A Synthesis Report on the ISCRAES 2022-OECD-CRP Panel Discussion

Towards net zero emissions without compromising agricultural sustainability: what is achievable?

Sponsored by

the OECD Co-operative Research Programme: Sustainable Agricultural and Food Systems

Written by

Mohammad I. Khalil[1,2]*, Bruce Osborne[1,2,3] and Astrid Wingler[4,5]

[1]School of Agriculture and Food Science, University College Dublin, Ireland; [2]School of Applied Sci-Tech, Prudence College Dublin, Ireland; [3]UCD Earth Institute; [4]School of Biological, Earth & Environmental Sciences, University College Cork, Ireland; and [5]UCC Environmental Research Institute.

Submitted on behalf of ISCRAES 2022 to the OECD Co-operative Research Programme: Sustainable Agricultural and Food Systems, Organisation for Economic Co-operation and Development (OECD), Paris, France in September 2022.

A Synthesis Report on ISCRAES 2022-OECD-CRP Panel discussion on

Towards net zero emissions without compromising agricultural sustainability: what is achievable?

Background

Agriculture-related modifications in land use and associated management interventions that affect the sources and sinks of greenhouse gases (GHGs) have been linked with a number of negative environmental impacts, such as the deterioration of water and air quality. The UNFCCC, UNECE, EU Directives, the Paris Agreements and subsequent national commitments have emphasised the urgency of identifying technological approaches for mitigation actions to make agriculture carbon neutral. Combating climate change is a core global priority in the pursuit of a sustainable, low carbon economy and requires the introduction of appropriate mechanisms to achieve these goals. The 2nd International Symposium on Climate-Resilient Agri-Environmental Systems (ISCRAES) held in 2022 was aligned with national and international obligations and policies with a particular focus on a reduction of GHGs and environmental pollution and adaptation to a changing climate, as well as the identification of the impacts of climate change on ecosystems for developing adaptive measures, while sustaining increased production and ensuring economic competitiveness.

With the above goals in mind, the panel discussion *"Towards net zero emissions without compromising agricultural sustainability: what is achievable?"*, which was independent of, but within the overall scope of ISCRAES 2022 (www.iscraes.org), was designed to provide an international platform to discuss research findings/outputs, exchange scientific ideas and expertise and contribute to the climate change and environmental pollution debate, including the soil and water dilemma associated with various management approaches within agricultural systems. Advanced technological alternatives that enrich agricultural biodiversity and exploit trade-off opportunities were also targeted with the aim of reducing the climate and environmental pressures from agriculture and associated sectors, leading to recommendations for changing the current policies and the adoption of environmentally and economically viable best practices. This includes re-defining best practice approaches and the introduction of measures that are beneficial to both the farming and wider community.

The panel discussion sponsored by the OECD-Cooperative Research Programme (CRP): Sustainable Agicultural and Food Systems within the ISCRAES-2022 meeting was a particularly timely event given the introduction of the Climate Action Plan and similar initiatives/directives at an EU and global level for mitigating GHGs and reducing the environmental pressures associated with sustainability in agricultural production systems. The panel discussion brought together academics, researchers, industry and policy makers to exchange ideas and expertise with a focus on developing climate-smart agricultural systems which are productive and profitable and can make agriculture carbon-neutral by 2050. This provided a basis for knowledge and technology exchanges, communication and information dissemination, stimulating research and education on climate change and adaptation, whilst also contributing to legislative and policy development. The outcomes aligned with national and international obligations/commitments and their impacts on the wider community.

The objectives of the panel discussion were in line with the OECD-CRP Research Theme I and part of Theme II. Panel members having wide-ranging expertise across the agricultural sector were invited to contribute through their knowledge and expertise, providing evidence-based ideas on how to achieve net-zero emission from agricultural systems with little or no impact on soil and water bodies, for example to:

- address the challenges associated with land use and ecosystem management for climate change mitigation whilst sustaining agricultural productivity for socio-economic and environmental benefits to society.

