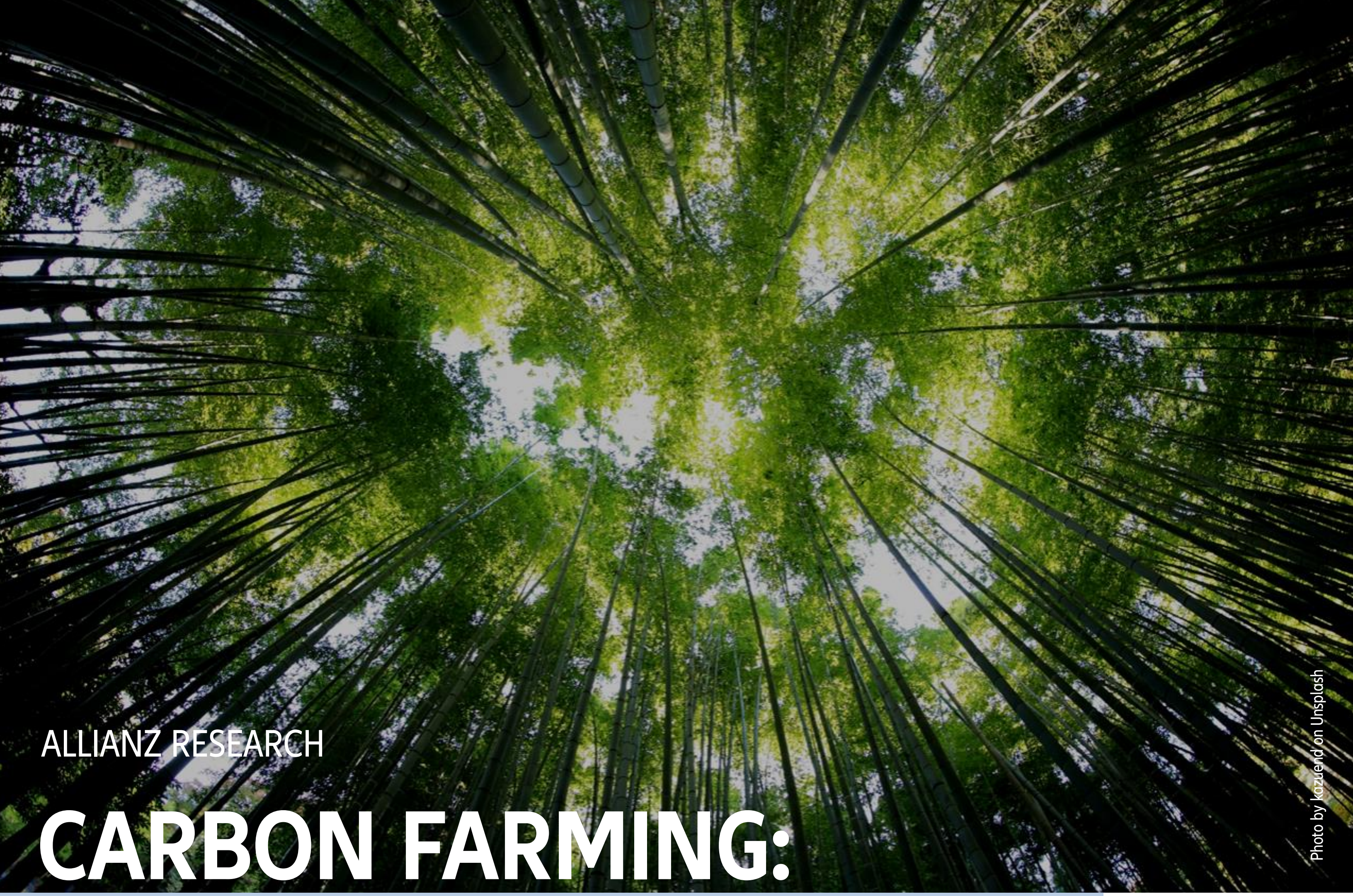

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ALLIANZ RESEARCH

CARBON FARMING: A TRANSITION PATH FOR AGRICULTURE & FORESTRY

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EXECUTIVE SUMMARY

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The agriculture and forestry sectors are at the frontline of climate change. Research shows that in the last 50 years, severe heatwaves and droughts have already caused crop losses to triple in the EU. With an increasing risk of extreme weather conditions and drought, by 2050, climate change could further drag down corn yields by up to -22% across the region, and wheat yields by up to -49% in southern Europe. This highlights the vulnerability of our food system to climate change, and why adaptation is needed to make it more resilient.

The two sectors are also both significant sources and sinks of greenhouse gas (GHG) emissions. In 2019, agriculture and forestry accounted for 1.5% of EU GDP[1]. However, agriculture alone was responsible for around 11% of total GHG emissions in the EU, amounting to 386Mt CO2-eq[2] of non-CO2 emissions such as methane and nitrous oxide, mostly from livestock and mineral fertilizer use, respectively. In fact, the agriculture industry was the largest sectoral source of these emissions. In addition, forestry and land use change was responsible for another 118Mt CO2-eq of GHG emissions. At the same time, agriculture and forestry also play a significant role as carbon sinks: forests can remove CO2 from the atmosphere and store it as biomass. In 2019, land use and land use change and forestry (LULUCF) removed about 368 Mt of CO2, resulting in a net emission of 137Mt CO2-eq for the whole sector.

In this context, the EU seeks to strengthen its terrestrial carbon sink and boost adaptive farming practices to make both sectors more resilient. The EU's proposed Fit for 55 package outlines two key objectives for the land-use sector: The annual net removal should reach 310 Mt CO2 by 2030 and, by 2035, agriculture, forestry and land use combined should achieve complete climate neutrality. To support these objectives, at least 10 EU strategies exist with their own sub-targets, which propose various adaptive farming and forestry practices to build sustainability in the sectors, including cover cropping, crop rotation, precision farming, organic farming, agroforestry, integrated pest management, the use of adapted crops, climate-smart silviculture, low/no tillage and polyculture.

However, to comply with the 1.5°C goal, the EU needs total investments of EUR185bn and an annual investment gap of EUR8.3bn needs to be filled. Projected investment until 2030 ranges around EUR240mn per year, but it needs to be increased by another EUR30mn per year to achieve the 1.5°C ambition. This is still low compared to the 2030-50 period. After 2030, investments need to see a massive increase to EUR760mn to meet the basic ambition of the EU's Ff55 proposal. Assessing the necessary increase to enhance the ambition to 1.5°C in the 2030-50 period suggests that an average of EUR9.1bn per year should be invested; this gives us the whopping shortfall of EUR8.3bn per year.

Looking ahead, a new results-based approach proposed with carbon farming is expected to take off in the next decade, boosting the carbon sink and incentivizing land managers. The EU plans to propose a regulatory framework for the certification of carbon removal by the end of 2022, which could essentially lead to the creation of an EU-regulated carbon market and further incentivize land managers to adopt more resilient practices. The objective is for each land manager to have access to verified emission and removal data by 2028, with the potential for carbon farming initiatives to remove at least 42 Mt of CO2-eq by 2030 (contributing to the overall net removal target of 310 Mt CO2-eq).

1 https://ec.europa.eu/eurostat/documents/3217494/12069644/KS-FK-20-001-EN-N.pdf
2 https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en
Note: 1 Mt CO2-eq = 1.000.000 t CO2-eq = 1.000.000.000 kg CO2-eq

Agriculture and land use – a GHG source & sink...

386 Mt CO2eq
Agriculture

118 Mt CO2eq
Land use

-368 Mt CO2eq
Land use carbon sink

GHG emissions across the EU agriculture & land use in 2019

368 Mt of CO2-eq
Removed from atmosphere by forestry in 2019....

137 Mt of CO2-eq

More CO2 was removed than emitted in LULUCF*

...looking forward to carbon farming and an EU-regulated carbon market

Fit for 55 proposes overall objectives of

- **Removal of 310 Mt CO2-eq each year by LULUCF* by 2030**
- **Achieve net neutrality in land sectors (AFOLU**) by 2035**

... proposing adaptive practices for a more resilient farming & forestry sector:

Crop rotation	**Use of adapted crops**	**Polyculture**
Cover cropping	**Climate-smart silviculture**	**Agroforestry**
No-tillage	**Precision farming**	**Organic farming**

And don't forget about carbon farming

42 Mt of CO2-eq
To be removed by 2030, via:

- **Afforestation**
- **Restoring peatlands**
- **Agroforestry**
- **Adaptive farming practices**
- **Cropland to grassland conversion**

Levers to boost carbon farming:

EU-regulated carbon removal certification scheme by **2022**

€60/tCO2 Carbon price to enhance carbon sink by 124 Mt

Share of funding from Common Agriculture Policy for climate measures **40%**

The EU's creation of their own monitoring, reporting and verification of carbon credits opens the opportunity for their own compliance market, as the UNFCCC phases in the new Sustainable Development Mechanism.

Feeling the first effects of climate change

Expected impacts from climate change across the EU:

- Extreme weather
- Resource scarcity
- Biodiversity loss
- Sea-level rise

This could result in a **general decline of most crop yields,** up to 22% for corn in the EU and up to 49% for wheat in Southern Europe.

Investment needs

To meet the 2030 and 2050 targets, substantial investments are still required to close the ambition gap

	2020-2030	2030-2050
Total investment	€2.67 bn	€181.84 bn
Total Investment (p.a.)	€0.27 bn	€9.09 bn

**Land-use, land-use change, forestry; **Agriculture, forestry & land use*

AT THE FRONTLINE OF THE CLIMATE CRISIS

Agriculture is essential to our lives and is arguably the foundation of our civilization. Throughout history, civilizations have risen (and fallen) based on their agricultural productivity and land management. Across the EU-27, agriculture dominates land use, covering an average of around 39% of the EU's total area, followed by around 35% for forestry in 2018[3]. The agriculture and forestry sectors also supported around 10mn jobs in 2019 and accounted for around 1.5% of the EU's GDP.

