for an agricultural project is usually lower than the forecast. For CDM projects, the emission reductions actually achieved amounted to 61% of what we came across in PDDs (Figure 12). This is higher than for projects in the "landfill gas" sector, which only deliver 41% of the credits expected, but lower than for industrial gas projects, which outperform by between 108% and 115%, depending on the gas in question.

Figure 12 – Comparison between the credits issued and the credits that were expected for CDM projects (MtCO₂ per year)



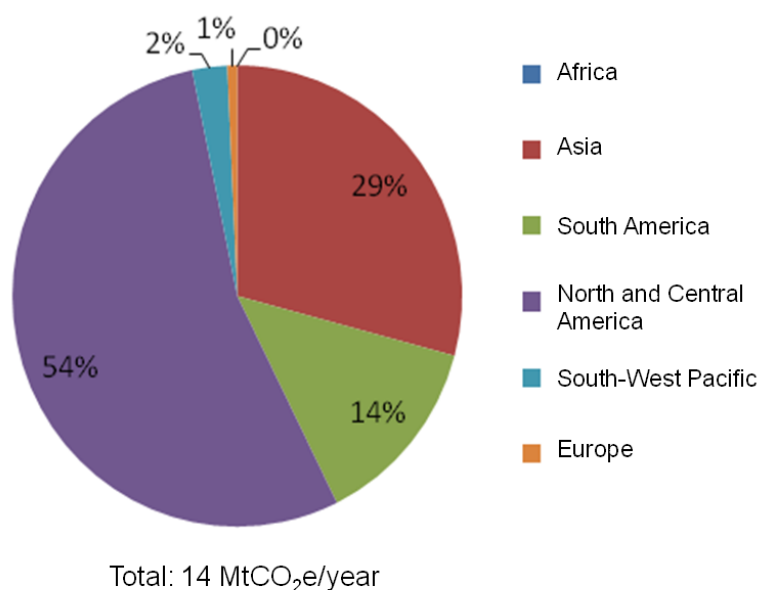
Source: UNEP RISOE (2011).

The case of the CCX standard is somewhat different. This standard opted for a monitoring process based on practices, and not on actual emission reductions, and has lower requirements in terms of additionality. This explains the high level of “soil carbon sequestration” projects. This approach has enabled the development of a large number of agricultural projects, but it does have consequences. This lower level of stringency has impacted purchasers’ confidence, which partly explains why the price of CCX credits is lower than for other standards.

B. Agricultural projects are not equally divided between areas

The amount of credits issued bears no geographical relation to mitigation potentials and to emissions. Central and North America have generated the largest amount of carbon credits, although they have the lowest mitigation potential. In contrast, Africa, where the mitigation potential is double that of Central and North America, has not generated any carbon credits to date (Figure 13).

Figure 13 – Breakdown of credits issued per region, across all standards



Note: information about the number of projects currently under approval by the CCX and VCS standards is not available.

Source: CDC Climat Research based on the UNEP RISOE, the CCX Registry, the VCS Registry, the ACR Registry, the CAR Registry, and the GS (Gold Standard) Registry.

North America is leading the market, because of the high number of credits issued by the CCX rather than the fact that there is a significant reduction potential. Asia has succeeded in attracting the largest number of projects, mainly ones registered under the CDM, both in agriculture and in other sectors, while Africa's share is nil. Unlike the industry and energy sectors, where its emissions are marginal on a global scale, Africa has a real mitigation potential in the agricultural sector. The lack of African credits appears to indicate that the barriers to investment created by a problematic geopolitical environment have prevailed, especially for bio-energies. Meanwhile, methanisation projects are hard to implement among nomadic or extensive grazing systems, which are significant in Africa. In Europe, there are still not many JI projects involving the agricultural sector. However, this sector seems hard to include in a "cap-and-trade" scheme like the European Union Emission Trading Scheme; therefore the number of JI-type agricultural projects will probably grow.

