Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE
MINISTÈRE DE L'AGRICULTURE DE L'AGROALIMENTAIRE ET DE LA FORÊT

Analysis

CENTRE FOR STUDIES AND STRATEGIC FORESIGHT
—
no. 73 October 2014

French agriculture and the challenge of climate change: what are the prospects for mitigating its greenhouse gas emissions?

Agriculture can contribute to combat climate change and cut down on net emissions of greenhouse gas (GHGs) by reducing its own emissions, storing carbon in the soil or producing renewable energies that mitigate GHGs by replacing fossil fuels. This analysis looks at several recent studies in this area across France as a whole and outlines the main lessons learned in terms of future actions and the economic cost of mitigation in the agricultural sector by 2030 and 2050.

The latest report from the IPPC[1] has once again warned of the unsustainable current climate trend. In spite of the numerous public policies and private initiatives already introduced and implemented, human-induced emissions of GHGs have never grown so quickly and will never have been so high as in the last decade. Additional efforts are therefore needed and will be at the heart of the political agenda in the coming months. Agriculture is undoubtedly playing a greater role in climate negotiations – marked, in 2014, by the preliminary discussion on the 2030 Framework for Energy and Climate within the European Union and on a global scale by preparations for the 21st Conference of the Parties (COP21), which will be held in Paris in 2015 – although its treatment in these arenas remains a delicate matter. On the one hand, it is one of the sectors that is most severely affected by climate change, to which it must inevitably adapt[2], in a context where the growth in the global population and the increase in living standards are driving demand for food even higher. On the other hand, agriculture can make a significant contribution to mitigation efforts. Nonetheless, it is important to emphasise that emissions from agriculture and forestry are specific insofar as they are due, mainly, to diffuse biological processes, which make them more difficult to monitor, report and verify.

As regards French agriculture's contribution to reducing GHG emissions, several recent studies have explored some more or less ambitious mitigation scenarios looking ahead to either 2030 or 2050. Six of them have been analysed for this note[3]:

- the foresight study *Agriculture énergie 2030*[4], produced by the French Centre for Studies and Strategic Foresight in 2011 with the support of a working group; it aims to shed light on the links between agriculture and energy, also on possible changes in agriculture given different energy contexts;

- the study commissioned from INRA by the MAAF (French Ministry of Agriculture, Agri-food and Forestry), MEDDE (French Ministry of Ecology, Sustainable Development and Energy) and ADEME (*Agence de l'environnement et de la maîtrise de l'énergie* – French Agency for the Environment and Energy Management), *How can French agriculture contribute to reducing greenhouse gas emissions*[5] was published in 2013; its objective was to estimate the potential for mitigation and the cost of ten actions affecting agricultural practices, without significant impacts on production levels;

- the sectoral study *Agriculture et facteur 4*, produced in 2012 by Solagro, ISL and Oréade-Brèche, commissioned by the MAAF and ADEME; it explores contrasting trajectories that mark a shift away from current systems and were selected for pedagogical interest, in order to reduce significantly GHG emissions and to achieve "factor 4"[6] by 2050;

- the *Afterres* exercise[7] from Solagro, conducted in 2013, which proposes a sustainable scenario for agriculture and land use by 2050 (with a 2030 intermediate point). *Afterres* 2050 aims to study, in quantitative terms, France's capacity to respond in a "sustainable" manner to the multiple requirements facing agriculture and forestry within this time frame;

- the study *Visions Énergie-Climat 2030-2050* (ADEME, 2013), which puts forward two energy and climate scenarios: one, based on

1. Intergovernmental Panel on Climate Change (IPCC). http://www.ipcc.ch/home_languages_main_french.shtml
2. See the Agriculture and Forestry planning exercise *Climat : vers des stratégies d'adaptation* carried out in 2013 by the French Centre for Studies and Strategic Foresight (*Centre d'Études et de Prospective* - CEP) http://agriculture.gouv.fr/Seminaire-de-restitution-AFCLIM
3. With regard to direct agricultural emissions, the recent report by the CGAAER (*Conseil Général de l'Alimentation, de l'Agriculture et des Espaces Ruraux* – the French Advisory Board for Food, Agriculture and Rural Affairs at the Ministry of Agriculture) entitled *Les contributions possibles de l'agriculture et de la forêt à la lutte contre le changement climatique* is based mainly on the study *Quelle contribution de l'agriculture française à la réduction des émissions de GES* by INRA (*Institut National de la Recherche Agronomique* – the French National Institute for Agricultural Research) and is therefore not reproduced here.
4. See the report: http://agriculture.gouv.fr/rapport-final-agriculture-energie
5. See the study: http://institut.inra.fr/en/Missions/Inform-public-decision-making/Advanced-Studies/All-the-news/Study-on-reduction-of-GHG-in-agriculture
6. France has committed to a fourfold reduction in its GHG emissions by 2050 compared with 1990.
7. See the scenario: http://www.solagro.org/site/393.html

voluntary actions, seeks to identify in realistic terms the maximum potential energy savings and renewable energy gains by 2030; the other, based on a normative approach, aims to achieve factor 4 by 2050;

- and the study *Trajectoires 2020-2050 vers une économie sobre en carbone*[8], carried out in 2011 by a committee chaired by Christian de Perthuis. The study aims to outline a climate policy that combines a significant reduction in GHG emissions with positive economic impacts.

Following an assessment of agriculture's contribution to GHG emissions at various scales, this note presents the figures proposed by those six studies in terms of reducing emissions and the corresponding future image of the French agricultural sector. This is followed by an analysis of the main mitigation mechanisms. Finally, the economic aspect is addressed through abatement cost curves as a decision-making tool.