- discuss how to best exploit soils and soil processes to understand carbon and nutrient dynamics for GHG mitigation, increasing carbon sequestration and reducing nutrient losses from agricultural systems.
- address the importance/benefits of conservation measures and the restoration of biodiversity losses through the identification of more appropriate management practices for sustainable use and policy development.
- best use integrated Agricultural Production Systems (e.g. carbon farming, novel farming, agro-forestry and silvo-pastoral systems) for the maintenance of sustainability and biodiversity with a low environmental footprint.
- evaluate the potential risks associated with agricultural production, climate change and adaptability, including their analyses and mapping, as well as the role of predictive systems-based models to facilitate policy development and to provide advice on integrated policy formulation.
- provide information on how best to make use of existing and new technologies for crop and/or livestock improvement for climate change mitigation and adaptation in the wider context of profitable, sustainable and resilient farming systems.
- assess the technological options for reductions in water usage and the attainment of sustainable water management strategies in agricultural systems.

Approaches

The ISCRAES meeting is projected to be a biennial event, and this was the second conference that provided a platform for discussing the scientific and technical aspects of a range of cross-cutting issues associated with the environmental impact of agricultural systems on climate and the environment. The main theme of the 2nd ISCRAES was *"Implementing the New Green Deal: The Path Towards Sustainable Agriculture"* and the subthemes consisted of (i) Arable Cropping Systems, (ii) Grassland Systems, (iii) Agro-Silvo-Pastoral Systems, (iv) Decision Support Systems, (v) Novel Farming Systems and (vi) Carbon Farming and Nature-based Solutions. These are all interlinked with public perception, regulatory and socio-economic factors and the identification of solutions for mitigating climate change, reducing environmental pollution and ensuring food security.

Based on the above themes and the overall goals for scientific advancement and the identification of solutions, the panel discussion on *"Towards net zero emissions without compromising agricultural sustainability: what is achievable?"* was submitted as an application for OECD-CRP sponsorship, which was successful. Keeping in mind the need for a multidisciplinary approach, the panel members were selected on the basis of their knowledge of the wide agricultural sector, including the farming community. Within ISCRAES 2022, the panel discussion was held on 31 August 2022 at the Talbot Stillorgan Hotel, Dublin, Ireland and was moderated by Prof. Bruce Osborne. In the panel discussion, about 80 of 130 participants from 45 countries attended. The rapporteurs (Dr. Ibrahim Khalil and Prof. Astrid Wingler) were assigned for detailed note taking, leading to the preparation of this report to the OECD-CRP and to disseminate through various media outlets the lessons learned. The invited panel members funded mostly by OECD-CRP were:

1. Prof. David Laird, Iowa State University, USA (OECD-CRP funded).
2. Prof. Roslyn Gleadow, Monash University, Australia.
3. Dr. Anne Mottet, Food & Agriculture Organizations of the UN, Italy (OECD-CRP funded).
4. Dr. Ben Henderson, Agricultural Policy Analyst, OECD, France (OECD-CRP funded).
5. Prof. Daniel Rasse, Norwegian Institute of Bioeconomy Research, Norway.
6. Prof. Maria Mosquera, University of Santiago de Compostela, Spain (OECD-CRP funded).
7. Dr. Carles Ibáñez Martí, EURECAT, Spain (OECD-CRP funded).
8. Mr. Liam Brennan, Dept. of Agriculture, Food & the Marine, Ireland (OECD-CRP funded).
9. Mr. Tim Cullinan, President, Irish Farmers Association, Ireland.

10. Dr. Marta A. Alfaro, Instituto de Investigaciones Agropecuarias – INIA, Chile (OECD-CRP funded).
11. Dr. Örjan Berglund, Swedish University of Agricultural Sciences, Sweden (OECD-CRP funded).

The panel discussion commenced with each panel member giving a 10-minute oral presentation followed by an open discussion and a question and answer session.