However, these sectors are also most under threat from the impacts of climate change, given their sensitivity to weather patterns. Higher temperatures and carbon dioxide concentrations, uncertain rain patterns and the greater frequency of extreme weather events are all on the rise – key ingredients for creating volatility.

Across the EU, the following effects are expected:

- Mediterranean region – Portugal, Spain, Italy, Greece, Croatia
  - ⇒ Increase in heat extremes, drought, biodiversity loss, water demand
  - ⇒ Decrease in precipitation, crop yields
- Continental region – Germany, eastern France, the Czech Republic, Poland
  - ⇒ Increase in heat extremes, river floods
  - ⇒ Decrease in summer precipitation
- Atlantic region – Western France, Belgium, Netherlands, Northern Germany, UK
  - ⇒ Increase in heavy precipitation events, risk of river/coastal flooding, damage from winter storms
- Boreal region – Sweden
  - ⇒ Increase in heavy precipitation events, precipitation, damage from winter storms, lower crop yields
- Mountain regions – Norway, European Alps (Switzerland, Italy, Austria), Northern Hungary
  - ⇒ Larger temperature increase than EU average
  - ⇒ Upward shift of plant and animal species
  - ⇒ Increase in hail risk, risk from rockfalls and landslides

The productivity of our current food system is dependent on ideal amounts of sun, water and nutrients that allow our crops to flourish, and the yields from EU agriculture contribute significantly to the global food supply. It is estimated that EU farmers produce one eighth of the global cereals output, two thirds of global wine production and three quarters of the world's olive oil. EU agricultural exports topped EUR324.8bn in 2019 and accounted for 8% of total EU international trade[4]. But as climate conditions change, productivity will change, too, albeit mostly in a negative way. On a global scale, a recent study[5] observed that based on the current climate change prospects, corn yields could decline by as much as -24% by 2030. The yield projections for soybeans and rice suggest that they will also decline in some regions. Meanwhile, wheat could grow as much as +17% globally as its growing region is being expanded into higher latitudes with a warmer climate. For Europe, the projections are similar[6]: corn yields are expected to decline by up to -22%, while wheat yields in Northern Europe could experience some productivity gains as the ideal growing climate shifts north. Yields could decrease by -49% in Southern Europe (mostly due to the limited availability of water that the region is expected to experience under a changing climate).

3 IMF (2021): World Economic Outlook database, October 2021.

4 Source : Agriculture, forestry and fishery statistics, EUROSTAT (2020).

5 Source: Jägermeyr, J., Müller, C., Ruane, A.C. et al. Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nat Food 2, 873–885 (2021). https://doi.org/10.1038/s43016-021-00400-y

6 Source: Analysis of climate change impacts on EU agriculture by 2050, JRC (2020)

Box: Will climate change benefit some crop yields?

For the most part, the impacts of climate change are expected to negatively affect the yields of most crops, but this is not the case for a few. The process of photosynthesis uses CO2 and water to make energy, which begs the question: Does this mean that increased levels of CO2 mean more photosynthesis, resulting in higher yields? The answer is yes and no. As with soils, not all photosynthesis are created equal. There are different types of photosynthesis. Most plants are C3 type photosynthesis plants (including rice, wheat, oats, barley, cotton, soybeans), while C4 plants (which include corn, sugarcane, sorghum) are a unique minority that are most adapted to higher temperatures and drier climates. What is important is that C3 plants are limited by CO2, which means that higher concentrations in the atmosphere will result in more growth and yield[7], albeit in a limited way. On the other hand, higher CO2 concentrations do not have any significant results on C4 plant yields because this type of photosynthesis is not limited by CO2. As temperatures rise in northern latitudes, the area that C3 plants (e.g. wheat) can grow in is expanded. In addition, the higher CO2 concentrations in the atmosphere are favorable for them. This can partially explain why wheat yields are expected to increase in the coming years, though these benefits are not expected to last. Under higher CO2 concentrations, nitrogen now becomes the limiting factor in yield growth for C3 plants. To sustain the benefits of increased growth, it is likely that higher soil nitrogen concentrations will be needed, most likely in the form of fertilizers, which if in synthetic form are not completely sustainable, especially if used improperly.

These impacts are highly dependent on geography, but local impacts will resonate globally. Because of the industrialized nature of our agriculture system, disturbances that affect certain locations can rock the global market. For example, at this moment, cash crops in the US (corn, soybean, wheat) are taking a hit due to extreme drought and heat conditions, pushing up global wheat prices by +12% and corn prices by +11%[8]. In the EU, a study found that in the last 50 years, severe heatwaves and droughts have caused crop losses to triple. This highlights the vulnerability of our food system to climate change, and why adaptation is needed to make it more resilient.

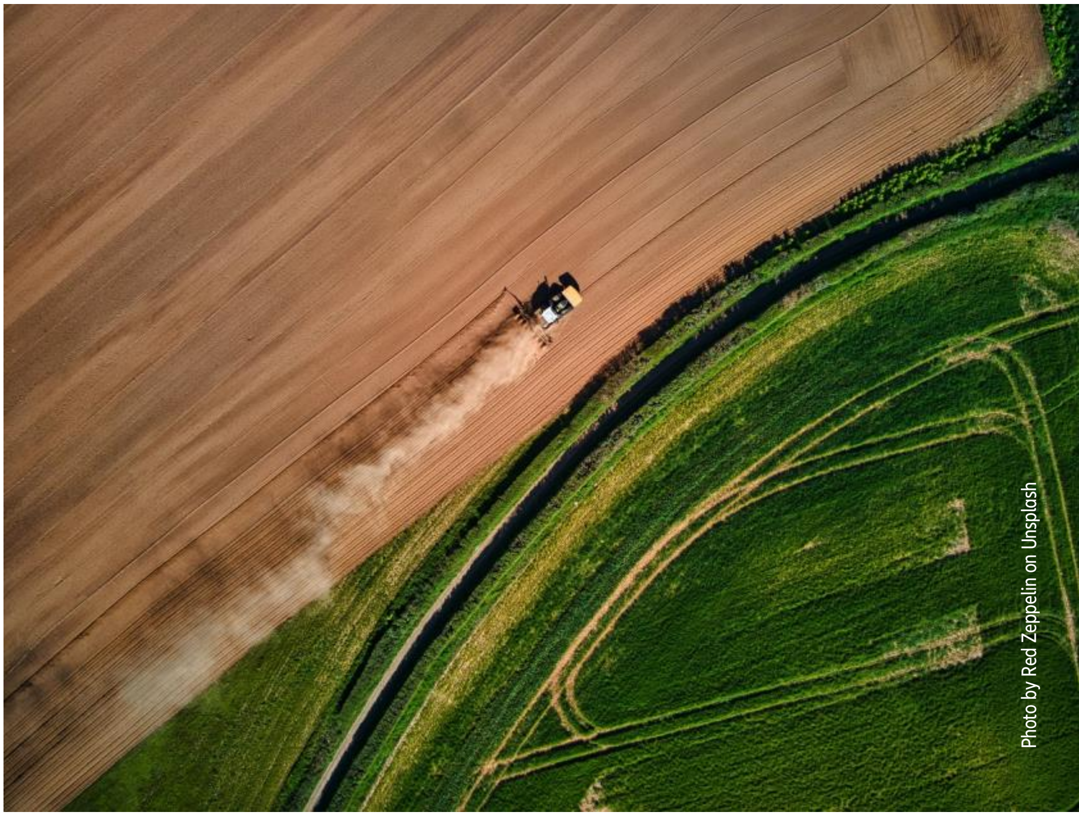


Photo by Red Zeppelin on Unsplash

7 *Source: Taub, D. (2010). Effects of rising atmospheric concentrations of carbon dioxide on plants. Nature Education Knowledge, 1(8).*

8 *Source: Farm Policy News (2021)*

A NATURAL SOURCE OF AND SINK FOR GHG EMISSIONS

The question of adaptation is particularly relevant for the agriculture and forestry sectors because they are both a source of and sink for greenhouse gas (GHG) emissions. In the EU-27, farm-gate emissions are responsible for 11% of total emissions (excluding LULUCF). The agriculture industry is also a major source of non-CO2 GHG emissions, such as methane (CH4) and nitrous oxide (N2O), which have a higher global warming potential[9]. From a sector standpoint, agriculture has always emitted the largest share of non-CO2 GHG and, in 2020, agriculture led emissions, with 383mn tons CO2-eq, followed by energy (149mn tons), waste (150mn tons) and industry (27mn tons). Approximately 59% of EU methane emissions are anthropogenic (caused by humans), with agriculture leading with a share at 53%, sourced from livestock (enteric fermentation, 80.7%), manure management (17.4%) and rice cultivation (1.2%). Meanwhile, N2O is mostly sourced from agriculture as well from the (improper) use of mineral and organic fertilizers.

Perhaps the most unique aspect of the agriculture and forestry sectors is that they are not only a significant source of emissions, but also a natural sink for GHG emissions – meaning that more emissions are removed from the atmosphere than released. Land use, land use change and forestry (LULUCF) – referring to how we use and manage land (whether it is for agriculture, forestry or settlements) – largely determines the amount of emissions released or removed from the atmosphere.

