Agriculture to Feed humanity and Take care of the climate

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Abstract

For two centuries, energy consumption has continued to increase, particularly that of fossil fuels, coal, oil and gas. Annual global greenhouse gas (GHG) emissions have increased accordingly, reaching 38 billion tons in 2023.

In France, agriculture contributes 19% of greenhouse gas emissions. And it will probably suffer the effects of climate change more than other sectors. For agriculture and beyond, for all infrastructures, the cost of adapting to a warmer climate of around 4.4°C will be very high. In addition, due to a reduction in the amount of energy available, we will have fewer resources for this adaptation (see the RTE report).

This article aims to show how agriculture can doubly contribute to limiting global warming: on the one hand by reducing its own energy consumption, and on the other hand by considerably developing its capacity to capture and store carbon in the soil. This cultivation method also allows farmers to increase their income.

The European Union wants to achieve carbon neutrality by 2050. One of the EU's proposed measures is to regularly increase, from 2026, the remuneration of companies that store carbon, including farmers practicing Soil Conservation Agriculture. These agricultural companies store significant quantities of carbon in the soil each year and should therefore be concerned by this EU measure.

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1. Abundant energy, the driving force of industrial civilization

Figure 1 shows that the energy transition is non-existent. The use of renewable energies is added to the previous ones without the consumption of fossil fuels decreasing. Of course, energy efficiency has increased fivefold in two centuries, but energy consumption has increased 25fold (Jevons paradox). Contrary to what almost all economists claim, energy efficiency in itself does not automatically lead to an energy transition. For the time being, we are rather on the path to global warming of 3°C, agriculture will have to adapt!

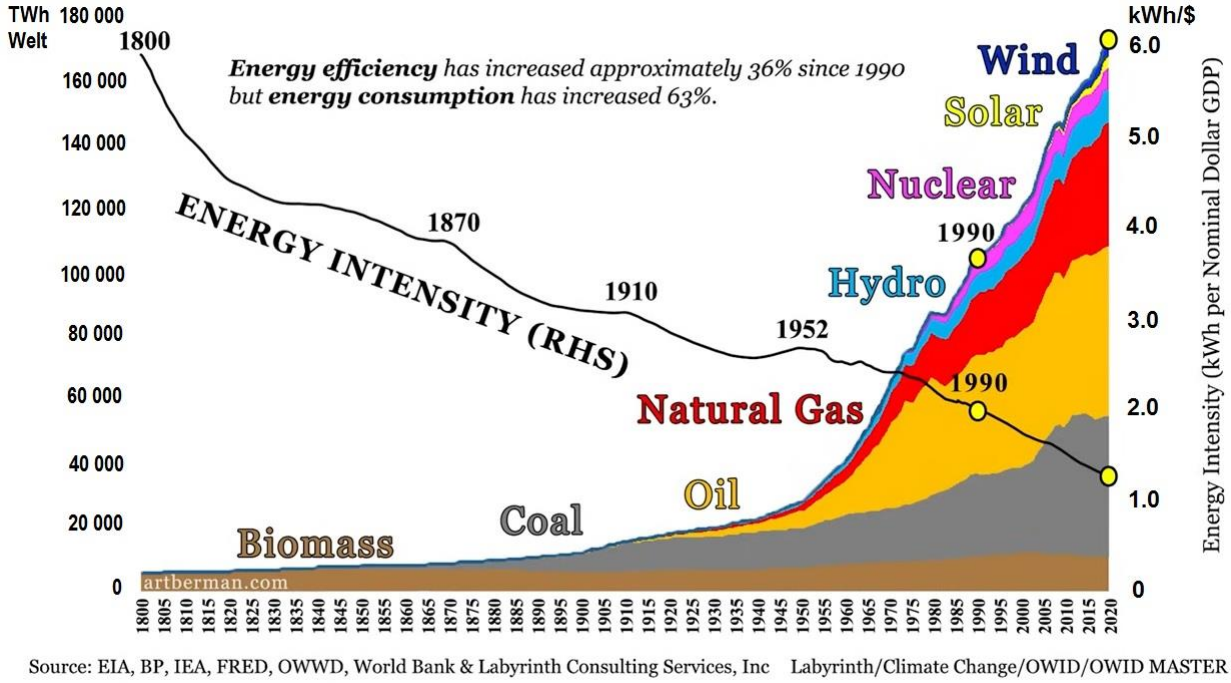


Figure 1: Energy intensity: In 1800, 6 kWh produced $1 of GDP. In 2020, it only takes 1.2 kWh to produce $1 of GDP. Yet, energy consumption increased 300 fold.