1 - Agriculture's contribution to GHG emissions

Agricultural emissions in France

In 2012, according to official inventories[9] from the Interprofessional Technical Centre for Studies on Air Pollution (*Centre Interprofessionnel Technique d'Études de la Pollution Atmosphérique* - CITEPA), agriculture represented 18% of direct GHG emissions in France (excluding energy consumption and land use changes), or almost 90 million tonnes of carbon equivalent (Mt CO_2eq)[10]. Adding emissions linked to energy consumption on farms, agriculture emitted a total of 101 Mt CO_2eq in 2012, or around 20% of French GHG emissions.

Nitrous oxide (N_2O) represents approximately half this total. N_2O emissions are the result of nitrification and denitrification reactions linked to the use of nitrogen fertilisers and management of animal manure. Methane (CH_4) contribution is around 40%. These emissions are due to fermentation in anaerobic conditions, either enteric fermentation in ruminants, or of stored manure or organic matter in the soil. The remaining emissions (CO_2) are energy related, from burning fossil fuels to run engines or heat buildings (see figure 1).

This calculation of GHG emissions comes from official inventories, which are based on the scientific literature and rigorous methods. Nonetheless, it is a complex exercise (cf. box 1) and subject to some significant uncertainties. There are also numerous debates and in some cases controversy about these methods, which are regularly reviewed and improved in line with scientific advances.

8. See the report: http://www.developpement-durable.gouv.fr/IMG/pdf/2011-10_Rapport_Comite_preside_par_M-_de_PERTHUIS_Trajectoire_2020-2050.pdf
9. See: http://www.citepa.org/fr/inventaires-etudes-et-formations/inventaires-des-emissions
10. Source: CITEPA, 2014.
11. IPPC: http://www.ipcc.ch/

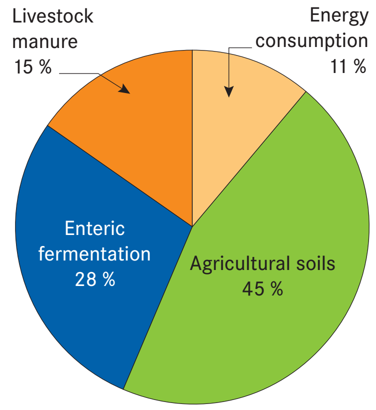
Box 1: the question of calculation methods

Agricultural emissions are based on biological mechanisms and are necessarily diffuse, which can explain the lack of certainty around the most significant emissions in this sector[5]. The calculation method for the official inventories produced by the CITEPA, which follows the relevant IPPC guidelines[11], consists of multiplying unit emission factors often with little contextual information, by activity levels that are aggregated at the level under consideration (categories of livestock, quantity of nitrogen spread, etc.). The current scope of the agricultural sector in the inventories is restricted to N_2O and CH_4 emissions on farms only, and thus excludes CO_2 storage in the soil (which is included in the "Land Use, Land Use Changes and Forestry" sector -LULUCF) and substitutions for fossil fuels (which are counted in other sectors). Some promising levers (e.g. methanisation) are not currently taken into account, primarily because of a lack of up-to-date data. It should be noted that the reference year is also an important element to fully understand the results.

The scope and methodology of the projects studied in the second part of this note, however, do not always follow the official guidelines and can vary significantly, in terms of the type of gases covered (whether CO_2 is included or not), and whether or not indirect emissions (for example, CO_2 and N_2O production resulting from mineral fertiliser or animal feed production), emissions avoided through substitution (e.g. energy from biomass) and carbon stocks and sinks in agricultural soil are taken into account. Furthermore, even on a constant basis, a re-evaluation of GWP (global-warming potential) for N_2O and CH_4, and unit emission coefficients can have a significant impact on results.

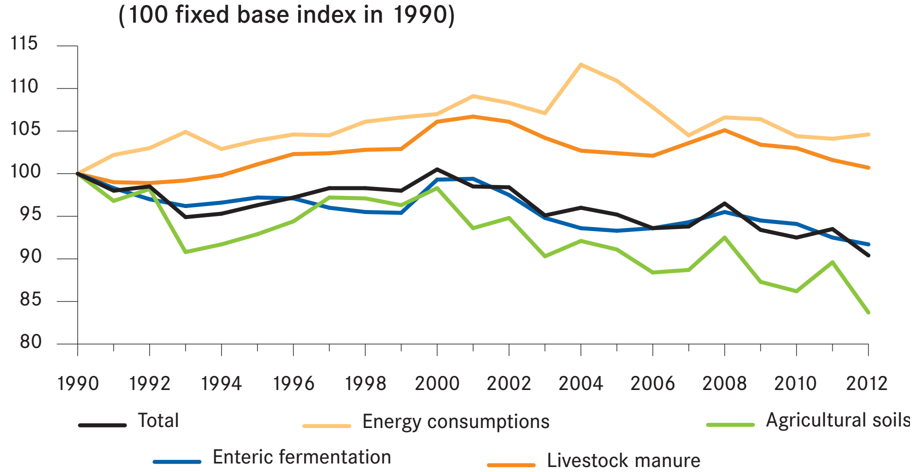
The INRA "mitigation potential" study usefully illustrates the importance of these issues: calculations of GHG reductions vary by a factor of one to three depending on the calculation methods used (emission coefficients and scope) for the same actions, implemented in exactly the same way - and in the current format, it is one third of the total potential that would be taken into account. This is a good example of the fact that progress on methods for calculating official inventories is a key priority for ensuring a more accurate consideration and therefore a better assessment of the potential reduction from agriculture. Nonetheless, it is important to emphasise that such uncertainties and differences in approach or scope are rarely sufficient to invalidate the overall direction of an assessment: a scenario that is more positive than another in terms of GHG mitigation will often remain more positive, regardless of the method used (as box 2, below, tends to confirm).