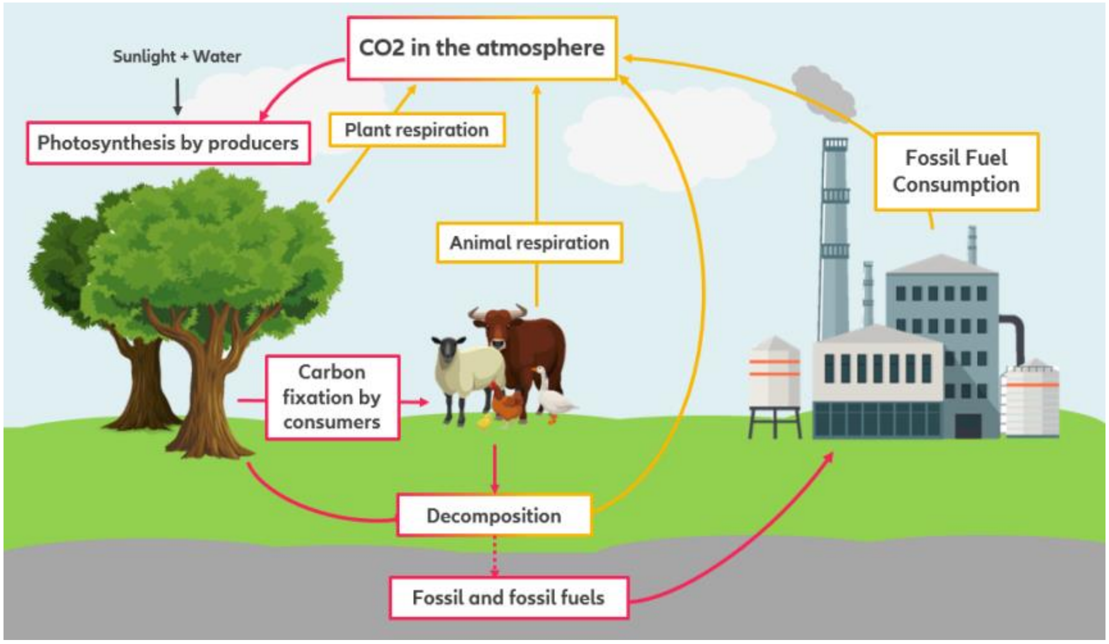
To best understand the concept of a carbon sink, it helps to look at the (terrestrial) carbon cycle (Figure 1). Starting with photosynthesis, plants take in carbon dioxide (CO2) and water and use it to produce sugar and oxygen. Once this CO2 is captured by plants, it is then stored in their biomass (leaves, stem, roots etc.). Biomass is the first place that carbon can be stored over the long term, like forests or grasslands. Once carbon is in plant biomass, it can then transfer to the soil via the decomposition of dead matter or via nutrient exchange in the roots.

Soil is the second place that it can be stored over the long term, but not all soil is equal: they come in many different shapes, sizes, colors and characteristics. The two main types of soil that play an important role in carbon sequestration are organic and mineral soils. Organic soils, which include peatlands/wetlands, have a high carbon content (at least 20%) and are thought to cover 8% of the EU land area. Their waterlogged conditions prevent microbial decomposition; therefore, the soil's organic carbon stays put and is not released into the atmosphere. But they are currently under threat of being drained to use for settlements or agricultural land. Once drained, microbial decomposition is activated, and the soils begin to release their stored carbon into the atmosphere. It is thought that these drained soils currently emit approximately 5% of the EU's total GHG emissions.

The second soil type, mineral soils, is generally what is thought of in terms of agricultural land. Mineral soils have carbon content below 20% and are what you'd call the "black gold" of farming – high soil organic matter (SOM) and carbon content means healthy soil, which means healthy plants (and consequently higher yields). When soil lacks SOM and carbon, synthetic fertilizers must be applied to cover for the lack of nutrients. Unfortunately though, most mineral soils have low SOM, resulting from years of unsustainable farming practices, which reinforces the dependence on synthetic fertilizer application. It is thought that each year this has caused around 7.4mn tons of carbon to be lost from mineral cropland soils.

9 *Over a 100-year time period, CH4 is a global warming potential of 27.9, while N2O has a global warming potential of 273 by the IPCC AR6. .*

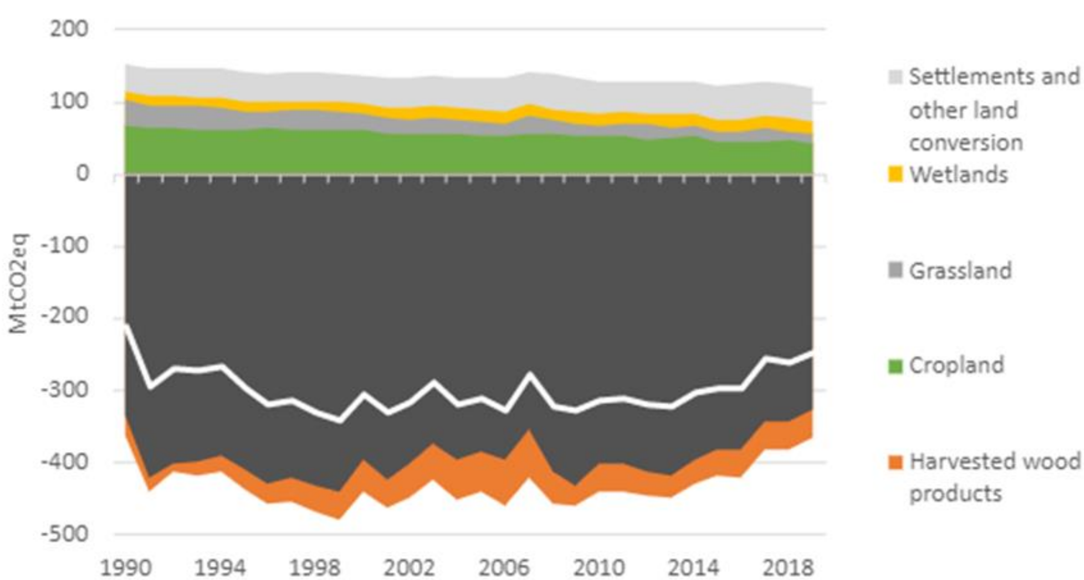
Figure 1: Carbon cycle



Source: Allianz Research

In 2019, LULUCF was responsible for around 118mn tons of CO2-eq emissions, but a total of 367mn tons of CO2 emissions were removed, resulting in a net sink effect of 249 million tons of CO2-eq emissions (i.e. LULUCF acts as a net sink of -7%). Forest coverage is the EU's largest natural sink, having removed approximately 329mn tons of CO2 emissions out of the atmosphere in 2019 (Figure 2), and is largely responsible for determining the net-sink result each year.

Figure 2: LULUCF GHG emissions and carbon removals 1990-2019 in the EU-27

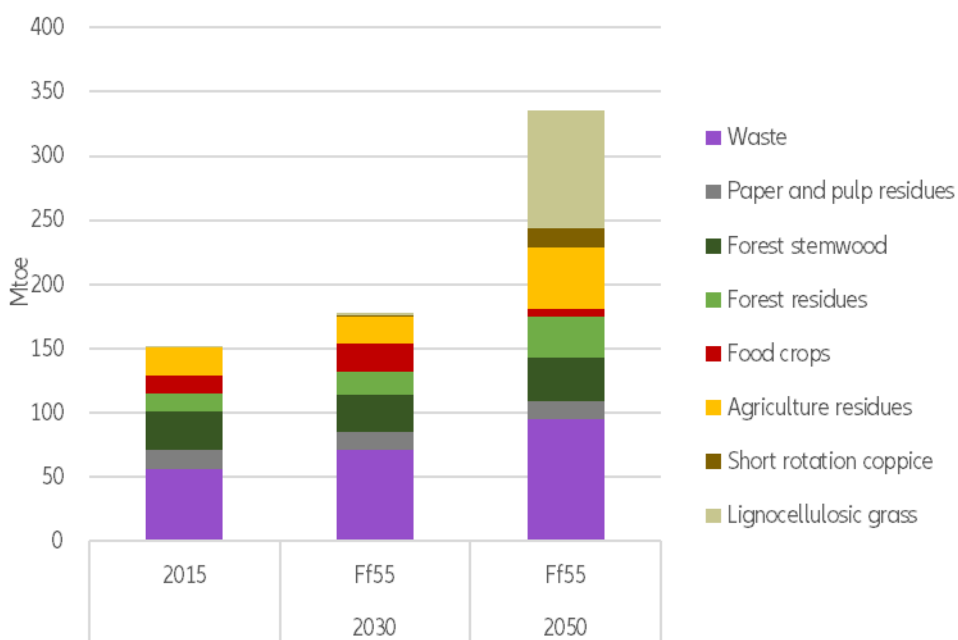


Source: Allianz Research, European Environment Agency

A Rising demand for bioenergy feedstock: Unlike wetlands and conversion for settlements, LULUCF emissions across grassland and cropland have shown a continuous decrease since the beginning of the millennium. However, this could change as the demand for biomass to be used for bioenergy increases. Until 2050, production of bioenergy feedstock is expected to more than double to 300 Mtoe. By sector, bioenergy demand is expected to be driven by power generation and residential heating. By 2050, the demand coming from the transport sector is not expected to be more than 20% of the total. Based on the EU's Fit for 55 scenario, 93% of all bioenergy demand will be met domestically, also adding to supply security and independence from imports.

From a forest perspective, production has increased by about 200mn cubic meters since 1990 without significant impact on the forest sink, although it is thought that the limited decline that was observed over recent years was due to pests, wildfires and more intensive harvesting activities. Currently, though, forests (stem wood and residues) represent a minority share in bioenergy feedstocks (30%) and their share is expected to decrease to 19% by 2050 (although their absolute value will continue to increase, from 45 Mtoe in 2015 to 65 Mtoe in 2050). Instead, the feedstocks that will expand most include waste, agricultural residues and lignocellulosic grass (Figure 3). As expected, food crops as a feedstock are expected to decline (both in absolute and relative values) to only 2% of feedstock by 2050.