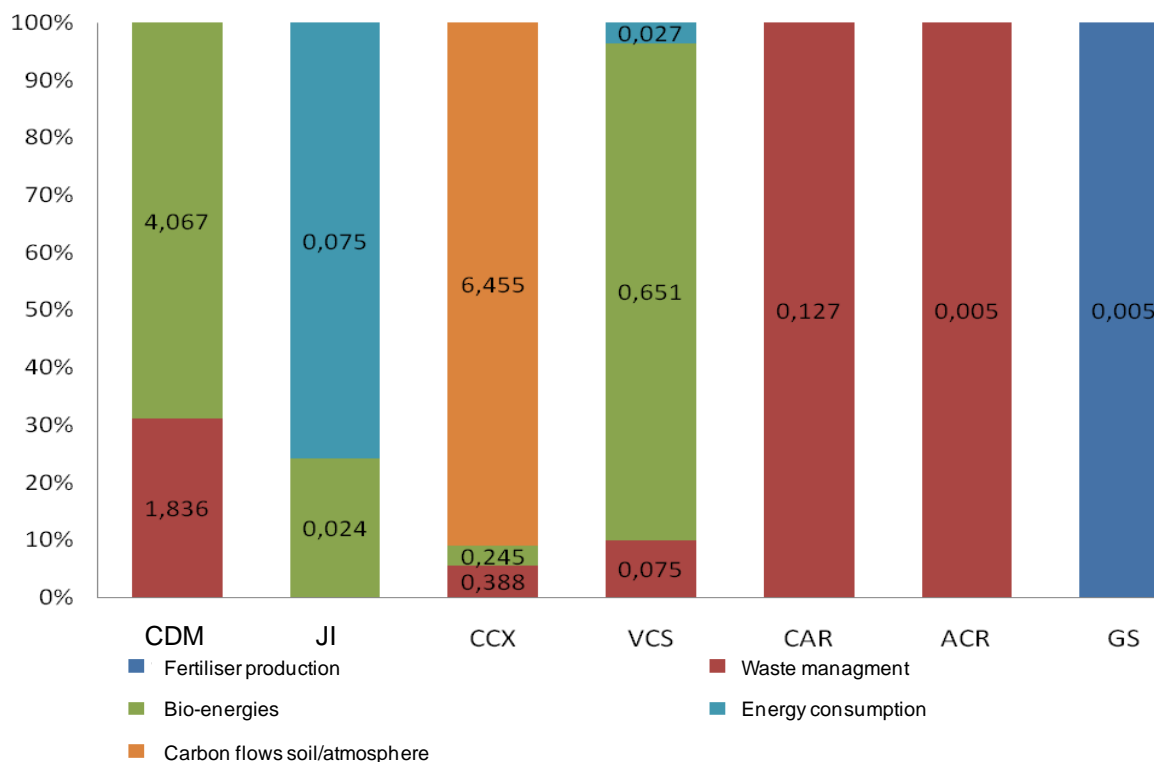
C. Several standards for different types of projects

The vast majority of agricultural carbon offset projects are CDM projects. The CCX standard is in pole position when it comes to the number of credits issued per year, and in second place in terms of the number of projects registered. The standard adds variety with its soil carbon sequestration projects. Where the VCS standard is concerned, half of the 40 projects registered are pre-CDM²⁴ projects. The other standards are not really present in the agricultural sector at this time.

²⁴ Since March 31st 2007, "retro-crediting" is no longer allowed for CDM projects. Only emission reductions achieved after the projects was registered may be monetised. Some project developers have their projects registered quickly under a voluntary standard, such as the VCS, in order to generate carbon credits while waiting for registration from the CDM Executive Board. This approach is known as a "pre-CDM" approach.

The profiles of the CDM and VCS are relatively similar (Figure 14). This is partly explained by the fact that 50% of VCS projects are pre-CDM projects. The CCX standard has a different profile due to its simplified monitoring method. The CCX standard requires that the proper application of practices is certified, but does not assess actual emission reductions. This explains the high percentage of “no-till”-type projects included in the “soil carbon sequestration” sub-sector. We can draw no lessons at present where JI projects are concerned, given that only two projects have issued credits.

Figure 14 – Breakdown of the annual credits issued for each standard (MtCO₂e per year)



Note: the credits delivered were calculated on the following basis:

- for CDM and JI projects: the credits issued for each project were reduced to a one-year period by dividing the accounting period. The average annual credits issued calculated on this basis for each project were aggregated, in order to obtain the total number of credits issued per year;

- For VCS, CCX, CAR, ACR and GS projects: the credits issued per year correspond to the total of the average annual credits issued by each project.

Source: CDC Climat Research.

See Appendix 8 for credit delivery per standard and overtime.

D. Diffuse emissions mean high transaction costs

One of the main features of the agricultural sector is the diffuse nature of its emissions. Although the agricultural sector’s emissions are undoubtedly significant (it ranks third world-wide in terms of greenhouse gas emissions), they break down relatively evenly between billions of farmers and hectares of cultivated land. The credits generated at the farm level do not necessarily offset the transaction costs related to monetising emission reductions: drawing up a methodology, setting up the project, auditing, registration, monitoring the emissions and marketing the credits.

Two strategies emerge to make agricultural projects viable, despite these transaction costs: aggregation and replicability.

Aggregation consists of sharing the transaction costs, most of which are fixed, over a higher volume of emission reductions. This is the case with the French CO₂ project – a French version of JI – involving the

pre-wilting of alfalfa, where the project developer is the Luzéal cooperative, a French pre-wilting cooperative, not each individual alfalfa producer. The cooperative promotes the practice of pre-wilting in the field to its members, and takes care of the project's administrative set-up and the first stage of marketing the credits (Box 2).

Box 2 – French alfalfa drying initiative

Dried alfalfa is a quality animal feed, but the production process consumes energy

Two kinds of initiatives in this area have been implemented in France:

- an energy savings initiative: flat pre-wilting consists of spreading out the mowed alfalfa to dry in the sun for a few hours first. This enables energy savings of around 20% to be achieved.