Figure 1 - **French agricultural emissions by main sources in 2012**



Source: authors, based on CITEPA data (2014)

Figure 2 - **Change in agricultural emissions by main sources (100 fixed base index in 1990)**



Source: authors, based on CITEPA data (2014)

Historical and international comparisons

Between 1990 and 2012, agricultural emissions fell by 9.6% in France (cf. figure 2) compared with just over 12% considering all sectors. The reduction can be explained by a decline in the use of nitrogen fertilisers, the reduction of utilised agricultural land and cattle numbers (primarily as a result of more intensive dairy farming), and the drop in energy consumption since 2004.

Agricultural emissions as a proportion of total emissions are higher in France (around 20%) than in Europe as a whole (9-10%). This is explained in part by the fact that agriculture represents a higher proportion of the French economy than in other European countries, and the significant proportion of nuclear energy, which produces very few emissions, in the French energy mix. Between 1990 and 2012, European emissions of GHGs of agricultural origin (excluding energy combustion) fell from 617 to 469 Mt CO_2eq, a reduction of 24%[12].

At a global level, total GHG emissions reached 49 Gt CO_2eq in 2010, with the largest proportion coming from burning fossil fuels and industry. According to the latest report from the IPPC, the Agriculture, Forestry and Other Land Use (AFOLU) sector[13] contributed to 24% of the total GHG emissions, or around 10 to 12 Gt CO_2eq, mainly due to deforestation, enteric fermentation and management of fertilisers (mineral or organic). It is the only sector to have seen its per-capita emissions fall since 2000. In 2010, agriculture alone represented around 12% of global emissions[14].

Whilst France and the European Union are reviewing their commitments to limiting global warming (through the 2030 Framework for Energy and Climate), more research is being undertaken to better understand agriculture's potential for mitigation.

2 - Potential for mitigation in French agriculture by 2030 and 2050

Presentation of studies analysed

Six studies on evaluating the potential for reducing national GHG emissions from agriculture were identified, two of which focused specifically on 2030: the foresight study *Agriculture énergie 2030* and INRA's "mitigation potential" study, along with ADEME's *Vision 2030* scenario. The sectoral study *Agriculture et facteur 4* looked at 2050, as did the *Vision 2050* scenario. The *Afterres* scenario was geared to 2050 but also provides data for 2030 as an intermediate point for 2050. The Perthuis study, *Trajectoires 2020-2050 vers une économie sobre en carbone*, gives results for both 2030 and 2050.

These exercises differ both in their intentions (normative or exploratory foresight[15], business-as-usual scenarios or more significant breakthroughs) and in the ways in which they quantify GHG emissions. The INRA study, for example, is an assessment of sources and sinks used to estimate the potential for mitigation - and the cost to farmers – of ten technical actions. The calculations follow, on the one hand, CITEPA's inventory methodology, and on the other, an "expert" method based on the literature available. The Perthuis study puts forward three normative scenarios (- 50% in 2050) with intermediate points in 2020, but does not explain in detail how emissions reductions are calculated for the agricultural sector. Out of the other four studies, the scenarios are exploratory for the foresight study *Agriculture énergie 2030* (four contrasting scenarios) and for *Vision 2030*[16]. They are more normative, however, for the *facteur 4* study (excluding the business-as-usual scenario), for *Afterres* and for *Vision 2050*. In the four latter studies, emissions reductions are calculated using the Climagri® tool, which can also be used to estimate some indirect emissions and carbon storage in soil and forestry biomass (but based on methods of quantifying direct emissions that are different from the CITEPA inventories).

As said in box 1, the differences in approaches and methods between studies have an impact on the results they produce, which makes them difficult to confront. We have tried to correct some of these discrepancies to make comparisons easier. The reductions in GHG emissions for each exercise have therefore been recalculated based on a single reference year, 2005, which was also used by the European Commission for the 2030 Energy and Climate Framework. As far as possible, we have also tried to use an identical scope for each study (cf. figure 3): we have therefore included reductions in direct emissions of agricultural origin (including CO_2), but not indirect or induced emissions[17], or substitutions.

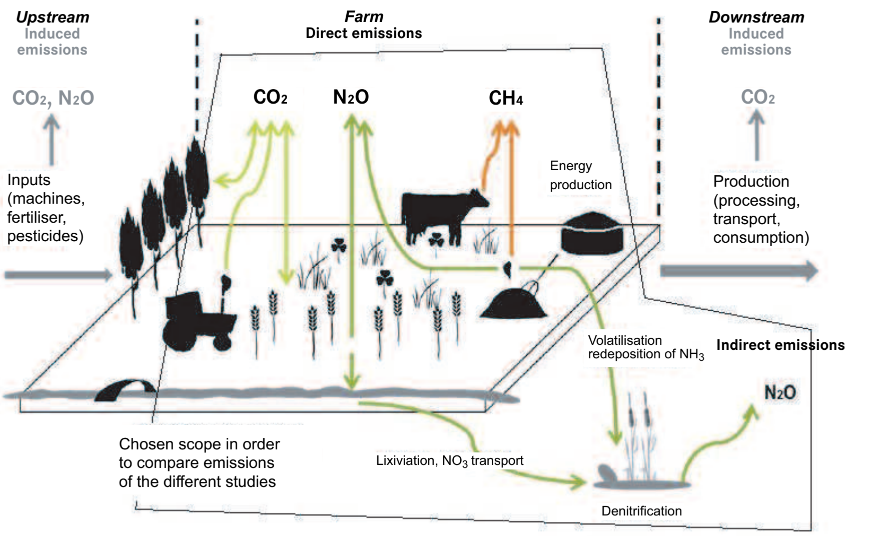
Presentation of results

The tables and figures below present a summary of the results of the six studies for 2030 (table 1, figure 4) and 2050 (table 2, figure 5) respectively.