Figure 3: Breakdown of bioenergy feedstocks



Source: Allianz Research, European Commission

The build-up of lignocellulosic grasses as a bioenergy feedstock is welcome. Lignocellulosic grass refers to the dry matter once it has been cut. What is beneficial about this source is that grasses can be grown on a wide range of land, including those in poor condition and not suitable for crops. They are also better at preventing soil erosion and require few inputs compared to row crops. The most beneficial aspect, though, is their potential to become a net carbon sink instead of currently being a net emitter. Trees store most of their carbon in their biomass above ground, while grass stores its carbon underground in its roots. Therefore, grasslands can play a role as a carbon sink and bioenergy feedstock seamlessly, and perhaps even perform better than forests in regions with increased fire risk. A study by UC Davis found that grasslands were better performing and more resilient carbon sinks than forests in California because they are less affected by droughts and wildfires, which are expected to increase in frequency and severity because of climate change. In the EU, the use of grasslands rather than forests as carbon sinks is especially applicable in the Mediterranean region, where fire hazards have increased over the last few years. Nevertheless, all EU countries could benefit from grassland carbon sinks as fire risk increases with rising temperatures and more frequent droughts.

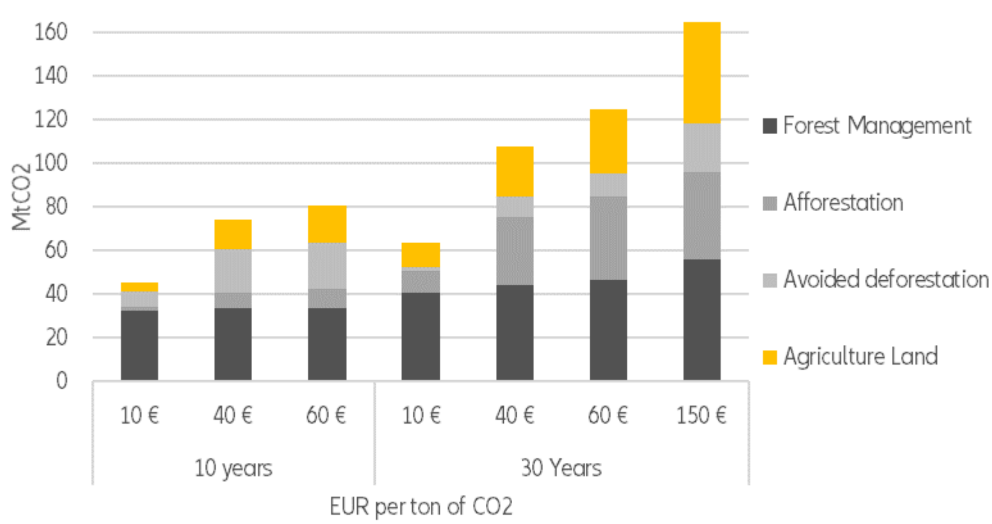
Photo by Daiga Ellaby on Unsplash

IMPROVING THE SINK CAPACITY

The EU's climate neutrality pathway will require a substantial amount of carbon dioxide removal (CDR), with both nature-based and technological solutions applied. By 2050, it is estimated that 424mn tons of CO2 or more will need to be removed each year by the land-use sector, which is way beyond the current sink values (a low of 249 tons in 2019).

As one of the largest natural carbon sinks, forest resource management plays a key role in influencing the overall sink function. In an analysis of the LULUCF sink enhancement, a carbon price of EUR60 per ton of CO2 would result in a sink enhancement of almost 80mn tons by 2030, split between forest management (34 Mt), avoided deforestation (21 Mt), agriculture land (17 Mt) and afforestation (8 Mt). By 2050, assuming the carbon price remains at EUR60 per ton, the total sink enhancement would increase to 124 Mt, most notably from new, mature forests that were planted by 2030, in addition to the existing old-standing forests (Figure 4). This could enhance the EU MIX scenario carbon sink in 2050, from forests, from 279mn tons to 403mn tons, but it is still short of the 424mn tons needed (The EU MIX is included in the EU assessment of the EU Ff55 proposal and is commonly used as the representative scenario for the expected EU Ff55 pathway).

Figure 4: Potential LULUCF sink enhancement, by carbon price



Source: Allianz Research, European Commission

The Annex includes the underlying analysis, which shows the potential for enhancing the LULUCF sink at different carbon prices in the long run. A CO_2 price of EUR150 in 2050 could increase the forest sink by 118 MtCO_2 and the total LULUCF sink by 165 MtCO_2, compared to a situation without a CO_2 price for the LULUCF sector. With a CO_2 price of EUR70, the total LULUCF sink could already exceed 130 MtCO_2. While these sinks are relatively large compared to emissions by 2050, they are small compared to current emissions, underscoring the need to reduce emissions first. The greatest potential lies in optimizing forest management practices (changes in stand rotation length, ratio of thinning to final harvest, harvest intensity or harvest locations) and could increase the forest sink by 56 Mt CO_2. Improving agricultural practices to store more carbon in the soil would increase the LULUCF sink by an additional 47 Mt CO_2. Incentives for additional reforestation could remove 40 Mt CO_2 from the atmosphere annually, which would require converting about 5 Mha of land to new forests by 2050. Finally, avoided deforestation can add another 22 Mt CO_2 to the annual carbon sink potential.

For agricultural land, there are several strategies across the EU that work together to reduce emissions and enhance the carbon sink potential, such as the Soil Strategy for 2030, Farm to Fork Strategy, Biodiversity Strategy for 2030 and the Common Agricultural Policy (CAP) framework.

The first, the EU Soil Strategy for 2030, was introduced in 2021 to contribute to the objectives of the EU Green Deal and Ff55 proposal of helping achieve a net GHG removal of 310 million tons CO_2-eq per year. Some other objectives of this strategy include combating desertification through soil restoration, achieving no net conversion of land for settlements by 2050, reducing nutrient losses and chemical pesticide usage by 50% by 2030 and achieving land-based climate net neutrality by 2035. For agriculture use, sustainable soil-management practices will play a key role, such as minimizing soil erosion, building SOM, mitigating soil compaction and improving soil water management.

Photo by Chris Ensminger on Unsplash

Next, the Farm to Fork Strategy outlines how the EU will overhaul its food system from farming to consumption. It includes specific 2030 targets as well, such as reducing chemical pesticides and nutrient losses by 50%, reducing fertilizer use by 20%, reducing the sale of antimicrobials for farmed animals by 50% and increasing the share of organic farming to at least 25% of agricultural land. From the consumer standpoint, there are also objectives in this strategy to develop a sustainable food labelling framework that addresses the nutritional, social and environmental aspects of food products, as well as proposing legally binding targets to reduce per capita food waste by 50% at the retail and consumer levels.

The EU Biodiversity Strategy has the following objectives by 2030: establishing protected areas for at least 30% of land and sea in the EU; promoting biodiverse landscape features and halting and reversing the decline of pollinators (e.g. reducing pesticide use by 50%); restoring at least 25,000km of EU rivers to a free-flowing state and planting 3bn trees. It should be kept in mind that land conversion (e.g. for settlements), deforestation and current practices in livestock farming are larger threats to European biodiversity than climate change[10].

Although many of these strategies and targets overlap and interplay, there are several adaptive practices on a farm level that will help the agricultural and forestry sector weather the impacts of climate change (Table 1, opposite).

Photo by Elaine Casap on Unsplash

10 https://ec.europa.eu/environment/nature/conservation/species/redlist/trees/summary.htm

Table 1: Benefits of alternative, more adaptive and sustainable agriculture/forestry practices

Adaptations	**Description**	**Benefits**
Crop rotation	Growing different types of crops each year on the same land.	Enhances biodiversity and soil nutrient management (reducing use of fertilizer and pesticides).
Cover cropping / mulching	Crops that are planted between growing seasons of a cash crop, which cover the soil.	Enhances biodiversity and soil nutrient management (reducing use of fertilizer and pesticides), prevents soil erosion, can attract beneficial insects / pollinators.
Polyculture / intercropping	Growing different types of crops on a single piece of land in close proximity, for example planting rows of different crops side-by-side.	Reduces use of pesticides and herbicides by preventing the spread of pests/diseases, increases soil fertility (reducing use of fertilizers), can attract beneficial insects / pollinators.
No or minimum tillage	Minimizing soil disturbance by leaving the crop residue on the soil's surface and, ideally, depositing seeds directly into the soil.	Reduces soil erosion, enhances soil microorganism biodiversity and soil nutrient management (reducing use of fertilizes), increases soil moisture.
Integrated pest management	An ecosystem-based strategy that focuses on the long-term prevention of targeted pests by using biological control, habitat manipulation and modifying practices. Seeks to promote beneficial organisms and only target harmful pests.	Enhances biodiversity (avoids / reduces use of pesticides, insecticides).
Agroforestry	Intentional integration of trees / shrubs into crop and animal farming systems.	Enhances soil nutrient management (more efficient nutrient recycling by trees), reduces soil erosion and nutrient leaching, enhances biodiversity (attracts pollinators), increases diversification.
Organic farming	Using organic (not synthetic) fertilizers and inputs.	Reduces use of synthetic pesticides, herbicides and fertilizers, builds soil organic matter and carbon, making soil more resilient and fertile.
Precision farming	Using on-farm modern technology (E.g. satellite data and tools for precision navigation) to increase the efficient use of inputs like water, fertilizers and pesticides.	Increases efficiency of inputs, reduces use of pesticides, herbicides and fertilizers, reduces waste.
Use of adapted crops	Introducing crops that are expected to be more resilient to changing climate conditions. In forestry, examples include searching genetic pools for species that are resistant to certain pests or more resilient to drought stress.	Reduces the impact of extreme weather risks, can increase biodiversity and genetic diversity of species.
Close-to-nature silviculture or climate-smart silviculture	Promotes natural or site-adapted tree species, mixed forests, diverse stand structures, natural regeneration, clear-cut avoidance.	Increases forests' resilience to climate change impacts (drought, fire, extreme weather events), increases productivity, enhances biodiversity, decreases susceptibility to pests and diseases compared to "plantation" or even-aged silviculture.