Presentations

Biochar's impact on soil carbon sequestration and sustainability of crop residue harvesting for bioenergy by David Laird (USA)

Autothermal fast pyrolysis converts biomass into biochar and various bioenergy co-products, a critical societal need for drop-in liquid transportation fuels that offset fossil fuels, and the biochar co-product should be addressed in broader sense i.e. beyond agriculture for carbon sequestration with the possibility of reducing GHG emissions by 50%. Biochar amendments are effective for increasing total soil organic C content (28-93%), new biogenic carbon formation with biochar as catalyst and also increasing water-holding capacity and nutrient availability. This also includes the potential for increasing the carbon saturation level of soils by providing surfaces that adsorb dissolved organic compounds and facilitating their transformation into stabilized biogenic humic materials. These have the capacity to compensate for most of the negative effects of biomass harvesting on soils (7.8 Mg C ha^{-1} lost through crop residue removal), but enough residues should be left on soil surfaces to prevent erosion. The innovative approaches including autothermal regulation and stage fractionation consists of four products such as glucose, fuels, hydrogen and biochar. The vision for 2050 is >12,000 pyrolizers, and 1 Gt of biomass/year to displace 1.9 B barrels of oil, producing jet fuel 0.8 GT CO_2e $year^{-1}$ in the US and 8 GT globally to link with circular economy.

Integration of livestock with various land uses for reducing the carbon-footprint by Anne Mottet (Italy)

As a large emitter, livestock systems have a key role to play in climate change mitigation through the application of best management practices such as feed supplementation or manure treatment and its application to reduce GHG emissions, with potential reductions from 14% to 41% according to species, system, and region, whilst increased soil carbon sequestration. For this, the FAO has identified three main strategies: (i) Improving animal herd efficiency and productivity, (ii) Better integration of ruminants into the circular bioeconomy by enhancing the use of by-products and crop residues as feed, which also reduces feed/food competition, and recycling of energy and nutrients from manure including waste and (iii) Increasing soil organic carbon content, particularly in pastures. Despite reduction potentials of 20-30%, improved practices and technologies to increase productivity may trigger absolute emissions but cut down on meat could improve emissions. However, strategies more adapted to intensive than extensive production systems, including animal feeding indoors and collection of manures, usually come at a higher cost than measures targeting a higher efficiency. Though 92 developing countries have included livestock in their nationally determined contributions (NDCs)/policies under the Paris Climate Agreement, in addition to data availability, these commitments are often conditioned to accessing finance and capacity development, and more emphasis should be given to influence farmers rather than consumers. The use of crop residues, by-products and waste as animal feed could have a significant impact in GHG reductions but there are large knowledge gaps. It is important to invest in low-carbon livestock systems, that have a large potential for mitigation with short-term positive impacts for methane reduction, and to explore climate co-benefits from livestock as a "solution" with appropriate scientific and technological supports for low C livestock development.

Carbon farming and nature-based solutions for GHG offsetting by Daniel Rasse (Norway)

Carbon farming aims at managing agroecosystems to increase C sequestration in soils, while enhancing soil health for sustainable food production. An ensemble of methods can provide efficient and low-cost solutions for climate mitigation, targeting a 55% net reduction in GHG emissions by 2030. Allocation of more photosynthate to roots and fostering its stabilisation in the form of soil organic matter is a key to carbon farming. Cover/catch crops/intercropping in combination with biochar and compost/manure application as trade-off, as well as deep-rooting crops, which is still under development, enhance the year-round fixation of C and its stabilisation. For grassland, over-grazing is a problem, but clear evidence of grazing effect is absent whereas improved grazing potentially increases C sequestration, but as a trade-off N_2O emission may increase. Location-specific and easily implementable matured management practices/technologies must be considered to achieve expected C sequestration potential with certainty. For example, no-till solutions may increase soil C sequestration in dryer and warmer climates, but the impacts are highly variable in colder and wetter climates. There are opportunities to combine these approaches with conservation and regenerative agriculture, but not enough data is available to quantify any benefits and the lack of clear understanding of the processes and the magnitude of the synergistic effects over time to attain sustainability and the capacity to implement these solutions efficiently.