In spite of the differences in approaches and methods, we can take some orders of magnitude from the following tables: regardless of the time line, the "business-as-usual" scenarios, for which there is no increased effort in terms of mitigation compared with

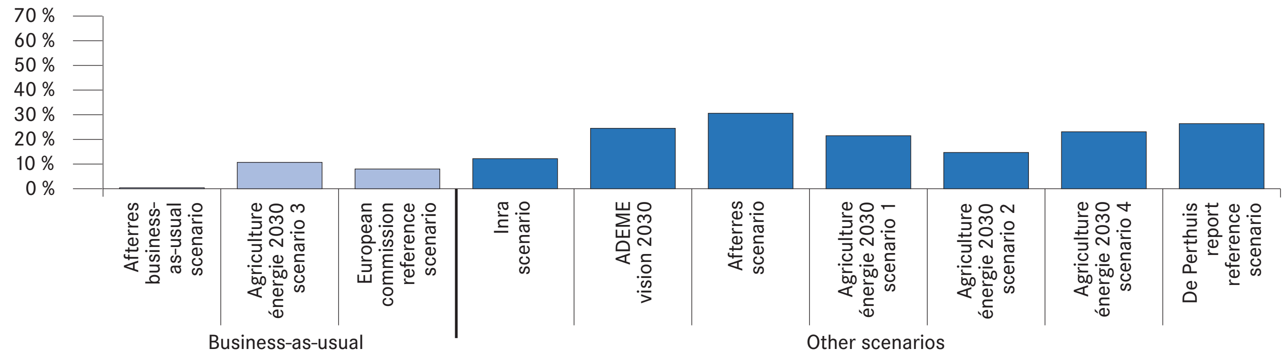
12. Source: Eurostat. The decline is much higher for new Member States (in Eastern Europe). The fall in the EU-15 Member States was around 16% over the same period.
13. The AFOLU sector also includes forest, peat-bog fires and peat-bog decomposition.
14. Source: 5th report from the IPPC (2014), WGIII *Mitigation of climate change*.
15. A foresight study is classed as normative when it sets a target to be achieved and explores possible paths and trajectories for achieving it; it is said to be exploratory when it puts forward future scenarios without trying to achieve a specific objective.
16. The "ADEME Visions" studies are currently being expanded to include more detail, looking specifically at 2030.
17. The term differs depending on studies and sectors (agricultural, industrial, etc.). INRA distinguishes indirect emissions, which occur outside the scope of the farm because of a physical transfer of molecules, from induced emissions, which are linked to both upstream and downstream commercial exchanges. The scope used in this note for the INRA study, for example, includes direct and indirect but not induced emissions. Studies based on the Climagri tool include direct emissions only, not indirect ones.

Figure 3 - **Schematization of the scope used to compare the studies**



Source: Inra, modified by authors

Figure 4 - **Mitigation of agricultural GHG emissions in 2030 compared to 2005 given the different scenarios**



Source: authors

Table 1 - **Studies results for 2030 ("E" for exploratory-type scenario and "N" for normative)**

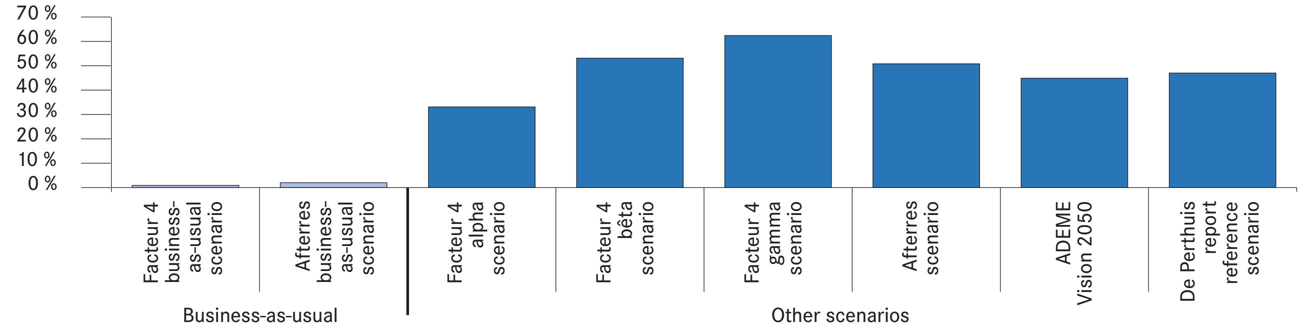
Scenario	Change in GHGs/ 2005[18]	Some main characteristics in agriculture and food by 2030
European Commission: reference scenario (E)	– 8%*	Activities decline or stagnate, excluding the pork and dairy sectors, where production tends to increase. The number of cattle decreases whilst intensive dairy farming increases. Use of nitrogen mineral fertilisers continues to fall.
INRA "mitigation potential" study (E)	– 12%**	Production systems do not undergo any major changes and production levels do not fall by more than 10%, in linewith the study's requirements. France continues in its role as an exporter. In practice, the 2030 scenario consists of using technical and agronomic levers aimed at reducing GHG emissions.
Agriculture énergie 2030: scenario 1, "Territorialisation and moderation in response to the crisis" (E)	– 21%	Production systems become more diverse and are relocated. Yields decline (– 20%) as well as plant production. Areas used for grazing increase to the detriment of arable crops, and protein crops increase sharply.
Agriculture énergie 2030: scenario 2, "Dual agriculture and energy realism" (E)	– 15%	Two models of agriculture co-exist: on the one hand, precision "corporate" agriculture that uses a high level of inputs, positioned for the export market (including the development of GMOs for biofuels); on the other, "multifunctional agriculture", with a diversification of activities and remuneration of environmental services.
Agriculture énergie 2030: scenario 3, "Agriculture and health with no significant energy constraint" (E)	– 11%	Crop rotations and yields remain stable. The number of cattle is reduced (– 10%) but milk yields increase. Second-generation biofuels increase strongly. The use of phytosanitary products is significantly reduced and nitrogen inputs decrease slightly.
Agriculture énergie 2030: scenario 4, "Ecological agriculture and energy management" (E)	– 23%	Plant and animal production decreases slightly in spite of relative stability in yields and the number of livestock. Production of protein crops increases and applications of mineral nitrogen are very significantly reduced.
ADEME *Vision: 2030* (E)	– 24%	The UAA (Utilised Agricultural Area) needed for direct human food production is stable as the result of a drastic reduction in avoidable losses (– 50%). French diets change little except with regard to proteins. Agroecological practices increase (10% of "integrated" production, 20% of the UAA for organic agriculture). The number of cattle decreases slightly (– 11%) and imports of oil cake decline. The pace of artificialisation is halved. Nitrogen consumption decreases by 22% and average yields decrease.
Afterres: business-as-usual scenario (E)	0%	The UAA is stable, with a limited increase in arable crops (+ 5% in surface area) and a slight decline in areas used for grazing (– 3.5%). Use of irrigation is high (+ 80%). Use of phytosanitary products declines only slightly (– 13%) and the nitrogen balance does not improve. The number of livestock remains steady but with a swing from meat to milk. Agroecological infrastructure increases slightly.
Afterres : sustainable scenario (intermediate point in 2030) (N)	– 31%	Conventional agriculture declines to the benefit of organic agriculture, integrated agriculture and agroforestry. The number of cattle begins to fall sharply (– 36%; – 53% in suckler cows). Livestock farming systems become more extensive. Areas used for arable crops increase slightly whilst fodder crops reduce by 15%. The use of phytosanitary products and mineral nitrogen falls (– 42% and – 33%). Exports of cereals and dairy products decrease by 14% and 10% respectively, whilst imports of oils and oil cakes fall. Diets change (– 17% in consumption of animal proteins, – 21% for milk, notably).

