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Essay

State of Knowledge on UK Agricultural Peatlands for Food Production and the Net Zero Transition

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Abstract: Agricultural peatlands are the most productive soils in the UK for the cultivation of many food crops. Historical drainage of peat for agriculture (i.e., cropland and managed grassland), without consideration of other associated environmental and climatic impacts, has resulted in a significant emission of greenhouse gases (GHGs). There is a need to reduce GHG emissions without compromising the rural economy and jeopardizing food security in the UK to a greater extent than is currently being experienced. In March 2023, in a bid to identify alternative land management systems for agricultural peatlands to support the UK's commitment to achieving net zero GHG emissions by 2050, a group of forty investigators met at a workshop convened by the AgriFood4NetZero Network+. The workshop reviewed the state of knowledge surrounding the Fens of Eastern England and their importance for food provision, the economy, cultural identity, and climate change mitigation. A broad consensus emerged for research into how GHG emissions from agricultural peatlands could be reduced, whether alternative farming methods, such as seasonal farming or paludiculture, would offer a solution, and how a localized approach for the Fens could be defined. The development of a holistic, inclusive, and plausible land use scenario that considers all aspects of ecosystem services provided by the Fens is urgently needed.

Keywords: agriculture; greenhouse gas emissions; peatland; drainage; paludiculture; land management; the Fens

Citation: Lloyd, I.L.; Thomas, V.; Ofoegbu, C.; Bradley, A.V.; Bullard, P.; D'Acunha, B.; Delaney, B.; Driver, H.; Evans, C.D.; Faulkner, K.J.; et al. State of Knowledge on UK Agricultural Peatlands for Food Production and the Net Zero Transition. *Sustainability* **2023**, *15*, 16347. https://doi.org/10.3390/su152316347

Academic Editor: Jan Hopmans

Received: 25 September 2023
Revised: 20 October 2023
Accepted: 24 November 2023
Published: 27 November 2023

1. Introduction

Peatlands cover approximately 3%, or around 400 million hectares, of the Earth's land area [1]. Globally, agriculture is the dominant land use on productive peatlands for both arable and livestock production. Despite peatland landscapes playing an important role in food provision, the drainage practices required to enable agricultural production lead to substantial greenhouse gas (GHG) emissions [2].

In the UK, the total peat area is approximately 3 million hectares [3]. Of this, 0.46 million hectares are lowland peatland [4], of which 0.25 million hectares are used for agriculture (which includes arable and livestock production) [5]. The five main regions of agricultural peat across the UK are the East Anglian Fens, the Norfolk Broads, the Humberhead Levels, Northwest England (including the Manchester Mosslands), and the Somerset Levels [5]. The East Anglian Fens (hereafter the Fens or Fenland), a former floodplain mire of around 0.4 million hectares in Eastern England, spanning Cambridgeshire, Lincolnshire, and Norfolk (Figure 1), accounts for approximately 27% of England's total peatland [6–8]. Around 0.15 million hectares of Fenland are used for agriculture, and ~0.1 million hectares of this is wasted peat (<40 cm of peat) [5]. The Fens constitute half of England's highest-value agricultural land, providing 37% of the country's vegetables [5]. The Fens provide significant social and economic benefits; there are approximately 4000 farms in the Fens, providing employment and livelihoods to 80,000 people [9]. Peat soils in the Fenland are highly fertile and thus able to support productive agriculture [10].

In the early 1700s, the lowland peat soils of the Fens, which were previously utilized mainly for livestock grazing and reed cutting, were extensively drained [11] to increase agricultural productivity and allow for arable cropping and more intensive grazing. As of today, less than 1% of the original wetland habitat in the area remains in a relatively intact condition [12], and the hydrology of the Fens is heavily engineered and highly complex. As much of this Fenland now lies below sea-level due to large-scale peat surface subsidence following its drainage, water management significantly underpins Fenland food production. The average annual temperature in Eastern England ranges from 9.5 °C to 10.5 °C, and the area's precipitation is relatively evenly distributed throughout the year. Average precipitation is around 700 mm per year [13], making the region one of the driest in the UK.

Current agricultural production systems in the UK are a significant source of GHG emissions; in 2020, the agricultural sector accounted for 1.7% of the UK's CO_2 emissions, 48% of its CH_4 emissions, and 69% of its N_2O emissions [14]. The drainage of peatlands for agriculture exposes previously waterlogged organic matter, making it vulnerable to aerobic decomposition and rapid oxidation, and subsequently GHG emissions and a loss of soil. Agricultural use of peatlands is responsible for 33% of global peat GHG emissions [5]. At the UK level, emissions from agricultural peatlands contribute 1% of total UK GHG emissions. There is therefore a pressing need to reduce GHG emissions from these landscapes to achieve the UK's net zero by 2050 target [15]. There is considerable evidence to show that the adoption of wetter land use practices reduces net GHG emissions [16] from peatlands. For example, Knox et al. [17] measured CO_2 and CH_4 fluxes from drained peatlands in agriculture and restored wetland in the Sacramento–San Joaquin delta in California using eddy covariance. The drained peatlands acted as net C and GHG sources of up to 341 g C m^{-2} yr^{-1} as CO_2 and 11.4 g C m^{-2} yr^{-1} as CH_4, whereas the restored wetlands were net sinks of atmospheric CO_2 of up to 397 g C m^{-2} yr^{-1} but emitted large amounts of CH_4 (between 39 and 53 g C m^{-2} yr^{-1}) [17]. It is therefore important to consider trade-offs such as these when evaluating the suitability of alternative peatland management practices.