Box: Forget the fertilizers – the power of soil microorganisms

In modern agriculture, the two most common mineral fertilizers applied are for nitrogen and phosphorous. Both of these nutrients are considered limiting nutrients, which means that plant growth and yields are limited by the availability of those nutrients. But their application is not always beneficial – mineral fertilizers are a significant source of non-CO2 emissions, especially mineral nitrogen fertilizers and N2O, and manufacturing them is very energy-intensive. But the good news is that their application can be reduced by relying on the natural relationships between plants and soil microorganisms.

For nitrogen, cover cropping and crop rotation are supposed to be key agricultural practices to boost carbon storage in the soil but they can also lead to higher yields with fewer inputs. How can this be? The answer lies with legumes, which are a type of plant family that includes beans, peas, lentils, alfalfa, clover and soybeans. Legumes have an advantage over other crops: they can form symbiotic relationships with soil bacteria called rhizobacteria in order to "fix" nitrogen, which is the most common, limiting nutrient to plant growth and yield. There is plenty of nitrogen around us in the atmosphere as N2 but this form is not available for plants to use. This is where nitrogen-fixing bacteria step in: rhizobacteria can take nitrogen from the air and convert it to a usable form for plants (NH3, ammonia). Normally the bacteria population is too low to maximize nitrogen fixation but with legumes, they form "nodules" on the roots of legume. The legume feeds the bacteria glucose (carbon), while the bacteria feed the legume nitrogen, which is stored in the root nodules. Once the legume is harvested or dies, the stored nitrogen is released back into the soil, available for use by the next crop, such as corn or wheat. Cover cropping or crop rotations with legumes have shown the ability to lower emissions of CO2 and N2O compared to conventional agriculture that depends on mineral N fertilization, besides building soil organic carbon and reducing overall (fossil energy) inputs into the soil – all while increasing yields, too[11]. In fact, it was found that in temperate environments in Europe, crop yields were on average 17-21% higher in grain-legume systems than wheat mono-cropping.

For phosphorus, power is found in mycorrhizal fungi rather than bacteria. In agricultural soils, phosphorus is easily depleted in the root zone and even when it is present, it is found in very low concentrations and is generally immobile, meaning that it is not taken up by the plants very easily (or efficiently). This can be improved by mycorrhizal fungi, which form symbiotic relationships with all types of plants and trees. In this relationship, the plant exchanges sugar/glucose with the fungi and the fungi provides improved water and (phosphorus) nutrient absorption. In agricultural soils, 50m of mycorrhizal fungal networks (called hyphae) have been found in 1g of soil and their large networks offer plants an extended "reach" into areas that are otherwise inaccessible by the plant. The benefits of mycorrhizal fungi are plentiful but soil disturbances, such as conventional tillage, destroy fungal networks and diversity[12], which is why it is important to keep such disturbances to a minimum to allow these natural relationships to flourish.

In addition to implementing new agricultural practices, the role of technology is also increasing for farm and forest managers. For example, in forestry, decision-support systems (DSS) have emerged. These are database / modelling systems that help forest managers perform adaptation, mitigation and risk analysis of their forests. DSS help managers make informed decisions about how climate change will impact their operations, including what types of tree species would perform best under the expected future climate conditions for their sites. In both forestry and farm operations, drones or unmanned aerial vehicles (UAVs) are also gaining popularity. UAVs are an innovative risk-management tool for forestry as they can detect and map damages to forests (either from pests or weather disturbances). Other technologies in forestry also include camera sensors, which are used for the early detection of forest fires.

Similar technologies are also being applied to farming. Precision farming, mentioned above, uses technological solutions to monitor crop growth, as well as field conditions such as moisture and nutrient levels. For example, the use of crop and optical sensors can help apply fertilizers or other inputs in an effective manner, targeting specific areas where it is needed (reducing widespread application), as well as maximizing uptake. Remote sensing technology is also a rapidly expanding practice in agriculture, whereby drones are used to map land and can even be used to detect signs of malnourishment or drought even before physical signs begin to show on plants.

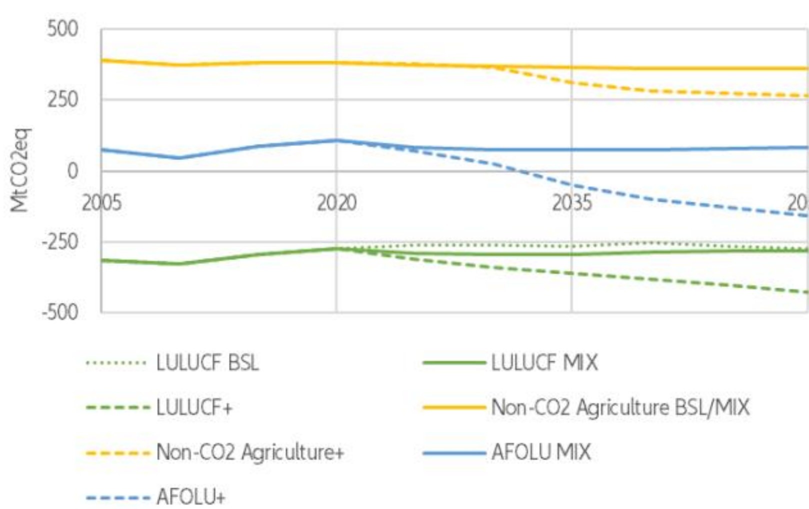
11 Source: Stagnari, F., Maggio, A., Galieni, A. et al. Multiple benefits of legumes for agriculture sustainability: an overview. Chem. Biol. Technol. Agric. 4, 2 (2017). https://doi.org/10.1186/s40538-016-0085-1

12 Source: Kabir, Z. (2005). Tillage or no-tillage: impact on mycorrhizae. Canadian Journal of Plant Science, 85(1), 23-29.

REDUCING EMISSIONS

To be compatible with a 1.5°C ambition, it is not enough to only increase carbon sinks. Emission reduction – and in particular of non-CO2 GHGs – is also required. In fact, starting in 2031, LULUCF carbon sink calculations will also include non-CO2 emissions from agriculture (CH4, N2O). To incentivize and drive down emissions of non-CO2 gases, a climate neutrality target of all GHG emissions by 2035 has been introduced, which includes LULUCF and non -CO2 agricultural emissions. Figure 5 shows the development paths in the EU baseline scenario (BSL), the EU MIX (MIX) scenario and the EU PLUS scenario (+), representing the pathways for enhancing carbon sinks to a 1.5°C compliant level. The BSL scenario sets our starting point to determine the investment requirements and the EU MIX scenario represents the policy ambition that is currently to be expected. The enhanced pathways "Non-CO2 Agricultural+" for emissions, "LULUCF+" for CO2 sinks and the sum of both represented by "AFOLU+" for net emissions show that removals and emissions would need to cancel out (or reach "no debits" in the EU terminology) just before 2035 and that sink capacity would need to continue to steadily increase to deliver "net credits" in subsequent years. Central to the current discussion on CO2 removals at the EU level is the design of accounting and trading for associated CO2-removal activities, which would likely require national approaches to setting targets and detailed analysis taking into account differences in the geographic distribution of removals and emissions, including these from non-CO2 emissions.

Figure 5: AFOLU+ emissions in the EU MIX scenario*



** The AFOLU line is the sum of the non-CO2 agriculture emissions as in the MIX scenario and the LULUCF sink projected without additional incentives to enhance the LULUCF sink in MIX. AFOLU+ includes additional action to enhance the LULUCF sink (LULUCF+). Source: Allianz Research, EU 2030 Climate Target Plan*

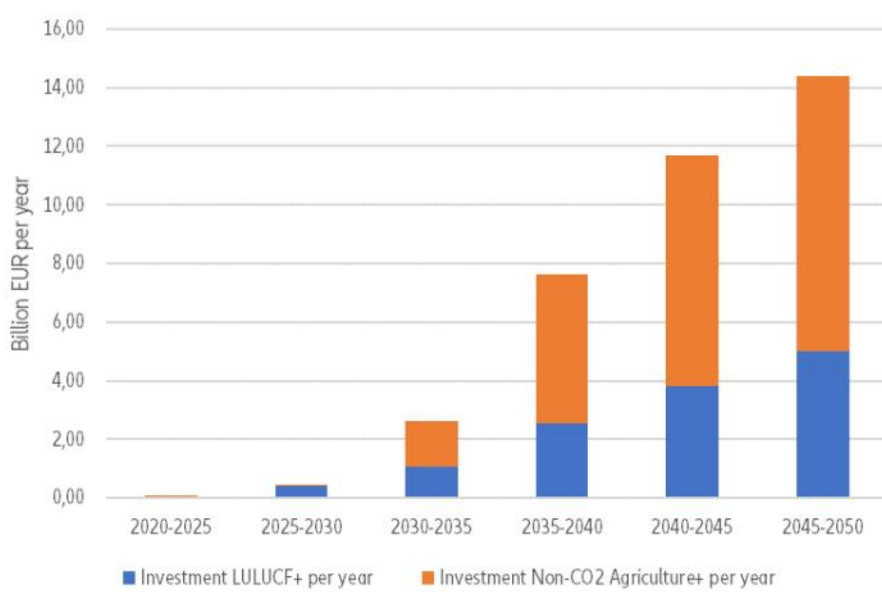
The enhanced pathways require additional investments. Figure 6 shows the gradual increase in associated investment needs, derived from the EU assessment of marginal abatement costs for agricultural emissions and carbon sink enhancement costs, as described in the Annex. The investments increase from an average of EUR460mn per year in 2025-35 to an average of EUR14.4bn per year in 2045-50, with about two thirds of the investment needs originating from non-CO2 GHG abatement and one third from enhancing carbon sinks.