** Excluding CO_2* *** Emissions based on the CITEPA calculation method, 2012 inventory*

Source: authors, based on the studies analysed

18. The reduction values in this table have been calculated by the CEP, based on the results available in various studies.

Figure 5 - **Mitigation of agricultural GHG emissions in 2050 compared to 2005 given the different scenarios**



Source: authors

Table 2 - **Studies results for 2050 ("E" for exploratory-type scenarios and "N" for normative)**

Scenario	Change in GHGs/ 2005[19]	Some main characteristics in agriculture and food by 2050
Facteur 4: business-as-usual scenario (E)	–1 %	Overall, production is relatively stable compared with 2006: stable in field crops and milk; an increase in industrial crops and tree farming; a decrease of 9% in wine growing, eggs and grasslands, and 7% in beef.
Facteur 4: alpha scenario "ecological intensification" (N)	– 33%	Agronomic and technological innovation lies at the heart of this scenario: conventional agriculture declines to the benefit of more ecological production methods (integrated production, agroforestry, intermediate crops, etc.). Arable crop production falls by 12%, grasslands by 27%, milk by 18% and meat by 26% (52% for beef). Conversely, tree farming increases by 15%. Diets remain similar. Imports and exports continue at their current level. Losses and waste fall sharply. The use of biomass resources is maximised.
Facteur 4: beta scenario "Food, self-sufficiency and moderation" (N)	– 53%	This scenario is driven by a fundamental change in diets. The proportion of animal proteins falls in favour of plant proteins. Integrated production and organic agriculture dominate crop production. Agroforestry increases. In livestock farming, production under quality standards and pastureland systems increases. Suckler cattle disappear in response to the changes. Arable crop production decreases by 29%, and industrial crops and wine grow by 15%. Milk production falls by 57% and meat by 48%. Losses and waste fall. Exports also fall and imports are adjusted in line with cattle requirements. The agricultural land freed up by the changes in diet is used to produce biomass as a substitute for fossil fuels, whose price has increased sharply.
Facteur 4: gamma scenario "Food, efficiency and storage" (N)	– 62%	This scenario is driven by carbon storage and production of renewable carbon, which leads to a conciliation of dietary changes and ecological intensification. Integrated agriculture, agroforestry and organic agriculture become dominant. Diets change significantly, with less demand for food and a decline in the consumption of animal products. Field crop production and natural grasslands fall by 41%, with industrial crops and wine growing declining by over 20%. Milk and meat production fall by almost 60% and suckler cows nearly disappear. Exports reduce by 50%. Losses are drastically reduced. The areas freed up are used for trees, storing carbon and producing biomass.
Afterres: business-as-usual scenario (E)	– 2%	The UAA is stable. Arable crops increase to a limited extent, with significant use of irrigation and little progress on the nitrogen balance or the use of phyotsanitary products. Cattle are retained for milk rather than meat and the area of grazing land falls slightly.
Afterres: sustainable scenario (N)	– 51%	This scenario is based on a "triple transition", in nutritional (sustainable consumption / moderation), agricultural (agroecological transition) and energy terms (lower consumption of fossil fuels and energy production from biological sources). Conventional agriculture gradually disappears to the benefit of organic agriculture, integrated agriculture and agroforestry. The number of cattle falls massively (– 70%; – 85% in suckler cows) along with the number of pigs and poultry. Livestock farming systems become more extensive. Areas used for arable crops decrease slightly and fodder crops fall by 40%. Equivalent yield coefficients per unit of surface area increase. Exports of cereals and dairy products decrease by 28% and 20% respectively. Imports of oils and oil cakes fall. Diets change significantly, with a twofold reduction in meat consumption and milk consumption cut by 2.5 times. Losses and excess consumption are significantly reduced.
ADEME *Vision: 2050* (N)	– 45%	By 2050, diets move towards a reduction in overconsumption and a rebalancing of animal and plant proteins. Consumption of animal products (milk and beef) falls. The reduction in avoidable losses reaches a ceiling. Agricultural practices move towards agroecological systems, integrated production or organic agriculture. Practices such as simplifying soil cultivation, agroforestry or associated crops are more widespread. Cattle farms are geared to grazing and protein independence. Use of nitrogen fertilisers is reduced by 37%, irrigation requirements increase by 30% (less than the business-as-usual requirements expected) and artificialisation stops in 2030. Imports of oil cakes fall; France maintains its export capacity in energy-equivalent .
De Perthuis study: reference scenario (N)	– 47%	R&D and the expansion of "ecologically intensive" methods are supported by the public authorities. Nonetheless, the study does not offer a detailed view of the future of agriculture.