According to the RTE report (Réseau de Transport d'Electricité), France should reduce its energy consumption by 40% in 2050 compared to 2010. This would therefore force agriculture to stop constantly increasing its energy use. Soil Conservation Agriculture (SCA) helps reduce energy dependence. SCA also contributes to achieve the goals formulated by RTE and approved by the French government:

- While the energy needs of Conventional Agriculture have been increasing steadily for over 50 years, the needs of SCA are much lower and, moreover, have been decreasing over the years.
- While Conventional Agriculture is responsible for 19% of greenhouse gas emissions in France, SCA can help reduce France's carbon footprint.

1.1 Consequences of the RTE report

Conventional agriculture requires large quantities of nitrogen fertilizers, the production of which is very energy-intensive, which is not compatible with the desired reduction in fossil fuel consumption. The six-fold increase in the price of natural gas in 2022 has led to a 500% increase in the price of nitrogen fertilizers. Without the import of shale gas from the

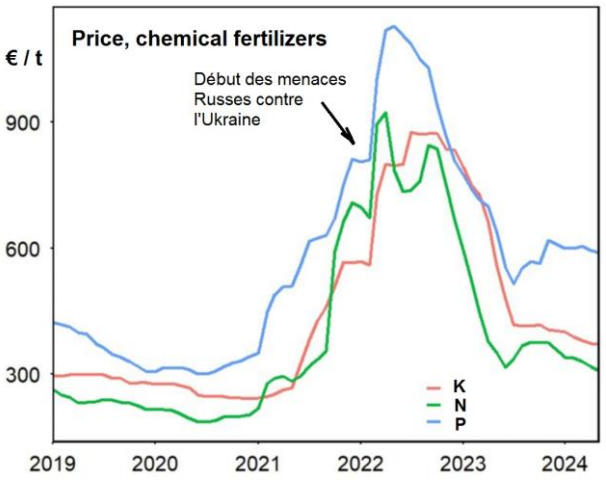
USA, conventional European agriculture would have been forced into bankruptcy after 2022.

Figure 2

The price of fertilizers, especially nitrogen fertilizers, depends largely on the price of natural gas and oil.

A similar price increase occurred in 2007-2008, when the price of a barrel of oil reached a historic peak of $148.

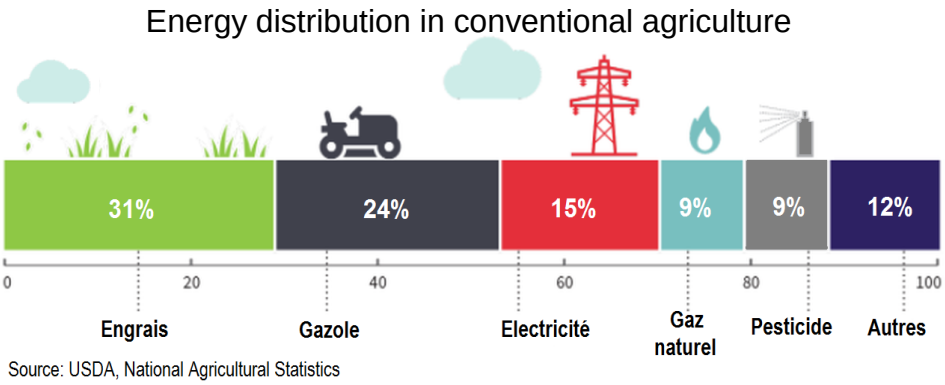
If President Trump stops shale gas exports, the price of nitrogen fertilizers will exceed €500 per ton, with devastating effects for conventional agriculture in Europe.



1.2 Energy needs

Figure 3

In conventional agriculture, fuel for machinery plus energy to produce fertilizers accounts for 55% of the total.



Source: USDA, National Agricultural Statistics

In Italy, a comparative study conducted over 20 years between Conservation Agriculture and Conventional Agriculture showed that in SCA the wheat yield is 10% lower.[1] However, in SCA, energy needs are overall halved (not counting heating of buildings). Energy needs for fertilizers is reduced by a factor of six.