- An initiative to replace fossil fuel by biomass energy: the alfalfa drying oven was powered by fossil fuel. Crushed wood waste pellets are now included in the mix.

The number of credits expected for both these initiatives amounts to 800,000 metric tons of CO₂ between 2008 and 2012, of which 194,000 have already been issued.

Replicability consists of setting up several projects based on the same model: this does not affect the monitoring costs relating to the diffuse nature of the emissions, but enables savings to be made in other areas, such as savings of around €100,000 in developing the methodology (Chenost, *et al.* 2010), or of around €40,000 for the Project Description Document (PDD) (Guigon, *et al.* 2009)²⁵.

This strategy has been broadly adopted by the CDM mechanism in cases where the same project developer plans to replicate the same project several times, often in a given region. For instance:

- **AgCert** has developed 170 animal waste methanisation projects, divided between Brazil and Mexico;
- **Agrinergy** was behind the first “bagasse” project. The organisation has a diverse project portfolio, which specialises mainly in bio-energies (especially in bagasse projects, but also in rice-husk and oil palm residue projects). Its projects are all exclusively located in India, except one, which is in Thailand. In addition to setting up projects, Agrinergy is developing new methodologies;
- **Ecosecurities** helps to set up CDM and voluntary projects, mainly involving waste methanisation and biomass (bagasse) energy, which are located in Asia. The organisation has also set up a bagasse project in Morocco. Like Agrinergy, it is also developing new methodologies;
- **Bunge Emission Group** is investing in CDM projects and developing others, including a number of biomass (rice-husk) projects in India, as well as two animal waste methanisation projects in Mexico;
- **Trading Emissions PLC** is a carbon investment fund. The fund has bought carbon credits generated by several identical livestock waste methanisation projects in the Philippines.

The projects are especially easy to set up and replicate they are part of a structured division where the various players are properly identified (rice husks in India, bagasse in Brazil, etc.).

E. Adaptability to the local environment and the pioneering nature of project mechanisms

In theory, project mechanisms have two advantages compared with larger scale public policies like the Common Agricultural Policy (CAP): they can easily adapt to a region's environment – the adaptation does not need to be planned in the policy, as local project developers prepare the emissions reductions methods themselves – and they can be used as a test before a practice is generalised: for example, by means of regulations.

This theory is partially corroborated by the examples we have examined: the CDM planners did undoubtedly not foresee that India would use it for the rice-husks they have, or that Brazil would adapt it for bagasse, which is abundant in their country.

²⁵ Although a specific PDD is required for each project, a lot of time can be saved if one can use an existing PDD from a similar project as a template.

F. Managing storage reversibility: temporary credits or insurance

Soil carbon sequestration is the first catalyst for reducing the impact of the agricultural sector on greenhouse gas emissions. One example of a practice along these lines is the simplified working of the land (surface work, no-till, etc.). However, the storage is reversible: if tilling is used again, the accumulated carbon may be lost in just a few years.

This non-permanency issue also exists in the forestry sector. Planting trees enables carbon to be stored as long as the trees remain in place. If a fire breaks out, or if a storm devastates the forest, the carbon stores that have been accumulated then return to the atmosphere. Solutions have been introduced to mitigate that risk.

- CDM plantation projects – soil carbon sequestration is not eligible under the CDM – generate temporary CERs. These temporary credits are valid for five years (for tCERs, which are used most frequently), after which they must be replaced by other temporary or permanent credits. This mechanism is very restrictive for buyers of carbon credits and market regulators – the European Commission for the EU ETS has prohibited the use of forestry credits – therefore forestry projects were not very successful within the CDM.

- A risk-pooling system has been introduced for most voluntary standards. A portion of the credits generated is set aside in an insurance fund that covers all projects where there is a non-permanency risk (soil carbon sequestration projects and forestry projects). Therefore, if the carbon sequestered is re-emitted due to an external event beyond the project backer's control, the carbon credits that have already been sold are replaced by the credits accumulated in the insurance fund by projects that are still in place. This mechanism enables permanent offsets to be guaranteed to buyers of carbon credits, without them having to worry about replacing credits themselves. The mechanism therefore seems to have a higher potential than the temporary credit system.

- The ACR standard offers a third way, in the form of insurance against the risk of reversibility. Project backers have to pay an initial amount into a common fund. The amount depends on the region where the project is located, the type of forest, its management, etc., and must enable a sufficient number of ERTs to be bought back to offset any potential return of the stored carbon into the atmosphere. To date, no ACR project has opted for this system.