Agroforestry for mitigating greenhouse gas emissions and resilience of agricultural farming by Maria Mosquera-Losada (Spain)

Agroforestry is the combination of woody perennials (e.g. fruit trees, shrubs or forest trees) and an associated herbaceous vegetation and is considered a sustainable way to manage many farming systems. The practices include mainly alley cropping or silvo-arable and silvo-pasture, extending to riparian buffer strips usually linked to the protection of water bodies, and home gardens. In Europe, silvo-pasture is used in around 10% of situations, while alley cropping is negligible (0.01%). Mitigation measures for arable lands and grazing management, as well as protection against fires because of the high amount of biomass in forest understories are key factors that require attention. It has been reported that agroforestry increases C sequestration by storing C associated with small particles in deeper layers, and there are no ploughing effects, enhancing the potential to reduce GHG emissions. Agroforestry may overcome the GHG emissions associated with livestock systems and facilitate the recycling of nutrients through introduction of livestock.

Towards a carbon-neutral and climate-resilient rice cropping systems by Carles Ibañez Martí (Spain)

Rice is the staple of food for a third of the world's population and occupies about 9% of the global cropland. The high productivity and flooding conditions enhance soil carbon storage, but rice production shows a low resilience against climate impacts such as drought while contributing to global warming through GHG emissions, accounting for 5 to 20% of anthropogenic CH_4 emissions. Water scarcity in the Mediterranean is a significant problem and rice production utilises 40% of the world's irrigation water. Considering the global methane pledge, the introduction of sustainable practices, such as alternate wetting and drying can help in achieving significant water savings and reduce CH_4 emissions by up to 90% during the growing season, but having the potential to produce and release of N_2O through the Birch effect. Considering temperate rice fields, two thirds of CH_4 are emitted during the fallow season so that delayed straw incorporation and management of water could be beneficial for reducing emissions. Importantly, the development of carbon farming and agri-environmental schemes, including the maintenance of biodiversity and provision of economic support to rice farmers to carry out the transition towards a climate-resilient rice production is essential. Sea level rise and salinity are also a threat to rice production in coastal areas.

Distribution of emissions from the AFOLU sector in Latin America by Marta Alfaro (Chile)

During the last decade, Central and South America have suffered extreme weather events including flooding and drought. These have had major impacts on fodder yield, forage crops and grazing systems, including fodder quality and forage/pasture composition. Livestock production makes a major contribution to human livelihoods, contributing 46% of agricultural GDP, especially for smallholder farming systems in Latin-American countries. The current global trend of increased consumption of livestock products is expected to continue, emphasizing the importance of developing effective emission-reduction options. Given the pursuit of mitigation and adaptation measures to benefit from synergistic effects of climate change, several mitigation strategies can be considered. Strategies and advances made in Latin-American grazing systems include new feeding strategies, the development of novel nitrogen fertilizers and the replacement of grassland monocultures by mixed legume-grass pastures. Moreover, manure management, smart grazing systems, integrated adaptation-mitigation measures, livestock NAMA (Costa Rica), smart fertilisers (slow release), feed additives, urea plus urease inhibitors are being recommended to reduce GHG emissions with no impact on yield. Several nutritional strategies that have been proposed are improved grazing management (new pastures are more productive) and pasture quality, including fat, combination of different species, such as *Bromus* and *Lotus*, vs. traditional oat and ryegrass; inclusion of methane-reducing feed additive (Bovaer) and seaweed. The introduction of silvopastoral systems has also been proposed for effective removal of CO_2eq from forestry by about 49%, either alone or in combination with enhanced soil carbon storage. Over time, adaptation has been the focus but the implementation of mitigation measures is becoming more significant.