1.3 Example of an industrial Carbon Capture Method

All carbon neutrality scenarios foresee large volumes of storage in the subsoil. But the most publicized methods have a very poor energy balance compared to the potential of agriculture. While agriculture stores carbon while reducing energy consumption, industrial methods of CO2 storage are very energy-intensive, expensive ... and covered in media praise.

To achieve carbon neutrality, humanity should, according to the company McKinsey, be able to store between 4 and 6 billion tons of CO_2 per year in 2050.[2] Unfortunately, the media as a whole only talks about industrial solutions, which are energy-intensive, and ignores the potential of agriculture. This blindness can be explained by a widespread

[1] Stagnari Fabio ; *Conservation Agriculture: A Different Approach for Crop Production Through Sustainable Soil and Water Management, 2009*

[2] McKinsey ; *Global Energy Perspective 2023: CCUS outlook*; 24 Jan. 2024

conception, for which the word "progress" is equivalent to "more technology consuming more energy".

Figure 4

The Swiss company Climeworks is making headlines in Forbes, NYT, FAZ, RTS, NZZ, Sud-Ouest, Les Echos, Science et Vie, …

It has stored 4000 t of CO2 in 2023 in Iceland at a price of $1000 per ton of CO2, or $3500 per ton of carbon.

To store 4 billion tons of carbon with this industrial method, the equivalent of the global potential of agriculture, would take the energy of all 440 nuclear power plants in the world!

To achieve carbon neutrality (CO_2 emissions and storage are equal), pure and clean CO_2 has a significant industrial utility. Climworks mineralizes CO_2 in the Icelandic subsoil and makes it useless for industry in the future. Together with hydrogen obtained by electrolysis, pure CO_2 can be transformed into synthetic liquid fuels such as e-methanol. For long-haul aviation and long-haul container ships, these synthetic fuels are the only carbon-neutral technological option in sight. On the path to carbon neutrality, storing pure CO_2 underground is a systemic error, while also being too energy-intensive and therefore too expensive.

There is no better solution for carbon storage than conservation agriculture.

2. Soil Conservation Agriculture and Carbon Capture

Soil Conservation Agriculture (SCA) consists of a set of agricultural techniques that promote the ecological resilience of a farm, in particular by reducing soil work and reducing the consumption of energy products (fuel or chemical inputs). The agronomic knowledge acquired over the last 40 years is now facilitating the transition to a sustainable and profitable model.

En limitant le travail du sol, la dépendance aux intrants, et en privilégiant une diversification des espèces végétales, les techniques innovantes de l'ACS augmentent la rentabilité économique des exploitations et améliorent la résilience face aux aléas climatiques.

Figure 5

In SCA, cereal grains are harvested, but the straw is left on the ground (see photo). The stalks contain lignin, a carbon chain, which is absorbed by the soil through the activity of bacteria, fungi and earthworms. In 2021, Brazil cultivated 38 Mha in SCA, Paraguay 22 Mha.

A field previously cultivated in conventional agriculture can store about 1 t of carbon per year and per ha.

1 t of C = 3.5 t of CO_2 (measurements done by Arvalis and Indigo-Ag).

2.1 Storage of Organic Carbon over time

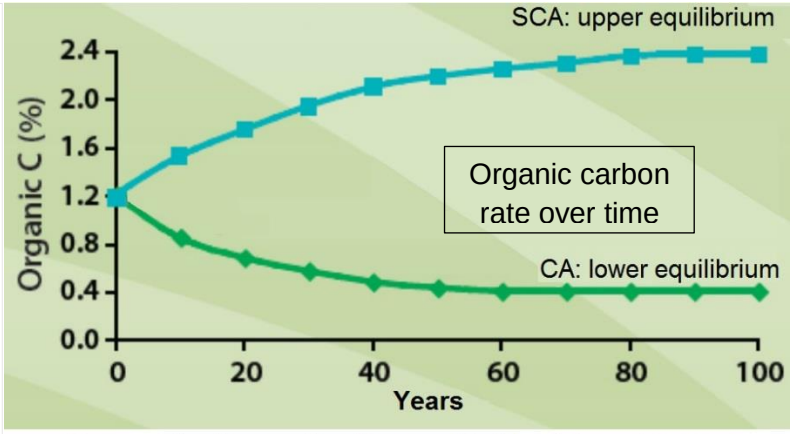
The annual additional carbon storage decreases over the years, but the farmer practicing Soil Conservation Agriculture should still be able to sell carbon credits for about 50 years.