IV. CONCLUSION

As agriculture is both a major contributor to greenhouse gas emissions and a substantial reserve of mitigation potential, it is necessary to introduce solutions aimed at reducing its impact on climate change. Carbon offsetting is one such solution, which has enabled emissions from the agricultural sector to be reduced by an average of 14 MtCO₂e per year up until now. This figure is very low when compared with the sector's mitigation potential, and involves a limited number of sub-sectors (soil carbon sequestration, bio-energies and waste management). The slow development of agricultural projects can be explained by the agricultural sector's intrinsic features: its emissions are diffuse, which results in high costs. Moreover, the physico-chemical mechanisms involved in greenhouse gas emissions are not always properly understood, and the related emission factors are sometimes highly inaccurate. The types of projects that have been set up are precisely those with the lowest level of uncertainty (replacement of fossil fuel by bio-energies, and methanisation of liquid livestock waste). The third type of project that has been set up on a particularly wide basis does not obey this rule: these are the no-till projects under the CCX standard. This situation is explained by the fact that this standard certifies practices, not emission reductions.

However, even if agricultural projects are still at a low development level, their number is increasing every year and new innovative methodologies are appearing. There are several reasons for this trend:

- the exhaustion of low-cost emissions reductions possibilities in sectors that initially set up carbon offset projects, like the industrial gas sector. Investors are therefore increasingly turning to agricultural projects;

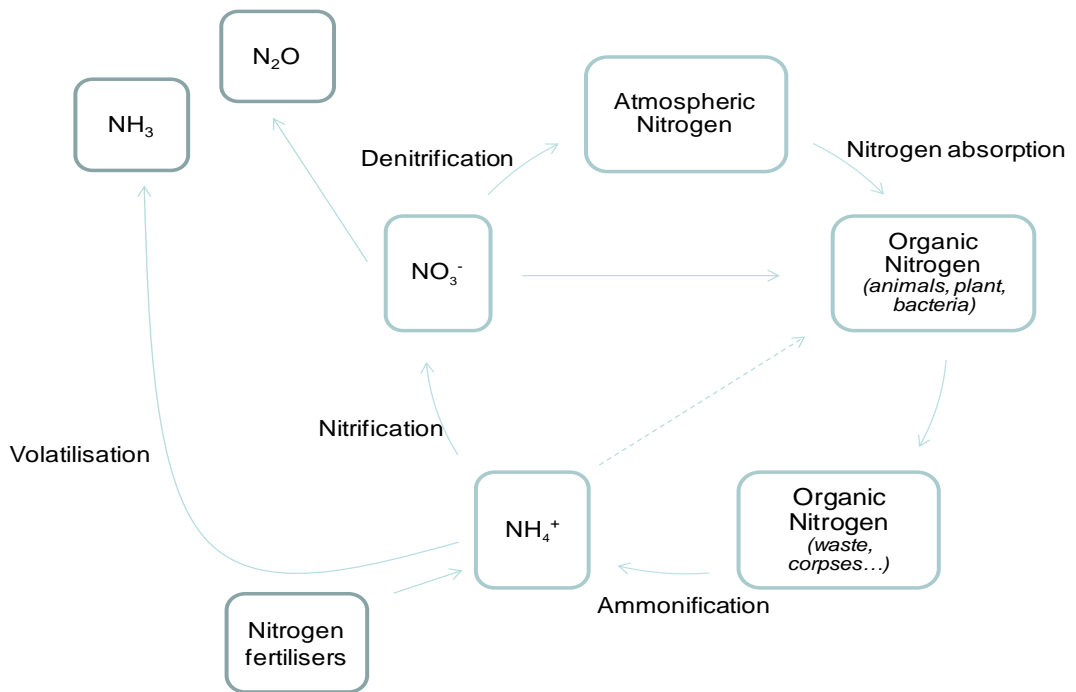
- the qualitative restriction on carbon credits generated by industrial gases like HFC-23 and N₂O from adipic acid under the European Emission Trading Scheme from May 1st 2013 onwards;
- the fact that the agricultural sector is perceived as one of the hardest to include in a “cap-and-trade” scheme, and is therefore likely to remain under the carbon offset scheme for a long time in many areas.

This tool nonetheless has its limits, and other options could be envisaged. At European level, those involved with the Common Agricultural Policy, due for review in 2013, are looking into the issue of including greenhouse gas emissions – at present not directly the case. This could be a good solution for sub-sectors that embody a high level of uncertainty in regard to emission reductions monitoring. Another solution would be to include the agricultural sector in the European Community Emission Trading Scheme (EU ETS), as the New Zealand carbon market has done.