Is it possible to reduce GHG emissions from cultivated peat soils while maintaining productivity? By Örjan Berglund (Sweden)

Peat soils are found mainly in areas where oxygen deficiency limits organic matter decay, and under cold climate >40% organic material deposit was reported. Peat soils that have a high pH are generally fertile, though there is a high potential for enhanced CO_2 and N_2O emissions. In Europe, the proportion of peat soils is particularly high in some regions such as Northern Finland or the Northern and Western coast of Norway, where they constitute up to 60% of the soils and contribute to a significant portion of the arable land area. Drained peatlands show aerobic activity, even in deeper layers, and become potentially significant sources of atmospheric gases. Peatlands dominate the emissions of CO_2 from agricultural land in many countries. For example, the estimated combined total emissions of CO_2 and N_2O from agricultural peat soils in Sweden in 2003 corresponded to approximately 6-8% of the total emissions of all GHGs, and in Finland, 8% and 25% of total national anthropogenic emissions, respectively. Paludiculture might be a viable option but is not suitable everywhere due to legal, climatic and management constraints. Other options to reduce GHG emissions include productivity maintenance, management of the water table properly, introduce different crops with high yield to improve carbon capture, keep land surfaces vegetated, adopt variable cultivation intensities, apply soil amendments i.e. sand addition (20% reduction of CO_2 is possible), copper fertilisation and soil compaction.

Biodiversity and resilience of agro-ecosystem functions for environmental sustainability by Roslyn Gleadow (Australia)

Rising CO_2 and thereby global warming, decline in invertebrate (including pollinator) abundance and habitat destruction are common. About 37% of global food production relies on pollinators, and "robo-bees" are considered in Australia. Given their potential for in increasing global food supplies, unique genotypes of crop wild relatives need to be protected as important sources of traits to improve agricultural productivity but are threatened by climate change and human activities. Extinction of plants around the world compromises the maintenance of global biodiversity, the conservation of ecosystems and sustainability, that are linked to the health and well-being of the human population. The maintenance of plants with unique chemicals could be used to cure diseases. Thus, plant scientists around the world are working to document diversity, collect seeds for storage in seed banks, develop more efficient crops that use less fertilizer and water and are resistant to pests and diseases without the need for the application of large amounts of agrichemicals. The aim of the Global Plant Council

(GPC), a coalition of plant science institutions and research organisations from around the world, is to facilitate the development of plant science for addressing global challenges, foster international collaborations, and enable the effective use of knowledge and resources. The GPC provides an independent and inclusive forum to bring together all those involved in plant and crop research, education, and training. It supports open access with benefit sharing rights, Nagoya Protocol, Convention for Biological Diversity. The GPC recognises the importance of a framework for sharing and use of digital sequence information.

Mitigation policy solutions for AFOLU in pursuit of net-zero by Ben Henderson (France)

Agriculture could reduce both its direct and indirect GHG emissions and contribute to sector-wide efforts including nature-based options through removal of atmospheric CO_2 into biomass and soils to achieves net-zero emissions while maintaining productivity and resilience. A combination of global emissions taxes and carbon sequestration subsidies in agriculture, forestry and other land use (AFOLU) sectors could mitigate 8 Gt CO_2eq year^{-1} in 2050, representing 12% of total global anthropogenic GHG emissions. Direct (agriculture) emission reductions would represent 29% of this total, soil carbon sequestration 9%, and other land use changes 62%. However, agriculture still lags behind other sectors in terms of climate change commitments and actions. By mid-2022, only 16 of 54 countries of OECD have targets for the agriculture sector, but key major emerging economies had set emissions reduction targets. The agriculture sector is often exempt from mitigation policies such as carbon pricing or equivalent regulatory measures though it receives policy support for agricultural knowledge and innovation systems and infrastructure and has declined from 16% to 13% over a decade, which constrains the transition to more resilient and sustainable production systems. For this mitigation and adaptation should go together to minimise adverse effects on food security and nutrition, safeguard livelihoods and protect the environment. Counter-productive or distortive supports provided to this sector increases rather than decreases emissions. Among the policy actions, subsidies could be less effective in reducing GHG emissions, but taxes reduce agricultural production and marked based instruments such as carbon pricing, carbon offsets, abatement subsidies, agricultural support, grants and preferential credits, environmental regulations, R&D and knowledge transfer could be effective. The phasing out policy measures that are worsening global warming and supports need to be re-purposed to lower emission production methods through (i) application of adequate mitigation incentives, (ii) Investment in innovations and knowledge transfer, and (iii) shifting to more sustainable consumption patterns (dietary patterns and preferences). There is still considerable scope for action by reforming agricultural support policies, providing direct incentives for adaptation and mitigation, and using social safety net policies to facilitate an inclusive transition.