Source: authors, based on the studies analysed

19. The reduction values in this table have been calculated by the CEP, based on the results available in various studies.

Box 2: comparison of agricultural GHG emissions for different scopes

In the four studies for which emissions have been calculated using the Climagri® tool (Visions ADEME, Facteur 4, Afterres and Agriculture énergie 2030) the comparison based on more or less wide scopes highlight that: the rankings in the scenarios (from most to least emissions) are fairly robust to changes in scope. Where the direct emissions for a given scenario are lower than those for another scenario, the same applies if indirect emissions (cf. above) and/or variations in agricultural and forest carbon stocks are included[20]. The (%) reduction in emissions is, in fact, generally higher if we look at a broader scope: we could refer to a "synergic effect" insofar as mitigating direct emissions creates "potential" for mitigating indirect emissions and for carbon storage. Reducing nitrogen inputs and the size of herds, which features in numerous scenarios, leads to lower consumption of inputs, and therefore to lower emissions linked to producing them. Similarly, in the more ambitious scenarios (beta, gamma and Afterres), where demand for food is reduced alongside the pressure on artificialisation, some agricultural areas are converted to forest areas, which are used to store carbon and reduce emissions to an even greater extent.

Finally, regardless of the scope considered, there is no "negative emissions" scenario with net storage of carbon here: to achieve this, we would also need to be able to take account of the emissions saved as a result of substitutions involving other sectors, which is not possible with the Climagri® tool.

the current situation or policies, do not result in a reduction in agricultural emissions (or only a small one, i.e. less than 10%). By 2030, the scenarios that rely mainly on technical levers (for example, the INRA "mitigation potential" study based on the CITEPA calculation method), without any significant changes in production, enable a reduction in emissions of around 10 to 20%. Exceeding this means moving to more disruptive scenarios: these result in reduction levels generally between 20 and 35% by 2030, and between 30 and 60% by 2050 (for example, the alpha, beta and gamma or *Afterres* breakthrough scenarios).

To achieve or get close to the "factor 2" by 2050, the levers used combine various technical actions (such as better nitrogen management or methanisation), but also more fundamental changes, for example in production practices, the size of herds and fields used to cultivate particular crops, the balance of trade, diets, reducing losses and waste, etc. None of the scenarios, even a very voluntarist one, achieve factor 4 for the agricultural sector by 2050 or exceed 35% by 2030.

3 - Levers available to reduce agricultural GHG emissions

In addition to the representations of agriculture associated with levels of reduction in GHGs by 2030 and 2050, the six studies presented above outline some similar technical levers. Three distinct approaches are apparent:

a) reduce emissions, either by improving the efficiency of existing production systems, with no significant change in activity, or by developing new practices or by reducing the level of production;

b) use substitution (e.g. energy production from biomass or reducing emissions by replacing fossil fuels);

c) store carbon in soils and biomass (e.g. through changes in land use from agricultural activities to forestry).

Mitigation actions can also be distinguished on the basis of their target, namely food supply or demand. As far as demand is concerned, this involves changes in terms of diets, i.e. limiting over-consumption and establishing a different balance between animal and plant proteins, or avoiding waste and losses. In the beta and gamma scenarios of the *facteur 4* study, for example, the proportion of animal proteins and daily intake of calcium through milk would be reduced, sometimes by half (to 33% and 200 mg per person per day, respectively). Avoidable losses would also fall, by 50% or even 60%. Other levers affect food supply, at the level of production patterns. These changes can then be made as a last resort, for example reducing consumption of fossil fuels by agricultural machinery through environmentally friendly driving (efficiency) or may represent more profound changes, for example, developing agroforestry (redesigning systems), generally as part of an agroecological approach. Numerous practices can contribute to mitigating GHG emissions, such as reducing soil tillage, introducing legumines or intermediate crops, lengthening grazing periods, etc. New opportunities are also likely to appear as a result of the changes affecting food supply and demand. In the *Afterres* study, for example, the agricultural land released is used for biomass production, including afforestation.

In total, INRA describes four major families of technical levers for improving the net balance of GHG emissions at farm level, with no significant impact on production volumes: reducing inputs of nitrogen-based mineral fertilisers[21]; storing carbon in the soil and biomass[22]; modifying animal feed[23]; using effluents to produce energy and reduce consumption of fossil fuels[24]. According to this study and the "expert" calculation method, the action with the highest potential for mitigation is methanisation. Yet, although this measure is found in most of the exercises cited, it is not currently taken into account in emissions inventories, although it would eventually be feasible to calculate it. Other actions with high mitigation potential are covering effluent storage pits and installing flares, switching to occasional tilling (one year in five) and reducing the application of mineral fertilisers by adjusting yield targets more accurately.

Although some scenarios in the six studies analysed may result in significant changes in agricultural activities, the technical levers under consideration are relatively "conservative"[25], relying on existing systems and techniques. Conversely, other options, not addressed in the exercises cited but dealt with in international studies (for example, anti-methanogenic vaccination and transgenesis) raise questions of acceptability and potential application to French farms.

4 - Cost of mitigation actions and economic efficiency

The studies presented so far are based on an evaluation of the potential for mitigating agricultural GHGs through the use of technical and scientific data for each lever studied. However, these approaches often leave the question of economic impacts unresolved, for example, the estimated costs of each scenario, how costs would be split between stakeholders, the effect on farmers' or sector revenues, etc.