APPENDICES

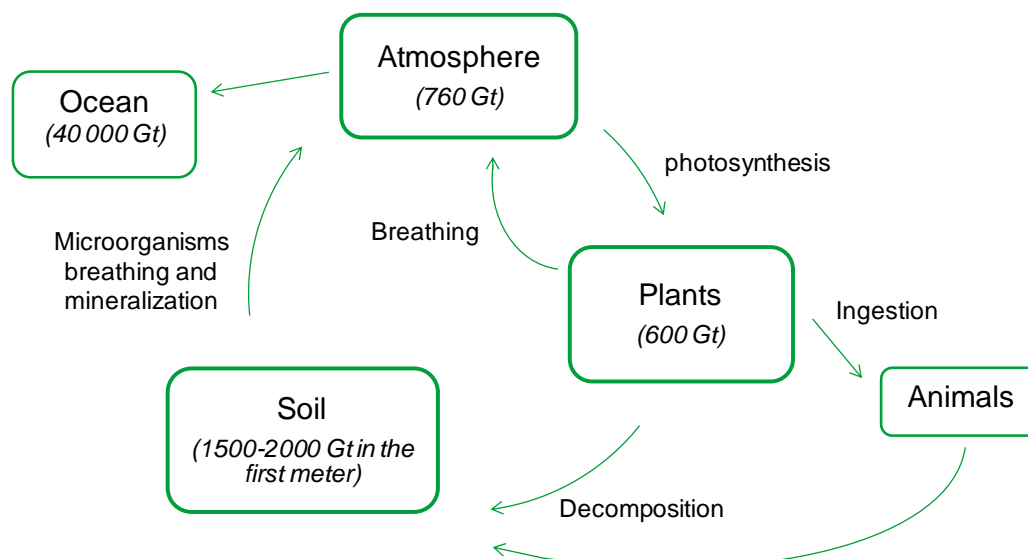
Appendix 1 – The nitrogen and carbon cycle

The addition of nitrogen fertilisers and the breakdown of organic matter enable the soil to be enriched with nitrogen in its ammonium form (NH_4^+). The soil's nitrifying bacteria enable NH_4^+ to be turned into nitrate (NO_3^-), the form of nitrogen that can be absorbed by plants. A portion of the nitrate formed in this way is directly transformed into N_2O *in situ* by the denitrifying bacteria; here we are talking about direct emissions. Another portion, which leaches out, is found in rivers, and will generate indirect emissions elsewhere than in the fertilised area. Other indirect emissions are due to the volatilisation of nitrogen compounds such as NH_3 and NO_x , when fertilisers are applied. Those fertilisers subsequently form other deposits, and generate N_2O emissions in turn. Legumes, meanwhile, have a specific ability to absorb nitrogen from the air by forming symbioses with rhizobia, the aerobic bacteria in the soil. This enriches the soil with nitrogen and is the source of the N_2O emissions generated by the denitrification process, as described previously.



The carbon cycle

Plants are able to absorb atmospheric carbon dioxide (CO_2) and transform it into organic carbon which is called photosynthesis. A part of the biomass will be ingested by other organisms and another part will be decomposed by micro-organisms leading to CO_2 emissions from soil. The carbon cycle is summarized in the following graph. The figures represent the amount of carbon in different compartments.



Appendix 2 – Estimating global emissions

Fertiliser production

Emissions from fertiliser production account for 1.2% of global emissions (Kongshaug 1998). In 2005, total emissions amounted to 44.2 GtCO₂e.

$$1.2\% \times 44.2 = 0.53 \text{ GtCO}_2\text{e}$$

Land conversion

The emissions taken into account for this sub-sector correspond to all the emissions linked to the converting forests and wetlands into cropland. The use of timber for commercial and heating purposes as a cause of deforestation has therefore not been addressed in this report.

Energy consumption

According to Baumert *et al.* (2005), GHG emissions amounted to 41,755 MtCO₂e across all sectors in 2000. 15% of those emissions came from the agricultural sector, if we factor in the emissions resulting from the consumption of fossil fuels and electricity. In 2000, the agricultural sector's emissions therefore amounted to $0.15 \times 41,755 = 6.26 \text{ GtCO}_2\text{e}$. 9% of those emissions were due to the consumption of fossil fuels and electricity, i.e. $0.09 \times 6.26 = 0.564 \text{ GtCO}_2\text{e}$.

Irrigation

Several sources of emissions could be taken into account:

- CO₂ emissions due to energy consumption;
- methane emissions due to the fermentation of organic matter in water-saturated soils;
- N₂O emissions due to the lack of soil aeration.

We should also note that irrigation enables better yields, and therefore a higher amount of crop residues likely to be returned to the soil.

As the last two points are hard to assess (they depend on the soil, the climate, and the type of crop, etc.), we will only concern ourselves here with the CO₂ emissions due to energy consumption.

There are two different types of irrigation:

- surface irrigation, which does not require energy to pump water, and therefore emits no CO₂;
- irrigation using pumps.

Only groundwater needs pumping. 112.9 million hectares out of the 300.9 million hectares that are irrigated use groundwater, i.e. 37.5% of the total irrigated area (FAO, AQUASTAT 2010).

The pumps use either diesel or electricity as a source of power. Electricity has a certain number of advantages, and farmers on smallholdings will choose to use it whenever possible. Moreover, the expansion of rural electrification may be illustrated by the change in the percentage of villages connected to the electric grid.

Where North America, Europe, and Australia and New Zealand are concerned, we are making the assumption that the various energy source proportions are similar to those of the United States, as shown in Table 4. The area irrigated by pumping in these regions amounts to 19.1, 7.3 and 0.9 million hectares respectively. The resulting estimate is 5,350 kC per year.