The financial incentive policy instruments designed to change practices in forestry and agricultural would mean that uses for the associated biomass products (wood, pulp and paper, fabrics, advanced biofuels etc.) would face new economic competition. In addition, the conservation of carbon stocks in the sector (increasing the sink through the avoidance of emissions rather than improved forest management) could be upgraded, with potential positive side effects for biodiversity and the other ecological functions of existing forests. Policies should also consider the resulting risk of changes in supply chains that may drive imports and reduce the global environmental benefit as well as the EU's economic and social benefits.

Table 2 summarizes the investment needs in the medium run until 2030 and in the long run from 2030-50. Notably, the long-run perspective reveals an investment gap of around EUR8.3bn per year. As in our previous publications, the difference between the EU ambition of Ff55 (referring to the MIX scenario) and the 1.5°C target (referring to the "+" scenario) is striking.

Particularly at high carbon prices, agriculture is the sector with the second-highest abatement potential. Figure A1 in the Annex illustrates this potential. Clear win-win investment opportunities include biogas recovery for dairy cows and cattle farms. Its use would also allow an increase in the supply of biomass available for biomethane production. Breeding selection can also enhance productivity, fertility and longevity to minimize the methane intensity of dairy and meat. Feed additives and feed-management practices can reduce methane emissions. Nitrification inhibitors and technologies allowing for more efficient fertilizer use are an option to reduce nitrous oxides. Figure A2 in the Annex displays the main investment opportunities in the LULUCF sector. They include – in decreasing contribution – the enhancement of the forest sink, optimizing forest management practices, improving agricultural practices to store more carbon in the soil, incentives for additional reforestation and avoided deforestation.

Figure 6: Investment needs for advancing LULUCF carbon sinks and agriculture non-CO2 abatement beyond baseline ambitions to the AFOLU+ goals



Source: Allianz Research

Table 2: Investment needs for advancing LULUCF carbon sinks and agriculture non-CO2 abatement beyond baseline ambitions to the AFOLU+ goals

Investment in billion EUR	2020-2030	2030-2050
Total investment MIX	2.41	7.61
Total investment MIX per year	0.24	0.76
Total investment+	2.67	181.84
Total investment+ in per year	0.27	9.09
Investment gap MIX vs. +	0.26	174.23
Investment gap MIX vs. + per year	0.03	8.33

Source: Allianz Research

Photo by Lucas van Oort on Unsplash

THE ROLE OF CARBON MARKETS

Carbon markets, where emission allowances are traded, are emerging as a key player in the climate neutrality pathway. The overall carbon market is expected to have reached a new record value of over USD1bn in 2021 globally, and could potentially reach USD50bn in 2030. There are two types of markets that exist: regulatory compliance and voluntary markets. Compliance markets are used where the law, companies or governments must account for their emissions. A prominent example is the Clean Development Mechanism (CDM), which was established in the Kyoto Protocol. This mechanism created binding targets for industrialized countries to reduce their GHG emissions but not for developing countries. GHG emission reduction could be achieved in three ways: reducing emissions in their own country, implementing projects to reduce emissions in other countries or trading. For industrialized countries, an emission-reduction project must take place in a developing country; after completion, a carbon credit called "Certified Emission Reductions" (CER) is generated. Most projects are focused on renewable energy or energy efficiency, while projects in the agriculture, forestry, and other land use sector are a bit more restricted. The CDM has faced several challenges and showed only limited success in reducing GHG emissions.

A major success of the COP26 in Glasgow was to finalize and agree on the formulation of Article 6 of the Paris Agreement (see Table 3). It builds on the aims of the CDM, addresses its deficits and provides a framework for implementing a global carbon market that includes the scaling-up of natural carbon sinks and the trade of the resulting carbon offsets. The institutions related to and the markets based on Article 6 have to be established within the coming years to allow the international linkage between offset activities and offset financing. In the process, the CDM will be replaced by the new SDM (Sustainable Development Mechanism).

Complementary to compliance markets, voluntary carbon markets have emerged as well, especially as companies have made collective agreements within their industries to address their emissions. These voluntary markets trade carbon credits on a voluntary basis. The carbon credits awarded here are called "Verified Emission Reductions" (VER), which are then registered at a specific carbon registry, which certifies the results. There are four main registries / standards for these carbon offsets: Verified Carbon Standard or Verra, Gold Standard, American Carbon Registry and the Climate Action Reserve.

For both markets, the certification standards ensure that the core principles of carbon finance are adhered to: additionality, no overestimation, permanence and exclusive claim. They also provide additional social and environmental benefits[14]. For the land use sector, such as projects in forestry or agriculture, permanence is a real concern. With these projects, there is a risk that the carbon that is stored or avoided is lost if a disturbance such as a fire or natural disaster occurs.

One example of a compliance mechanism that was recently established is CORSIA, the Carbon Offsetting and Reduction Scheme for International Aviation, which will require participating airlines to buy carbon credits for their emissions growth above their 2020 levels. Although this is a compliance scheme, they do allow credits from certain standards on the voluntary carbon market (e.g. Gold Standard) as long as the credits meet certain requirements. What is important for the land sector project, though, is that only certain types of land-use activities are allowed. For example, CORSIA will not accept CDM credits from afforestation / reforestation projects because of the lack of policies to ensure permanence. Furthermore, REDD+ credits (see box) are also not accepted.

14 See Annex I for definitions

Table 3: COP26 key takeaways for Article 6

Article	Confirmed Provisions
6.2	Provides for "cooperative approaches" to be established directly between countries for the purpose of trading Internationally Traded Mitigation Outcomes (ITMOs) units, with corresponding adjustments required for any ITMO transfers made. Like carbon credits, these ITMOs are where emission reductions are passed from one country's GHG account to another country's account. This can happen on both a government and corporate level. Regardless, double counting must be avoided by using applying a corresponding adjustment, where the "host country" (the country where the carbon reduction is located) must first approve the transfer then adjust its own GHG account, before being credited to another country.
6.4	Provides a "top-down" global platform for trading of ITMOs by all counties, operated by UNFCCC. This "Sustainable Development Mechanism" will replace the current "Clean Development Mechanism (CDM)" operated under the Kyoto Protocol. A Supervisory Body and secretariat housed within UNFCCC will provide oversight. Activities that generate emission reduction units are defined as emission reductions or removal activities and must not represent activities before 2021.
6.8	Provides for the facilitation and collective coordination of non-market approaches to be taken by countries to drive emissions reduction. These can engage both country and non-country actors and examples include pledge programs, initiatives, statements, roadmaps and commitments that collaboratively support emission reduction activities.

Source: Allianz Research

Box: What about REDD+?

Instead of carbon removal, there is also carbon avoidance. Perhaps the most recognized are **REDD+ projects**, which stands for **Reducing Emissions from Deforestation and Forest Degradation**. These projects avoid carbon emissions by preserving forests in specific areas that are at risk of deforestation.

However, it is particularly difficult to calculate the emissions avoidance potential in these projects. To calculate emissions avoidance, you must first have the "baseline" – which is the amount of carbon that would likely be released if deforestation occurred. With REDD+ projects, the baseline is calculated using the deforestation rate over the past 10 years in a nearby, comparable area. Because there is no absolute certainty, some argue that these projects violate a core principle of carbon finance: "no overestimation". But these projects generally have lower costs than afforestation projects and have immediate results (think of preserving a forest that already exists versus rebuilding a forest that takes time to mature).

It is important to note as well, though, that the CDM and Gold Standard exclude avoided deforestation projects and, at the moment, these credits or activities will not be accepted in the proposed Sustainable Development Mechanism (scheduled to replace the CDM), which sets higher requirements for reduction or removal activities.

In the context of carbon markets, one of the most interesting and critical implementations includes the EU's plan to boost the carbon sink via carbon farming. This new carbon farming initiative aims to develop and deploy natural carbon-removal solutions at scale across the EU using agricultural and forestry projects. To drive this new business model and develop incentives to boost carbon storage and removal via the land sector, the EU plans to now propose an EU regulatory framework for the certification of carbon removal by the end of 2022. This could essentially create an EU-regulated carbon market where farmers – or land managers in the new terminology – can be rewarded carbon credits by the EU, which they could then sell to the carbon market at their own discretion. These credits could become a new source of income for farmers and further incentivize them to adapt more resilient practices. Meanwhile, the consultations around EU carbon farming are still ongoing and the implementation is still largely unspecified.

The establishment of their own carbon removal certification scheme would be big step for the EU. After recognizing that private schemes and voluntary markets vary in transparency, integrity and quality, the EU decision to establish its own scheme to standardize the methods and rules for monitoring, reporting and verifying (MRV) carbon credits with scientifically robust requirements could provide an important benchmark for the global market. The objective is for each land manager to have access to verified emission and removal data by 2028, with the potential for carbon-farming initiatives to remove at least 42 Mt of CO2-eq by 2030 (contributing to the overall net removal target of 310 Mt CO2-eq).

The EU highlights the following practices as having the most potential in carbon farming:

1. Afforestation and reforestation
2. Use of conservation tillage and cover crops in agriculture to build soil organic carbon in mineral soils
3. Restoring, re-wetting and conserving peatlands and wetlands
4. Targeted conversion of cropland to fallow or permanent grassland
5. Agroforestry and other types of mixed farming


Photo by James Baltz on Unsplash

Box: The EU's reformed Common Agriculture policy: is it enough?

The EU recently reformed its **Common Agricultural Policy (CAP)** with the next funding period (2021 to 2027) having an annual budget of EUR386.6bn. At 26%, the CAP has the single largest share of the total budget. As its benefits cove around 85% of EU farmland, its reach is far, wide and influential.