Figure 6 illustrates the difference between Soil Conservation Agriculture and Conventional Agriculture in terms of organic carbon content in soils. It is assumed that conventional agriculture does not bring organic matter to the fields in the form of manure or slurry and that straw is not left on the fields after harvest.

Figure 6

Starting condition: Mown grassland. The maximum carbon rate varies depending on the average temperature and humidity of each region.

The amount of carbon stored in the soil with conservation agriculture increases the most during the first 15 years and peaks after about 60 years.



Source: https://www.soilquality.org.au/factsheets/organic-carbon

2.2 Two carbon markets: carbon quotas and carbon credits

The European Union (EU) requires large CO2-emitting companies to buy carbon allowances on the mandatory quota market if their emissions exceed an allocated cap. This cap corresponds to a certain number of carbon allowances that companies receive for free. The EU plans to lower this cap regularly until the year 2050, which will increase the price of allowances and encourage companies to reduce their emissions.

In addition to the mandatory carbon *quota market*, there is a voluntary market for *carbon credits*. On this voluntary market, the price of a ton of CO_2 ranges from 30 € to 800 $. Under the label "Low Carbon Farm", the price paid to French farmers for one ton of stored carbon lays between 30 € and 40 €, compared with the price of 2'800 $ paid to the company Climworks [3] (800$ / t of CO_2. 1 t of carbon is equivalent of 3.5 t of CO_2).

To achieve carbon neutrality, the EU also plans to store 280 million tons of CO_2 per year starting 2040 and 450 million tons per year from 2050.[4]

[3] The companies BCG and Amazon Signed a 15-Year Contract to Store CO_2 at 800 $ per Ton : https://www.consultor.fr/articles/le-bcg-signe-pour-15-ans-de-capture-de-ses-emissions-de-gaz-a-effet-de-serre

[4] https://climate.ec.europa.eu/eu-action/industrial-carbon-management/about-industrial-carbon-management_en

Figure 7

In July 2024, the price of carbon quotas for one ton of CO_2 was €70. According to EU estimates, in 2030, the price of these quotas should reach €200.
Carbon quotas only concern the most emitting companies: Cement plants, blast furnaces, brickyards, aluminum plants, boilers using more than 20 MW, etc. As soon as we get serious about decarbonizing the economy, this quota market will become a price indicator for the parallel market for carbon credits.

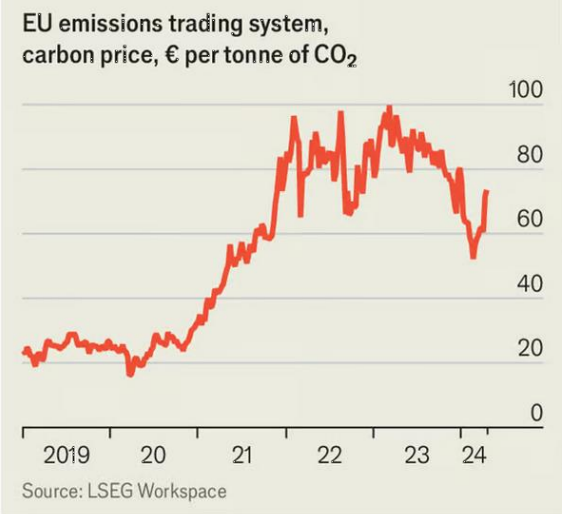


CHART: THE ECONOMIST

3. Measuring and certifying organic carbon storage

Carbon storage as measured and certified in France, for example by the ONF in the case of reforestation, is not affected by the corruption that has been discrediting global carbon markets for years. For example, there have been numerous frauds regarding hypothetical "CO_2 emissions avoided". For example, Kenneth Newcomb, former head of *Sequest Capital*, was indicted in New York in October 2024 for having falsified data on the impact of greenhouse gas reduction in Africa, in order to obtain millions of dollars in carbon credits. Another risk of dysfunction: a region of Brazil or an African country could promise to protect its forests from fires in order to "avoid" CO_2 emissions. This promise would allow it to sell carbon credits to financial companies that are active in this market and therefore collect money now – and yet let the forest burn a decade later!

Carbon credits could also be sold for reforestation, even if the young forest is subsequently poorly maintained and dies during droughts.
Instead of estimating the value of "avoided emissions" or producing fictitious carbon credits, it would be appropriate to precisely measure the organic carbon stored in agricultural soils in Europe in order to restore confidence in carbon credit markets.