→ $196 \times (19.1+7.3+0.9) = 5,350$ ktC per year for irrigation in the North America, Europe and Australia/New Zealand regions as a whole.

Where Asia, South and Central America and the Caribbean are concerned, we are taking the view that the sources of energy for irrigation are 50% electricity and 50% diesel. The emission factor per area is $171+236 = 203.5$ kC per hectare per year (see Table 4). The areas irrigated using pumps in these regions are 80.6 and 2.4 million hectares respectively. The resulting estimate is 16,890 kC per year.

→ $203.5 \times (80.6+2.4) = 16,890$ ktC per year for irrigation in the Asian, Central and South American and Caribbean regions as a whole.

Where Africa is concerned, we are taking the view that the sources of energy used for irrigation are 25% electricity and 75% diesel. The emission factor per area is $171 \times 0.25+236 \times 0.75$ kC = 219.75 kC per hectare per year (see Table 4). The area irrigated using pumps in this region is 2.5 million hectares. The resulting estimate is 549 kC per year.

→ $219.75 \times 2.5 = 549$ ktC per year for irrigation for the Asia, Central/South America and Caribbean regions as a whole. To calculate the CO₂ emissions, we multiply the result by 44/12:

$(5,350+16,890+549) \times 44/12 = 83,560$ million kg CO₂ per year = 83.56 MtCO₂ per year.

Table 4
Energy sources, area, and C emissions for irrigated cropland in the United States

Energy source	Area irrigated ^a		CO ₂ -C	
	By pumping (ha)	Energy use (Quads yr ⁻¹)	C-emission (MMTC yr ⁻¹)	Emission (kg C ha ⁻¹ yr ⁻¹)
Electricity ^b	8157210	0.1216	1.39	171
Natural gas	2463418	0.0406	0.59	239
Propane	660139	0.0032	0.06	85
Diesel	4160861	0.0491	0.98	236
Gasoline	64356	0.0011	0.02	334
Pumping (total)	15505994		3.04	196
All irrigated (total)	20246509			150

^a USDA, 1997b.

^b Electricity for irrigation in the US was estimated to be generated by 45% from coal, 40% from hydro-electric, and 15% from nuclear power.

Source: Follett (2001)

The data for the other emissions are drawn directly from the FARM (2010) report.

Appendix 3 – Estimating global mitigation potential

Conversion of forest land into agricultural land

The mitigation potential is taken from Bellassen *et al.* (2008).

Cropland and pasture, livestock farming and rice-growing

According to Smith *et al.* (2007), the global mitigation potential in the agricultural sector amounts to 6 GtCO₂e, with 2% for cropland and pasture, 4.5% for livestock farming and 4.5% for rice-growing. The remaining 89% corresponds to soil carbon sequestration. We therefore obtain the following mitigation values:

- Cropland and pasture: $2\% \times 6 = 0.12$ GtCO₂e
- Livestock farming: $4.5\% \times 6 = 0.27$ GtCO₂e
- Rice-growing: $4.5\% \times 6 = 0.27$ GtCO₂e

(Note: the storage capacity is therefore $89\% \times 6 = 5.34$ GtCO₂e.)

Fertiliser production

The mitigation potential is based on the assumption that a 20% reduction in nitrogen fertiliser consumption is achievable in developed countries. The same assumption is used by Smith *et al.* (2007) in order to estimate the mitigation potential of the “cropland and pasture” sub-sector. We therefore believe that the mitigation potential associated with fertiliser production corresponds to 20% of current emissions:

$20\% \times 530 = 106$ MtCO₂e.

Irrigation

The mitigation potential of 100 MtCO₂e is taken from the report by Smith *et al.* (2007). The authors take into consideration the fact that better water management leads to higher soil carbon sequestration.

Energy consumption

The assumption used is the same as for France (Leseur 2006), i.e. a mitigation potential of 4%:

$560 \times 0.04 = 22$ MtCO₂e

Combustion of organic matter

The combustion of organic matter corresponds mainly to slash-and-burn farming and setting fire to some types of crops (including sugar cane) to make harvesting easier. Agricultural machines that enable sugar cane to be harvested without setting fire to the field beforehand are now available.

The emissions recognised for the combustion of organic matter do not take just CH₄ and N₂O into account. The mitigation potential of this sub-sector is hard to forecast, since, in addition to a reduction in CH₄ and N₂O emissions, abandoning this practice may also have an impact on soil carbon sequestration.

In this report, we take the view that the technical mitigation potential corresponds to the total abandonment of these practices, i.e. the current emissions of 700 MtCO₂e per year.

Bio-energies

The 16 GtCO₂e correspond to the economic potential at a carbon price of €73 per tCO₂e, according to Smith *et al.* (2007).

Appendix 4 – Estimating emissions in France

Cropland and pasture, enteric fermentation, animal waste, rice-growing and energy consumption

The data are taken from the national inventory submitted to the UNFCCC (CITEPA 2011).