Agricultural measures and policies for climate change mitigation by Liam Brennan (DAFM)

The Irish Government is committed to achieving a 51% reduction in overall GHG emissions, including a reduction of 25% from agriculture, to reach 16-18 MtCO_2eq GHG emissions by 2030 and setting Ireland on a path to net-zero emissions by no later than 2050 as set out in the Climate Action Plan 2021. The plan will set Ireland on a more sustainable path, cut emissions, create a cleaner, greener economy and society on sectoral basis; and protect us from the devastating consequences of climate change. The high proportion of national emissions represented by agriculture in Ireland warrants adoption of its overall emissions reduction targets for a climate-resilient, biodiversity rich and climate neutral economy and society. Phase-based annual emissions changes and carbon budgets target a 4.8% reduction in the first phase and then 8.3% in the middle phase. Irish agriculture is dominated by livestock grazing, a pasture-based food system having a reputation for high quality and sustainably produced food, aligning with a global demand for credible evidence-based information. About 80% of agricultural GHG emissions are CH_4 and 75% from ruminants. In Ireland, the main focus for mitigation measures is a reduction in chemical nitrogen usage, improved animal breeding, improved animal feeding, reducing the finishing age of beef cattle, increasing the area of organically farmed land, using protected urea to replace CAN fertiliser, a target of 90% coverage for low-emission slurry spreading, and agricultural feedstocks for the production of biomethane.

A farmer's perspective on how to make agriculture carbon neutral by Tim Cullinan (Ireland)

Farmers are committed to playing a significant in the commitment to make agriculture carbon-neutral but this will be extremely challenging. A multitude of different options are needed to both reduce emissions and capture or store carbon in soils and woodlands. Improved efficiencies in food production should be the first step to bring the emissions down. Support for farmers is needed to overcome the capital and knowledge constraints to be able to access new technologies and adopt new practices to reduce their emissions at farm level. Science-based options and new technologies, for example genetic selection and breeding programmes, CH_4 inhibiting feed additives or vaccines, as well as technologies that improve production efficiencies need wider implementation. In addition to land use change for land-based mitigation, forests, hedgerow, peatland restoration and improved grassland management (including the use of clover/multi-species swards) can improve carbon stores, leading to other co-benefits, such as increased biodiversity and preservation of ecosystems. Ireland is the "most efficient" producer of dairy products globally and has a significant investment in low-emission slurry spreading, the use of protected urea, and 33% of farmland in agri-environmental measures. Further opportunities for farmers to explore are the production of renewable energy, including solar or wind and anaerobic digestion through the capture and use of CH_4. There is little focus on the measurement of carbon sequestration potential and a lack of on-farm rewards for carbon sequestration and storage. However, significant investment in research and development as well deployment of innovative solutions such as the development of carbon farming schemes at various scales and compensating farmers is required.