3.1 Four methods for measuring organic carbon in the laboratory

Four measurement methods that have existed for decades and are recognized as reliable, to measure the organic carbon content present in a soil.

1) Walkley and Black method

The method is based on the oxidation of potassium dichromate ($K_2Cr_2O_7$) which is catalyzed by an acid. The heat of the dilution increases the temperature to induce an oxidation of carbon to carbon dioxide.

2) Photometric method

Potassium dichromate ($K_2Cr_2O_7$) and sulfuric acid are mixed with the sample. After cooling for 1 hour, distilled water is added. The solution is measured using a spectrophotometer with different concentrations of sucrose solution.

3) Gravimetric method
Soil samples are subjected to calcination for 5 hours at 400°C. Then, the samples are weighed and the difference in mass corresponds to the organic matter of the soil.

4) Dry combustion
Samples are pretreated with hydrochloric acid to remove inorganic carbon. Then, the soil sample (often 30 mg) is placed in a capsule and burned at 975°C. An automatic analyzer with a thermal conductivity detector is used.

The American company Indigo-Ag primarily uses the latter method and obtains results accurate enough to allow it to sell *carbon credits* for farmers.

3.2 Rapid measurement of organic carbon in soil

Several companies and universities in different countries have tested and evaluated a method for rapid measurement of several parameters of agricultural soil fertility, including organic carbon content.[5]

As with laboratory carbon measurements, a soil sample must be taken by coring to a depth of at least 30 cm. When measuring the organic carbon content of a field for the first time, the sample is cleaned of roots and stones before being measured in the laboratory using one of the methods above and then also by a spectrometer.

Figure 8 : Core sampling with GPS position

Figure 9 : Measurement with a visible near infrared spectrometer (VIS-NIR)

The measurement with a spectrometer analyzes the reflection of near-infrared light from the soil sample to detect the amount of organic carbon, mainly composed of lignin. To test two spectrometers, 134 measurement points distributed over three sites were evaluated and compared. They were analyzed both with two spectrometers and in the laboratory, in order to calibrate a model capable of predicting laboratory data from spectral data.

[5] Belgium, Antoine Stevens, *Prediction of soil organic carbon for different levels of soil moisture using Vis-NIR spectroscopy.*
France, INRAE, *Comparison of soil organic carbon stocks predicted using visible and near infrared reflectance (VNIR) spectra acquired in situ vs. on sieved dried samples*; 2019
Publications similaires au Brésil, Canada, Etats Unis, Suisse, etc.

In contrast to the laboratory method, in which soil samples are dried before analysis, field spectroscopy measurements use fresh samples that contain different amounts of moisture. Soil moisture has an influence on the measured spectra, which is why the influence of soil moisture must be removed from the data by calculations using models.

Both spectrometers were tested on farms in Switzerland. After calibration by laboratory analyses of soil samples, both devices gave satisfactory results in predicting soil fertility parameters such as sand, clay, pH value, *organic carbon*, cation exchange capacity, total nitrogen content and available magnesium. [6]

4. How carbon markets work

There are two types of markets: the *mandatory carbon quota* market and the *voluntary carbon credit* market.

The mandatory ***carbon quota market*** only concerns industrial sites that emit the most greenhouse gases, including cement plants, blast furnaces, brickworks, aluminum plants, and all companies with a thermal power greater than 20 MW. Around 10'000 sites are concerned in the European Union. Agriculture is not concerned.

The voluntary ***carbon credit market*** concerns all companies that want to improve their image and avoid being associated with economic players that contribute to climate disasters: airports, chemical companies, data centers, etc.

Since voluntary carbon credit markets suffer from an image of corruption, different organizations have created labels and verification methods. The price of carbon credits often depends on the certification label. The best-known labels are: Bas Carbone (France), Verra, Gold Standard (WWF), MDP.[7] The price of the carbon credit depends partly on the reliability of the label.

Since the EU plans to store 280 million tons of CO_2 per year by 2040 and 450 million tons per year from 2050, the voluntary market for carbon credits is expected to grow considerably and offer opportunities to farmers. Example: Indigo-Ag is a company that certifies the carbon content of soils and sells the carbon credits for the benefit of farmers, taking a commission.[8]

For the steel, concrete and chemical industries, it will be advantageous to buy carbon credits from farmers rather than buying carbon quotas at very high prices! For the steel industry alone, if global warming is to be limited to 2°C, *Wood Mackenzie* estimates the carbon credit market at $250 billion.[9]

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[6] *Source: Swiss Agricultural Research, 10/2023.* Details in the paper: "*The use of visible and near-infrared spectroscopy for in-situ characterization of agricultural soil fertility*" : https://bsssjournals.onlinelibrary.wiley.com/doi/10.1111/sum.12952

[7] https://www.kabaun.com/post/compensation-carbone-standards-labels

[8] The American company Indigo-Ag charges a commission of $10 on a carbon credit worth $40.