Fertiliser production

The value was obtained as follows:

Emissions due to the use of fertilisers = Q x EFP

Q: quantity of nitrogen used in France

EFP: emissions in tCO₂ per metric ton of nitrogen produced

Where:

EFP = 5.1 tCO₂ per metric ton of nitrogen (Leseur 2006)

Q = 2,100,000 t for the 2009/2010 campaign (UNIFA)

Emissions due to the production of nitrogen fertilisers in France = 2.1 x 5.1 = 10.7 MtCO₂e per year.

Moreover, the production of nitrogen fertilisers accounts for 80% of the emissions associated with fertiliser production. Emissions associated with fertiliser production therefore amount to 13.4 MtCO₂e per year.

Appendix 5 – Estimating the mitigation potential in France

All sub-sectors (excluding fertiliser production, cropland and pasture)

Assumptions and data are taken directly from Leseur (2006).

Cropland, pasture and fertiliser production

The emission reduction potential has been calculated as follows: we believe that N₂O emissions due to mineral nitrogen fertilisation in France can be reduced by 10%, i.e. a reduction of 2.3 MtCO₂e per year, by introducing various techniques (limiting excessive fertilising, introducing intermediate nitrate trap crops, etc.). Given that the national inventory holds that a metric ton of nitrogen in mineral fertiliser form emits around 10.5 tCO₂e through direct and indirect emissions, the use of nitrogen fertilisers could potentially be reduced by 2.3/10.5 = 0.22 MtN per year.

However, we believe that producing a metric ton of fertiliser results in the emission of 5.1 tCO₂e during the production process. The reduction potential for fertiliser production is therefore 0.22 x 5.1 = 1.12 MtN per year.

Appendix 6 – Calculating the global mitigation potential breakdown

Cropland and pasture, rice fields, enteric fermentation/waste management and fertilisers

The mitigation potential has been calculated by multiplying the mitigation potential of each sub-sector at global level by the portion represented by emissions in each region for the same sub-sector:

$$M_{ij} = M_i \times E_{ij}/E_i$$

Where:

i: sub-sector i

j: region j

M: Mitigation potential

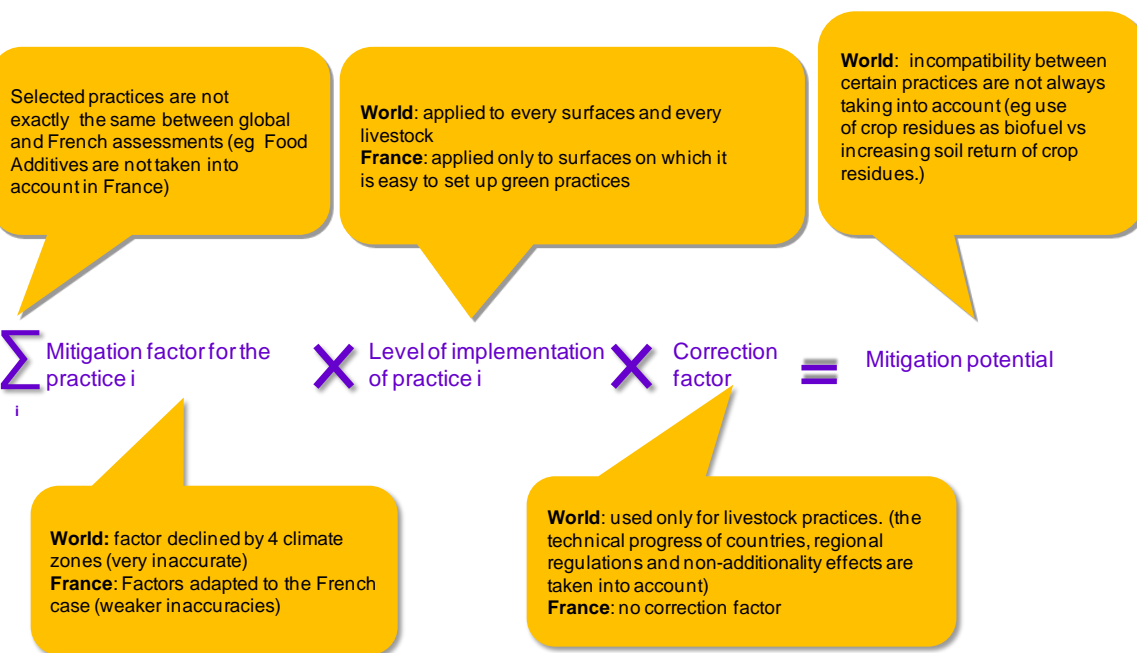
E: emissions

Sources: Smith *et al.* (2007), and Vergé *et al.* (2006)