The reform is welcome as the previous CAP was criticized for not doing enough to prevent climate change: An audit from JRC found that it did not contribute significantly to emission reductions. Considering this, the new reform has boosted funding and introduced several green amendments, which comprise:

- Introducing eco-schemes. The first pillar of the CAP, which accounts for the bulk of funding at EUR291.1bn, includes the direct payment of funds to farmers based on the size of their operations. From 2023 to 2024, 22% of funding will be dedicated to farmers who practice sustainable activities that contribute to the targets of the EU Green Deal; this will be increased to 25% from 2025 to 2027. This first pillar also comes with enhanced conditionality: To receive the funds, farmers must follow a stronger set of sustainable farming requirements, the "Good Agricultural and Ecological Conditions". For instance, crop rotation will be required on at least 10 hectares, and at least 3% of land on every farm must be dedicated to biodiversity (non-productive). Eco-scheme support would help achieve 7%. Wetland and peatlands must also be protected.
- Increased funding for rural development, considered the second pillar of funding (EUR95.5bn). At least 35% of this budget is assigned to environmental and climate measures. This pillar also includes research and development support in the form of advisory services, knowledge exchange and training actions, which will be an important resource to boost carbon farming.
- Operational programs. For fruit and vegetable production, these programs must dedicate at least 15% of their funds to the environment (+5pp compared to current program).
- CAP strategic plans: To receive EU funding during the next period, member states had to submit their own CAP strategic plans detailing how they plan to implement these rules by the end of 2021.

These reforms are aimed at helping provide funding that will drive the previously mentioned strategies (biodiversity, Farm to Fork, soil strategy and many others) and overall achieve the proposed Ff55 targets, with an expected 40% of the overall CAP budget contributing to environmentally friendly actions.

Where previously the CAP focused on action-based results, rewarding farmers for implementing certain practices in their operations (regardless of the result they produce), the new direct payments incentivize farmers to invest in their operations and transition to sustainable agricultural practices, especially via the eco-schemes. Moreover, to incentivize this even more, a results-based approach will be introduced via the carbon-farming initiative and carbon-removal certification system, which should be set up by the end of 2022.

LAST BUT NOT LEAST
DON'T FORGET THE DEMAND

Carbon Agricultural and land use policy isn't only concerned with the emissions associated with the farm-to-gate production side. In its farm-to-fork perspective, it also includes the emissions further down the value chain including the effects of consumption behavior changes like switching to a vegetarian diet. Globally, the FAO estimates that 31% of anthropogenic emissions came from the agri-food systems in 2019. In the EU-27, agri-food system emissions accounted for 32% of total GHG emissions. Of this share, most (51.1%) of the emissions were sourced from pre- and post- production emissions, followed by farm-gate emissions at 45.5% and lastly, land use change at 3.4% (Table 4)[15].

A Behavioral change towards a more sustainable, low-emission dietary choice is important as well. Food products differ a lot with regards to the GHG emission and energy consumption during their production and transport. Red meat is an example for a GHG-intensive dietary choice that pops to mind immediately. It is often resource and energy intensive and contributes directly to methane emissions. But also fruits and vegetables that have to be transported over long distances, or cooled for non-seasonal consumption can be rather GHG-intensive.

Table 4: EU-27 emission sources across the agricultural value chain, defined by FAO

LULUCF (without removal) (3.4%)	Forest conversion to other land uses
	Peat Fires
	Drained organic soils
Farm-Gate (45.5%)	Crop residues (incl. burning)
	Drained organic soils
	Enteric fermentation (E.g. livestock)
	Manure management (incl. soil application and pasture)
	Rice cultivation
	Synthetic fertilizers
	On-farm energy use
Pre- and Post- Production (51.1%)	Food transport
	Processing & Packaging
	Refrigeration
	Retail & Cooking
	Fertilizer manufacturing and other pre-production
	Solid food waste
	Incineration
	Wastewater (industrial and domestic)

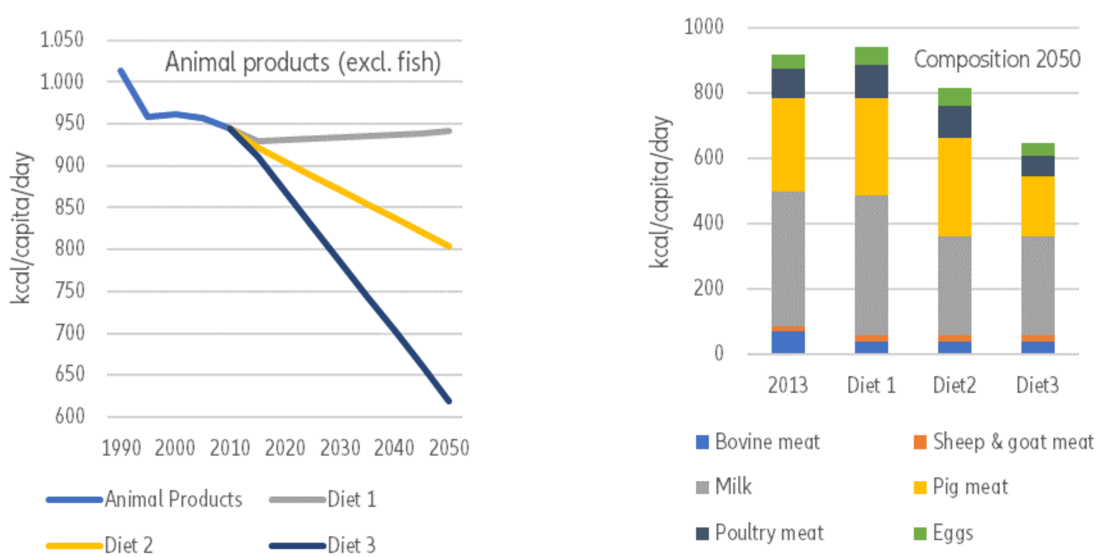
Source: Allianz Research, FAO

15 *The FOA definitions deviate from the EU ones used above, but they are still in the same ballpoint. According to FAO, roughly 16% of total EU GHG emissions result from farm-to-gate and LULUCF (49.9% of 32% of total GHG emissions from the agri-food system). In our EU analysis 11% result from non-CO2 agriculture plus about 4% from LULUCF if negative emissions are disregarded.*

Figure 7 lays out the evolution of the total consumption and the composition of animal products for three different dietary choices, ranging from light decreases in meat and dairy (Diet 1) to more substantial decreases (Diet 3). Diet 3 is consistent with reaching levels of meat consumption seen as in-line with recommended diets in a number of studies[16]. All dietary scenarios are also in line with the UN Sustainable Development Goal to halve per capita food waste generation at the retail and consumer levels until 2030[17].These diets would additionally bring with them co-benefits for health, though in all diets dairy and meat consumption would still remain at a relatively high level.

The moderate changes in food consumption patterns could significantly reduce emissions from agriculture production. The effect in 2050 ranges from 34 MtCO2eq with Diet 1 to 110 MtCO2eq with Diet 3 (Figure 8, p. 24). The transition would continue after 2050 to be fully implemented in 2070. In emission reduction, the behavioral change would be of an order of magnitude equivalent to the technical reduction potentials of the agriculture sector.

Figure 7: Evolution of consumption and composition of animal products for different dietary choices

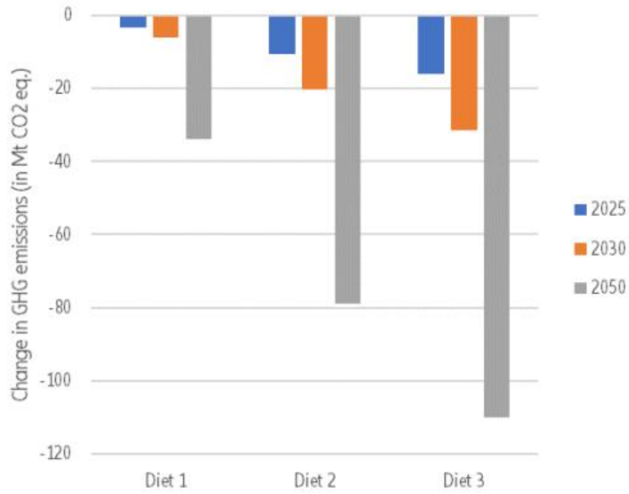


Source: Allianz Research, European Commission

16 *AgCLIM50 Project (2017) Challenges of Global Agriculture in a Climate Change Context by 2050. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC106835/jrc106835_agclim50_jrc_science_for_policy_report.pdf. Bajželj, B. et al. (2014), Importance of food-demand management for climate mitigation. Nature Climate Change, 4, pp.924–929. Bryngelsson et al. (2016), How can the EU climate targets be met? A combined analysis of technological and demand-side changes in food and agriculture, Food Policy, Volume 59, February 2016, Pages 152-164.*

17 *Transforming our world: the 2030 Agenda for Sustainable Development (2015). http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E*

Figure 8: Greenhouse gas emissions effects of different dietary choices through 2030



Source: Allianz Research, European Commission

Photo by Naseem Buras on Unsplash

Appendix I: Core principles of carbon finance:

- Additionality: The project should not be legally required, common practice or financially attractive in the absence of credit revenues.
- No overestimation: CO_2 emissions reduction should match the number of offset credits i ssued for the project and should take into account any unintended GHG emissions caused by the project.
- Permanence: The impact of the GHG emission reduction should not be at risk of reversal and should result in a permanent drop in emissions.
- Exclusive claim: Each metric ton of CO_2 can only be claimed once and must include proof of the credit retirement upon project maturation. A credit becomes an offset at retirement.
- Provide additional social and environmental benefits: Projects must comply with all legal requirements of their jurisdiction and should provide additional co-benefits in line with the UN's SDGs.