20. Carbon storage calculations are based on hypothetical changes not only to agriculture but also to forestry and the timber sector. Here, variations in stocks are due solely to changes in land use.
21. Reducing the use of synthetic mineral fertilisers by using them more efficiently and making better use of organic resources; increasing the share of legumes in arable crops and temporary grasslands.
22. Developing till-free cultivation techniques; introducing more intermediate crops, intercrops and grass buffer strips; developing agroforestry and hedges; optimising grasslands.
23. Replacing carbohydrates with unsaturated fats and using an additive in feed for ruminants; reducing the protein content of animal diet.
24. Developing methanisation and installing flares; reducing farms' consumption of fossil fuels for buildings and agricultural equipment.
25. Source: INRA "mitigation potential" study.

Mitigation costs: different approaches

The literature highlights two categories of research that address economic aspects[26]. The first uses models based on microeconomic theory: the farmer chooses between different mitigation strategies and maximises profits based on costs, which are themselves dependent on a "carbon price per tonne" included in the model via a tax or subsidy. There are two distinct kinds of model: supply-side models and equilibrium models (general or partial). The difference between the two relates to the refinement of the description of the agricultural sector, the representation of demand and the endogeneity, or not, of agricultural prices (i.e. prices calculated by the model or, conversely, fixed by the modeller). None of the studies presented above uses this kind of model.

The second category of research covers so-called "engineer" approaches[27], which propose an estimate of implementation costs for the different mitigation levers studied (opportunity costs, operational costs, investments, etc.). This method is based more on an accountancy approach and is the one proposed in the INRA study. Unlike modelling, it allows for the consideration of actions that apparently have "negative costs"[28], i.e. which would result in a gain at farm level. It also makes it easier to introduce innovations into mitigation measures[29]. With this method, however, analysing interactions between various levers is less easy than with models, and indirect effects (the price effect of lowering production following implementation of a given lever) are not taken into account.

Regardless of the approach taken, these studies are not without their limits. As a result, economic models are not able to represent abatement technologies in fine detail and are often only marginally modified to incorporate GHGs. Conversely, the use of expert assessments for "engineer" approaches makes each exercise unique, which does not make it easy to compare them with other studies. Both these methods (modelling *vs* "engineers") are stylised representations of reality. As the scientific objective is not to produce a faithful description of reality, it is important to understand the underlying hypotheses and the tools' limitations to use them effectively and accept that the results produced should be viewed as orders of magnitude.

Mitigation cost curves, construction and interpretation[27]

Both types of approach allow for the production of mitigation - also known as abatement - cost curves. These show the cost associated with the last unit of emission avoided. It is therefore a question of the "economic potential" of mitigation, i.e. the maximum quantity of GHG emissions that can be reduced for a given price (in euros per tonne of CO_2eq).

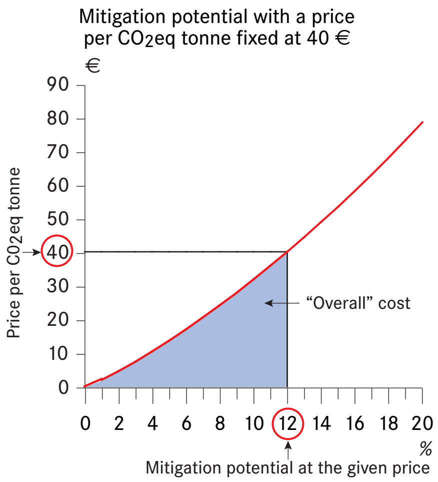
In the case of models, the mitigation costs curve is constructed by linking the reductions in emissions obtained for each simulated price level (cf. figure 6a). For the "engineers" approach, the graphic representation is based on the ranking of actions by increasing unit cost of mitigation (cf. figure 6b). In all cases, it is necessary to refer to the area beneath the abatement curve to estimate the "overall" cost of a given mitigation objective. This cannot be described as the "total" cost since it does not take into account the negative externalities avoided by reducing emissions; in other words, it does not include the cost of climate change (for example, flooding or emerging diseases) or the benefits associated with combating it.

Table 3 shows a selection of results that illustrate the mitigation potential for a given carbon "price".

These results, obtained using abatement curves, should be interpreted according to the scale concerned (World, Europe or France), the time line chosen (2020, 2030, 2050), the reference year (1990, 2005, etc.) and the calculation method (cf. box 1). In practice, the studies vary according to whether or not they include CO_2 (often N_2O and CH_4 only), and whether they take account of

26. Kesicki F., 2011, *Marginal abatement cost curves for policy making – expert-based vs. model-derived curves*, IAEE International Conference, 6-9 June 2010, Rio de Janeiro.
27. De Cara S., Vermont B., 2014, "Émissions de gaz à effet de serre d'origine agricole : coûts et potentiels d'atténuation, instruments de régulation et efficacité", *Notes et études socio-économiques* No. 38. The section on mitigation cost curves is based on this article.
28. For example: extending the duration of temporary meadows, reducing the amount of mineral fertiliser applied by adjusting the yield target, replacing synthetic mineral nitrogen with nitrogen from organic products, reducing fossil-fuel consumption to heat greenhouses or drive agricultural machinery, etc.
29. Such as new technologies that have not yet been deployed but with technical references (De Cara *et al.*, 2014). Cf. for example, the anti-methanogenic vaccines already cited.

Figure 6a - **Mitigation abatement cost curve and the modelling approaches**



Source: authors, based on De Cara and Jayet, 2011

Figure 6b - **Mitigation abatement cost curve and the "engineer" approach**

Source: Inra, 2013

direct and/or indirect emissions. Similarly, inventory methods may differ: the baseline for the emission coefficient for the same mitigation action, for example, may come from the IPPC or another expert scientific assessment. Finally, the technical levers considered and their speed of dissemination may also vary. Methanisation, for example, is not taken into account in De Cara and Jayet[30], unlike in Höglund-Isaksson *et al*[31]. The meta-analysis produced by Vermont and De Cara emphasises the importance of such precautions when comparing different studies.