[9] https://carboncredits.com/iron-and-steel-industry-buys-250b-carbon-credits-net-zero/

Aware of these problems, the EU has been seeking since April 2024 to regulate and encourage agriculture that stores carbon in the soil.[10]

Farmers have no access to the carbon quota markets, it is reserved for big polluters. Through *France Carbon Agri*, farmers have access to the voluntary carbon market, whose price per ton of CO_2 is much lower. Neither does *France Carbon Agri* measure the organic carbon content of the soil, it only estimates it. **For Conservation Agriculture, this estimate is 3 to 5 times lower than the actual measurements obtained in the laboratory.**

5. Conclusion and Proposals

The European Union has set up a program to finance collaborative projects between farmers, university researchers, citizens, businesses and local authorities. The aim is to show with a flagship project how land quality can be improved, farmer resilience increased and greenhouse gas emissions reduced.[11] We should pay attention to the EU's upcoming calls for projects in this area! **The financial aids are higher than those practiced by the French state and the bureaucratic formalities are simpler.**

5.1 Stages of a Project

1. A university, a company and an agricultural cooperative could develop reliable methods for measuring the organic carbon content of soils: Choice of the laboratory measurement method, choice of the spectrometer, choice of mathematical methods to validate the certification of the organic carbon measurement. The project can be built from the many existing research publications.

2. Then, a company, organization or agricultural cooperative would take soil samples from farmers along with the GPS position of these samples and measure the carbon content. The results should be published and the method be certified.

3. This same company, organization or agricultural cooperative would calculate and certify the gain of soil organic carbon every year. The company or organization should be able to support farmers in its region, including with technical advice to reduce inputs. *France Carbone Agri* supports farmers, but greatly underestimates the carbon storage potential and sells carbon credits after 5 years only. The price is €30 per ha for 5 years. **The incentive for the farmer is marginal. It is therefore necessary to measure the organic carbon rate of the soils in order to be able to certify its real amount and become active on a more lucrative carbon credit market**.

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[10] EU ; Climate Action ; *Carbon Removals and Carbon Farming, CRCF Regulation* https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en

[11] https://mission-soil-platform.ec.europa.eu/living-labs/
https://www.lilas4soils.eu/carbon-farming

4. Then, the company, organization or agricultural cooperative looks for potential customers to sell carbon credits on the carbon credit market for participating farmers. Starting from a price of €200 per ton of carbon (€55 / t of CO_2), the farmer should receive at least 80% of that amount. Since some companies like AMAZON, BCG and others pay $800 per ton of CO_2 stored in the subsoil ($2800 per ton of carbon), the carbon credit certificate for agriculture must be very reliable, also in the long term!

5. **The price difference between *France Carbone Agri* (€30) and *Climworks* ($2800) for 1 t of stored carbon is economically unjustifiable.**[12] As soon as the soil organic carbon measurement system is validated and certified, agricultural organizations should show this inconsistency in the carbon credit market. According to EU forecasts and plans, the demand for carbon storage will increase sharply. Farmers practicing SCA should be the biggest beneficiaries.

This conclusion assumes that humanity wants to limit global warming to 2°C. If humanity uses all available fossil fuels without storing billions of tons of carbon, it will cause global warming greater than 3°C. At 3°C of global warming, land areas will warm by 5°C and major cities by 8°C. Hot and densely populated countries like India, Pakistan, Sudan and others will become uninhabitable for several months each year, creating hundreds of millions of climate refugees. 10 million buildings in France will have cracked foundations (swelling - shrinkage of the clay), the repairs of which would cost 1000 billion euros. These are just two of the countless consequences.
It is preferable to pay farmers properly to store billions of tons of carbon in the soil, rather than emitting billions of tons as they do today.

[12] The CO2 captured by Climworks should be used to produce synthetic kerosene (e-methanol) for long-distance aviation and long-distance container ships, for which no other carbon-neutral technical solution exists! From the point of view of the post-oil society, storing pure CO_2 underground is a terrible system-error.