Recommendations

Academics, researchers, and stakeholders including a farmer's representative on the panel covered a number of areas that dealt with how to mitigate GHGs and adapt agro-ecosystems to a changing climate. The contributions pinpointed the current status, gaps and opportunities for further development of scientific and technological approaches to achieve agricultural systems with net-zero emissions. The panel members also highlighted relevant research and development actions and presented policy recommendations during their presentations and Question & Answer sessions, summarised as follows:

Biochar

1. Reduction of 50% GHG emissions is possible by considering both innovative agricultural management approaches and energy transition through autothermal fast pyrolysis, liquid energy products and biochar as a replacement of the C lost through crop residue removal.
2. Biochar does not protect against erosion but improves soil quality with a large potential to form new humic substances and biogenic carbon formation by serving as a catalyst, and improve water-holding capacity and nutrient availability.
3. Biochar application rates to increase C by 45% will depend on the amounts of dry biomass and how biochar is applied, such as injection or surface application, as well as the pyrolysis process i.e. slow pyrolysis yields 30% biochar, but yield is lower for fast pyrolysis.
4. Biochar has multiple synergies having a potential to increase CH_4 uptake mainly under aerobic conditions while reducing N_2O emissions and carbon sequestration although CH_4 emissions are possible under anaerobic conditions.

Livestock systems

5. For livestock systems, three main strategies to reduce GHG emissions should be taken: (i) improve animal herd productivity and efficiency, (ii) increase soil carbon sinks, and (iii) reduce waste and recycle – the circular bioeconomy.
6. Solutions to mitigate GHGs vary from country to country but a 20-30% reduction potential through adoption of improved practices and technologies, which are less adapted to extensive grazing systems than indoor systems, improved efficiency via the use of crop residues, by-products and waste as animal feed is feasible, in combination with a reduction in the use of meat.
7. There are large gaps in the knowledge and technological approaches to reduce GHGs from livestock systems and reversibility is a big challenge, warranting significant investment in low-carbon livestock production systems to mitigate GHGs and the achievement of short-term positive impacts from reducing CH_4 emissions, including climate co-benefits through research and development.

Carbon Farming

8. Carbon farming in agricultural systems has enormous opportunities to mitigate GHGs and enhance C sequestration by also combining this with biochar and restoring wetlands, the introduction of catch crop, cover crops, manure/compost application and adoption of conservation and regenerative agriculture, though not enough data is available to quantify this at the moment.
9. Impact of no-till and reduced tillage is uncertain and the increased allocation of photosynthates to roots is a key to carbon farming.
10. There is uncertainty in the impact of grazing but improved management of pastures, using cover crops and intercropping have large potential to mitigate GHGs while increasing C sequestration.

Agroforestry

11. Agroforestry plays a key role in arable lands and grazing management to increase C sequestration by storing C in deeper soil layers has long-term effects while reducing GHG emissions and protection against fires.
12. Agroforestry can counteract the large GHG emissions associated with livestock systems and more carbon can be stored while improving the recycling of nutrients for better plant growth and reduced losses.

Rice cropping systems

13. Rice ecosystems have a low resilience against climate change and produce a large amount of CH_4 under flooded conditions. However, alternate wetting and drying, straw management, particularly delayed straw incorporation after harvest (i.e. during fallow period), could reduce water use and GHG emissions, particularly CH_4 emission.
14. Carbon farming in the Spanish Ebro Delta rice fields has the potential to reduce GHG emissions by at least 50%.
15. Sea level rise and salinity are also a threat to rice production in coastal systems, and impacts on biodiversity (aquatic birds) and needs to be considered.

Pasture in Latin America

16. Livestock production has been suffering from the effects of flooding and drought. Adaptation should be the main focus but mitigation of GHGs becomes more significant without negative

impacts on production by introducing manure management, smart grazing systems particularly the introduction of new pastures, slow release fertilisers and inhibitors, feed additives including seaweeds and a combination of different species, such as *Bromus* and *Lotus* vs. traditional oat and ryegrass.

17. Inclusion of forestry (removal of atmospheric CO_2eq) importantly through silvopastoral systems has the potential to remove 49% through forest biomass and soil carbon.
18. Reduction of fertiliser use without compromising productivity should be another focus by introducing clover and multi-species swards, adjusting lime to increase pH, P and K, applying nano- and slow-release fertilisers, as well as maximising low-emission slurry-spreading.