Soil carbon sequestration

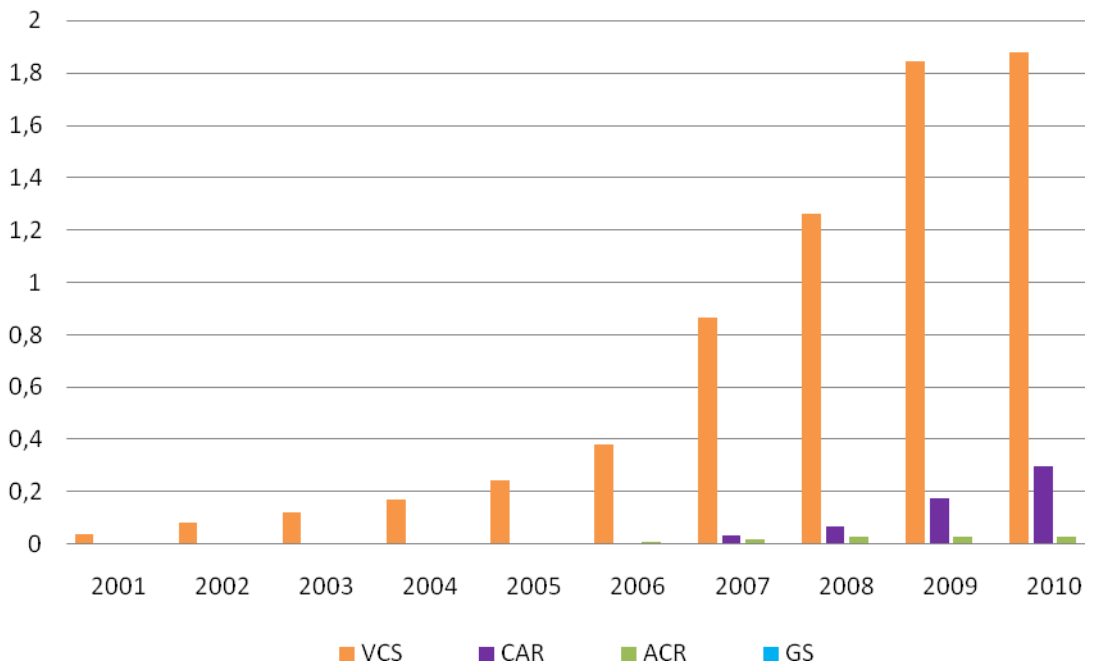
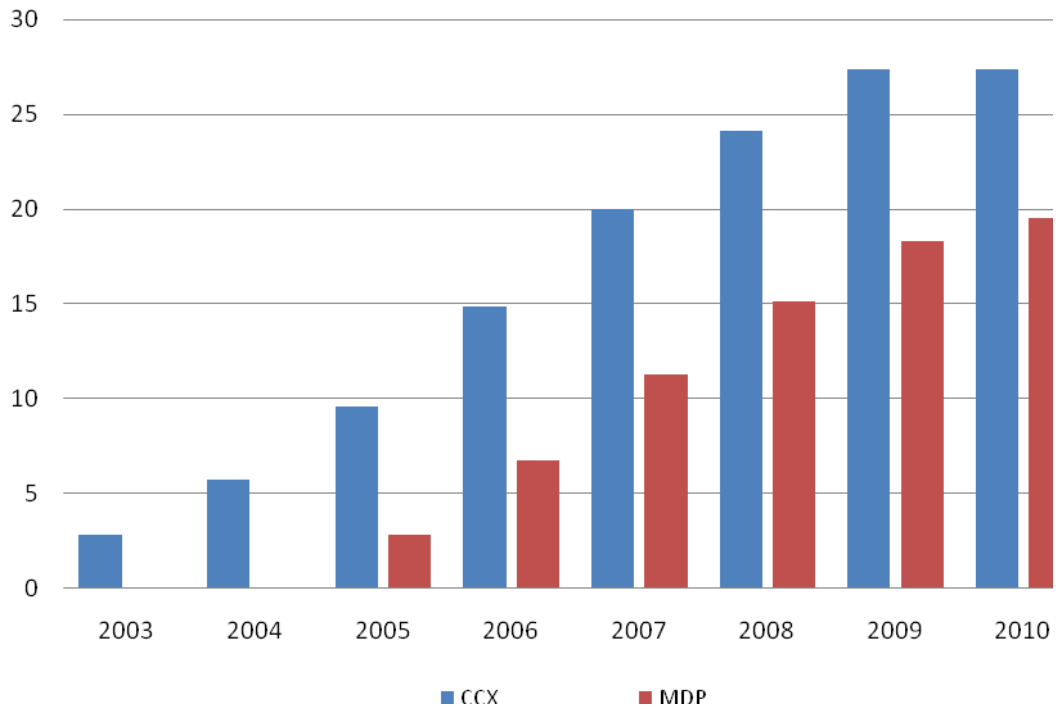
The regional mitigation potential for the four main sub-sectors and for soil carbon sequestration is provided by Smith *et al.* (2007). We therefore carried out a simple subtraction.

Appendix 7 – Difference between French and global mitigation calculation techniques



Appendix 8 – Change in the number of credits issued

Figure 15 – Change in the aggregate number of credits issued per standard (MtCO₂)



Source: CDC Climat Research

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