Appendix II: Calculation of investment needs

Investment needs are determined by the additional emissions that should be avoided or the carbon sink increase relative to the baseline scenario (BSL) in Table A1. The “MIX” scenario is the main scenario that we use from the EU assessment for the Ff55 proposal. MIX is already more ambitious than the BSL scenario for the LULUCF carbon sinks but is similar for the non-CO2 agricultural emissions. AFOLU is the sum of LULUCF and “Non-CO2 Agriculture”. “LULUCF+”, “Non-CO2 Agriculture+” and “AFOLU+” describe the enhanced ambition pathways from the EU assessment. Figure A1 shows the marginal abatement curve for the non-CO2 GHG-emissions in agriculture. For the analysis these have been linearly approximated. Figure A2 shows the EU assessment for the marginal potential enhancement of the carbon sink for increasing price levels as the blue line. For the analysis this has been approximated by the shown second order polynomial. As the underlying measures dominantly refer to capital investments and not to switching to processes that imply more operational costs, the total investment needs can be approximated in both cases by the integral under the marginal cost curve, according to economic theory.

Table A1: MtCO2-eq emissions in the EU Baseline, the EU MIX and the increased ambition EU PLUS scenario

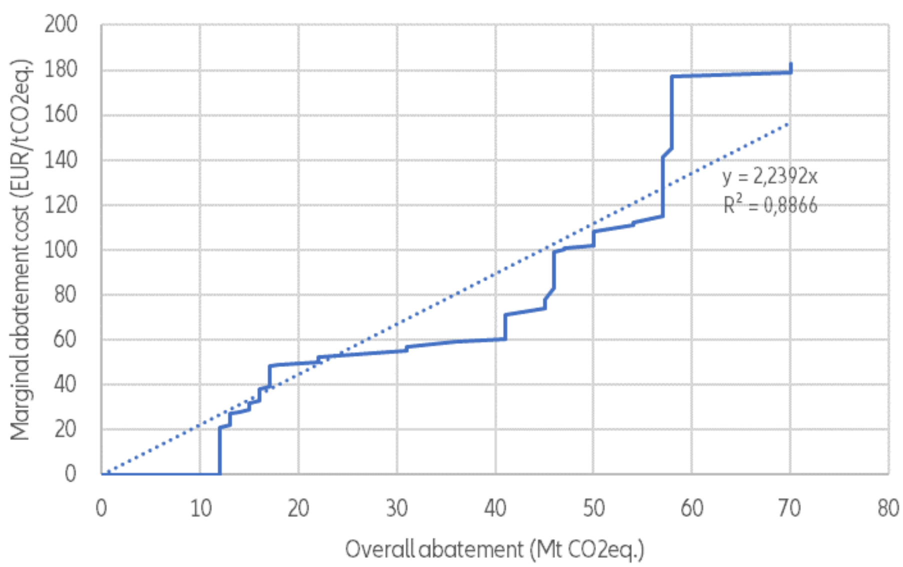
_	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
LULUCF BSL	-311	-315	-298	-252	-261	-258	-262	-251	-266	-271
LULUCF MIX	-311	-315	-298	-252	-289	-295	-291	-286	-280	-279
LULUCF+	-311	-315	-298	-252	-309	-340	-361	-381	-400	-424
Non-CO2 Agriculture BSL/MIX	393	381	390	383	373	368	365	363	362	363
Non-CO2 Agriculture+	393	381	390	383	379	363	312	283	274	267
AFOLU MIX	82	66	92	131	83	74	73	76	81	83
AFOLU+	82	66	92	131	69	24	-49	-99	-127	-157

Source: EU 2030 Climate Target Plan. “Commission Staff Working Document Impact Assessment” Accompanying the document “Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee on the Regions” Stepping up Europe’s 2030 climate ambition Investing in a climate-neutral future for the benefit of our people (SWD/2020/176 final)

Agriculture is the sector with the second highest-abatement potential, particularly at the higher carbon price. The Figure A1 below illustrates this potential and shows that mitigation options exist at significant price differences. The dotted lines indicate marginal mitigation cost of EUR10/tCO2-eq and EUR55/tCO2-eq, respectively reducing emissions by 3% to 8% compared to baseline in 2030. Of the most economical options that represent clear win-win strategies, farm-scale anaerobic digestion with biogas recovery is an important emission-reduction technology for dairy cows and cattle farms, for both small and large farms. Its use would also allow to increase the supply of biomass available for biomethane production, a technology that stakeholders see as relevant for the future. Breeding through selection could enhance productivity, fertility and longevity to minimize the methane intensity of dairy and meat products is an option both for dairy cows and sheep. Moreover, feed additives combined with changed feed-management practices can reduce methane emissions, again in large and small farms.

Overall, the results show that a significant number of win-win abatement technologies exist for agri-culture. Nitrification inhibitors are an option at higher marginal costs for larger farms (30 to 150 hectare) to reduce nitrous oxides at scale. The same applies for variable rate technology to reduce emissions of nitrous oxide emissions related to more efficient fertilizer use.

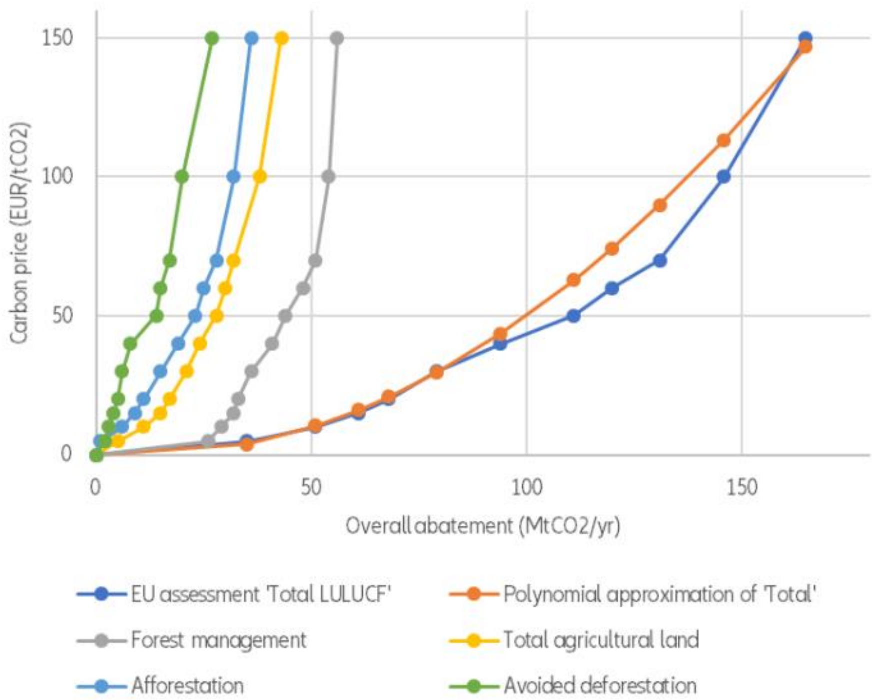
Figure A1: Marginal abatement cost curve for all non-CO2 greenhouse gas emissions in the agricultural sector[18]



18 For the investment analysis the marginal abatement curve is approximated by y'=2.24x. As this is dominantly composed of infrastructure and process change investments, we approximate the investment cost by the integral of the marginal abatement curve, which is y=1.12x^2 (y: difference baseline vs. enhanced ambition).

Source: EU 2030 Climate Target Plan. "Commission Staff Working Document Impact Assessment" Accompanying the document "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee on the Regions" Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people (SWD/2020/176 final).

Figure A2: Potential for carbon sequestration and LULUCF sink enhancement at different carbon prices[19]



19 For the investment analysis the marginal curve is approximated by the second order polynomial y'=0.006x^2-0.1x. Investments are approximate by the (positive part of the) integral of the marginal curve, which is max{0;y=0.002x^3-0.05x^2} (y: difference baseline vs. enhanced ambition). The investments can be decomposed on request into: Agricultural land, forest management, avoided deforestation and afforestation.

Source: EU 2030 Climate Target Plan. "Commission Staff Working Document Impact Assessment" Accompanying the document "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee on the Regions" Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people (SWD/2020/176 final) and "In Depth Analysis in Support of the Commission Communication COM(2018) 773 A" Clean Planet for all A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy.

Appendix III: Overview of the other pathway publications by Allianz Research, hitherto

SECTOR PATHWAY PUBLICATIONS	
08/12/2021	Jostle the colossal fossil: A path to the energy sector transition Coal, oil, gas: can they be phased out fast enough? The EU faces an implementation
10/11/2021	The EU utility transition: A pathway powered by solar and wind Electrification is the key to decarbonization in the EU, but renewable energy isn't ramping up fast enough to meet rising electricity demand...
03/11/2021	Transport in a zero carbon EU: Pathways and opportunities The EU Ff55 plan for the transportation sector is missing the target to limit global warming to 1.5°C. The EU could face an implementation gap of up to 14 years, or around EUR75bn of investments per year...

RECENT PUBLICATIONS

09/02/2022	China: Putting the tiger on a stronger footing in 2022
03/02/2022	Can 5G reignite the smartphone industry?
02/02/2022	European Central Bank: Last dove standing?
28/01/2022	Allianz Pension Report: Latam special 2022
25/01/2022	US Fed: A fata morgana hiking cycle?
20/01/2022	Mental health: Raising awareness and calling to action
18/01/2022	Will inflation spark a wage-price spiral in 2022?
13/01/2022	Economic Outlook: Don't Look Up!
16/12/2021	Public infrastructure investment: Enough bang for the buck?
15/12/2021	Social Risk Index: Leave the door open for development
09/12/2021	Global trade report – Battling out of supply-chain disruptions
08/12/2021	Jostle the colossal fossil: A path to the energy sector transition
03/12/2021	Monetary policy: Omicron management & beyond
01/12/2021	Global FX Volatility: Still waters run deep
25/11/2021	Chinese capital markets: the panda in the room
22/11/2021	US retail: A not so Black Friday for consumers
18/11/2021	Corporate credit: Life after policy support
17/11/2021	The middle-income trap: inequality across countries after Covid-19
12/11/2021	Diabetes and Covid-19: A silent EUR45bn problem
10/11/2021	The EU utility transformation: Powered by solar and wind
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