Agricultural peatland

19. Agricultural peatland is a major source of both CO_2 and N_2O emissions in response to drying and can be a source of CH_4 particularly under waterlogged conditions, but peatlands also have a mitigation potential by maintaining productivity and water levels.
20. Soil amendments (sand addition), different crops with high yield, vegetated surfaces, different cultivation intensities, copper fertilisation and soil compaction would improve carbon capture efficiency.

Agricultural Biodiversity

21. Given the importance of biodiversity for agricultural sustainability, it is important to protect invertebrate pollinators and crop wild relatives, as important sources of traits.
22. While enhancing photosynthesis may be important to increase carbon sequestration, there should be more focus on increased photosynthesis with a view to producing more food on less land.
23. The potential of gene editing e.g. to make plants fix their own nitrogen or tweaking of genetically modified (GM) crops to different environments could be beneficial to meet climate reduction targets.
24. The biodiversity and climate crisis should be addressed simultaneously as they are not mutually exclusive.

AFOLU Policy

25. Trade-offs of different marked-based policies should be explored to achieve net-zero emissions from agriculture.
26. The phasing out of policy measures that are worsening global warming and the re-purposing of additional supports to lower emission production methods, apply adequate mitigation incentives and invest in innovations and knowledge transfer should be considered.
27. Shifting to more sustainable consumption patterns (dietary patterns), agricultural knowledge and technology supports, R&D and knowledge transfer grants and preferential through credits such as carbon pricing, carbon offsets, and abatement subsidies including commodity-specific support should have a preference in policy formulations.
28. Accounting for the AFOLU contribution to climate stabilisation goals globally, and aligning current policy settings with mitigation pathways and the identification of policy packages, are highly important.

Agricultural Policies in Ireland

29. Given the Irish Climate Action and Low Carbon Development plan in place to achieve climate neutrality by 2050, phase-wise reductions of annual emissions and estimation of carbon budgets could be useful to achieve the set targets.
30. Mitigation measures, particularly for the reduction of N_2O emissions, should include, for example, the reduced use of chemical nitrogen and the use of protected urea to replace CAN fertiliser.
31. There are diversification opportunities, including carbon farming, for a reduction in pasture-based GHGs by targeting low-emission slurry spreading, improved animal breeding (milk recording and beef herd weight recording), improved animal feeding (reduced crude protein content; 3-NOP), early finishing age, increased organic farming, as well as agricultural feedstocks for the production of biomethane.

Farmers' views

32. Farmers particularly in Ireland have been adopting several management practices in agriculture to mitigate climate change, including the application of protected urea, the use of clover/multi-species swards, low-emission slurry spreading, the use of protected urea, and several others mentioned above.
33. Introduction of a licencing system to plant, thin and harvest trees coupled with subsidies rather than taxing, redesign land use planning for forestry, a clear policy for agroforestry and appropriate monitoring of CAP measures could be effective in achieving targeted mitigation goals.
34. Verifiable direct monitoring of carbon sequestration, and results-based subsidies could work better. As CAP has moved from producing food to protecting the environment, funding to compensate farmers is needed to keep people in rural areas like the new ACRES scheme in Ireland and regular inspections to ensure that measures are taken.
35. As in Ireland, sectoral targets to lower emissions should be based on socioeconomic conditions and feasibility, such as the potential for offshore wind energy production with effective and implementable political decisions through stakeholder consultation.

Concluding remarks

36. A carbon credit system should be introduced by considering the baseline year and the later accounting of stock changes using standard common protocols of measurement and monitoring and the permanence factor.
37. Allocation and spending of grants/subsidies should be used for producing public goods through well-monitored schemes, shifting of the funding from pillar 1 to pillar 2 for environmental measures linking to biodiversity, and include more room for nature restoration and sustainable intensification to minimise land use.
38. To make the actions effective, efficiency without limits do not work and measures should be for example oriented with changing consumption patterns, reducing livestock and balance diets, and development of carbon farming schemes on an urgent basis.