Given the orders of magnitude for GHGs presented in section 2, it is possible to have some estimates of the "carbon price" (€ per tonne of CO_2eq) for different levels of mitigation potential from the studies listed in table 3:

- for a mitigation potential of around 10%, the "carbon price" would be around 35 euros for France and 40-45 euros on a European scale[30];

- for a reduction in emissions of 20%, the "carbon price" would be around 70 euros per tonne of CO_2eq for France[27],

- for a reduction in emissions of 30%, the "carbon price" would be around 300 euros on a European scale according to the IIASA study[31].

In addition to the drawbacks already cited for each method used, other limitations are regularly raised in relation to abatement cost curves, namely: the absence of the transaction costs (e.g. administrative and information costs) or of an inter-temporal dynamic (distortion of the abatement curve over time), limited treatment of uncertainties, failure to take account of interaction with other sectors, etc. In spite of this, the simple representation provided by abatement cost curves (potential for mitigation according to the "carbon price") explains their recurrent use in public policies, to define or evaluate mitigation strategies, even if such results should only be viewed as orders of magnitude.

* *
*

An analysis of the studies available on the mitigation potential in French agriculture by 2030 and 2050 suggests a number of significant orders of magnitude, beyond the uncertainties associated with any quantification exercise: without additional efforts compared with the current situation, "business-as-usual" scenarios are likely to result in limited reductions of emissions (less than 10% by 2030). By improving the "carbon efficiency" of agricultural practices and making use of technical levers (e.g. nitrogen management), emissions could be reduced by around 10-20% by 2030. It should be noted that this technical potential is heavily dependent on the calculation methods used (emissions coefficients and scope), which makes this apparently technical subject a major topic for the coming years.

To achieve more than a 20% reduction by 2030 and get close to factor 2 by 2050, it will be necessary to focus on scenarios with a shift from current production and consumption systems. As a result, the most ambitious scenarios (− 50% to − 60%) are based on a fairly radical change of agriculture and food (reducing losses, cattle numbers, exports, consumption of animal proteins, etc.) but still do not achieve factor 4 by 2050.

These scenarios offer us probable or desirable images of the future rather than pathways or trajectories to help us achieve them. In particular, there is little explicit information on the drivers and factors of change that will move us from a business-as-usual scenario (with a limited reduction in GHGs) to 25% − 30% reductions, by 2030. Moreover, these scenarios are often based on technical, agronomic and physical coherence (resource/allocation balances) but do not provide any real economic coherence nor any estimates of the impacts in a specific scenario in terms of jobs creation or added value. From this point of view, mitigation cost curves derived from both modelling tools and expert approaches are of benefit by providing the public authorities with cost estimates associated with a given level of mitigation effort. Although such studies give useful orders of magnitude, the results produced are again still very sensitive to their underlying assumptions.

Beyond the uncertainties surrounding them, the results of the studies presented in this paper show the importance of supporting the agricultural sector towards reducing emissions, producing renewable energies (whose substituted emissions are currently recorded in other sectors) and increased carbon storage. Another major challenge will be to reconcile mitigation with the need for agriculture and related sectors to adapt to new climate conditions, in particular by supporting the design of production systems that are more resilient to unpredictable events. All challenges that are part of the national, European and global agenda.

Élise Delgoulet, Noémie Schaller, Pierre Claquin
Centre for Studies and Strategic Foresight

Table 3 - **Mitigation potential and "carbon price"**

Scale	Studies	Time frame	Potential reduction of agricultural emissions
France	INRA potential study, 2013[5]	2030	Around 10% at 40 euros per tonne[30]
France	De Cara and Jayet, 2011[31]	2020	Around 12% at 40 euros per tonne
Europe	De Cara and Jayet, 2011	2020	Around 10% at 40 euros per tonne
Europe	Höglund-Isaksson *et al.*, 2012[32]	2050	Around 13% at 40 euros per tonne
Europe	European Commission, 2013[33]	2030	28% at 40 euros per tonne
Europe	Vermont and De Cara, 2010[34]	2030	Between 8 and 26% at 40 euros per tonne (central estimate: 15%)
Monde	Vermont and De Cara, 2010	2030	Between 7 and 22% at 40 euros per tonne (central estimate: 12%)
Monde	IPPC, AR5, 2014[14]		Between 10 and 50% at USD 50 per tonne i.e. around 37 euros (exchange rate as at 7/08/2014)

Source: authors choice among the literature available

30. De Cara S., Jayet P.-A., 2011, "Marginal abatement costs of greenhouse gas emissions from European agriculture, cost-effectiveness, and the EU non-ETS burden sharing agreement", *Ecological Economics*, 70(9), pp 1680-1690.
31. Höglund-Isaksson L. *et al.*, 2012, "EU low carbon roadmap 2050: Potentials and costs for mitigation of non-CO2 greenhouse gas emissions", *Energy Strategy Reviews*, 1 (2012), pp 97-108.
32. CITEPA calculation method
33. European Commission, 2014, *A policy framework for climate and energy in the period from 2020 up to 2030*, impacts assessment.
34. Vermont B., De Cara S., 2010, "How costly is mitigation of non-CO2 greenhouse gas emissions from agriculture? A meta-analysis", *Ecological Economics*, 69, pp 1373. Data based on model 6, taking all independent variables at their average value except for those related to the price of carbon (EUR 40/tCO2eq), baseline year (2020 or 2030) and spatial coverage (Europe or World).

Ministry of Agriculture, Food and Forestry
General Secretariat
Division of Statistics and Strategic Foresight
Centre for Studies and Strategic Foresight
12 rue Henri Rol-Tanguy
TSA 70007
93555 MONTREUIL SOUS BOIS Cedex, France
Websites: www.agreste.agriculture.gouv.fr
www.agriculture.gouv.fr

Publication director: Béatrice Sédillot

Editor in chief: Bruno Hérault
Email: bruno.herault@agriculture.gouv.fr
Tel.: +33 1 49 55 85 75

Typesetting: SSP Beauvais