Approximately 8–9% of Fenland farmland is currently under environmental stewardship, a governmental agri-environment scheme that, *inter alia*, seeks to promote farming to improve soil health and water quality [7]. To achieve a reduction in GHG emissions and protect the remaining agricultural peatland soils, it will be important to consider raising the water table. This is something that farmers will be supported to do by the UK Government's new Environmental Land Management scheme [18]. Across the Fens, there are approximately 16,900 hectares of agricultural grassland on peat and 115,000 hectares of cropland on peat [5]. Water table depths are typically managed at between 40 and 80 cm below the soil surface for grasslands and 100 and 120 cm for croplands [2]. Estimates suggest that emissions would remain at 16.8 t CO_2-eq ha^{-1} yr^{-1} for grasslands and 20.9 t CO_2-eq ha^{-1} yr^{-1} for croplands with continued drainage on wasted peat [5]. Croplands on drained peat have inherently higher emissions than drained grasslands on peat because croplands are typically drained more intensively than grasslands. Despite these drainage practices being commonplace, deep agricultural peat is often drained to a deeper depth (>100 cm) than is required for cropping. This offers an opportunity to reduce GHG emissions with only a slight reduction in drainage intensity.

The cost of maintaining the Fen landscape is rising. The need to hold increasing quantities of water within the drainage network of the Fens for flood management, irrigation, public water supply, and drought mitigation will become more expensive as energy prices rise and the cost of operating drainage pumping stations rises commensurately [19]. The drainage network in the Fens is managed by several internal drainage boards (IDBs)—local public authorities that manage water levels in England where there is a requirement for drainage [20]. Under the 1991 Land Drainage Act, the primary role of IDBs is to manage water levels and reduce the risk of flooding within their district by maintaining existing drainage networks and new developments [21]. There are currently 53 IDBs within Cambridgeshire [21], 50 of which are responsible for pumping 95% of the area [22]. The larger rivers that pass through the Fens are managed by the Environment Agency (a government agency), with excess water pumped out to the North Sea via large sluices. The hydrological profile of the current Fenland landscape requires continuous investment of resources to mitigate flood and drought events, both of which are being exacerbated by climate change. The potential to raise water tables in the Fens is therefore a complex process, with trade-offs between local conditions and surrounding land uses. Areas managed with raised water tables, such as Wicken Fen (a National Nature Reserve), require intensive upkeep to maintain water levels against hydraulic gradients with the lower lying farmland and are at risk of drying up without ongoing investment to maintain surrounding banks and bunds [23]. Furthermore, many parts of the drainage network are manually operated, requiring an expert level of local knowledge and sufficient funding to maintain.

The historic wastage of peat soils, often by several meters, has led to a reduction in the area of the most productive land. Degraded (or wasted) peat soils are still farmed, and, should current C losses continue unmitigated, this will continue to reduce their productivity. Estimates suggest that the continued degradation of peatlands as a result of ongoing intensive land use will result in a decline in income generation from agricultural production [24]. According to the same estimates, however, a complete conversion from commercial farming to peatland restoration and conservation would result in an overall cost for landowners [24].

The interactions between these agricultural and restored land use systems revolve around the issue that if current production systems continue (i.e., business as usual), GHG emissions from the Fens will remain high. While there is money to be made from this agricultural production for the next 30–50 years [25], the land will eventually lose its productivity, potentially disrupting food self-sufficiency and livelihoods. Therefore, actions to decarbonize the agricultural system in the Fens and reduce CO_2 emissions from peat require a multidisciplinary and holistic landscape-scale approach. Consequently, agricultural peatlands and their potential to continue to contribute to meeting international agreements on climate change and biodiversity [26,27] are attracting national attention and are discussed in the Lowland Agricultural Peat Task Force Report [28], the UK Net Zero Strategy [15], and the UK's Environmental Improvement Plan [29]. The Lowland Agricultural Peat Task Force Chair's Report involves fourteen recommendations for more sustainable management of lowland peat soils, with most of these recommendations involving a focus on water management [28]. Actualizing the UK's commitments to international agreements such as the UN Convention on Biological Diversity and the

UN Framework Convention on Climate Change will require the implementation and maintenance of sustainable practices to facilitate changes to peatland management [30].

This essay synthesizes the discussions and outcomes of the 'Food/Net Zero Nexus in the Fens Workshop' held in March 2023, organized by the AgriFood4NetZero Network+. We identify alternative land uses for agricultural peatlands, considering sustainability and the UK's net zero emissions pathway, in the context of the relevant literature. The essay follows the structure of the discussions held within the workshop and ends with recommendations for further research into how the Fens can best be managed in the future.

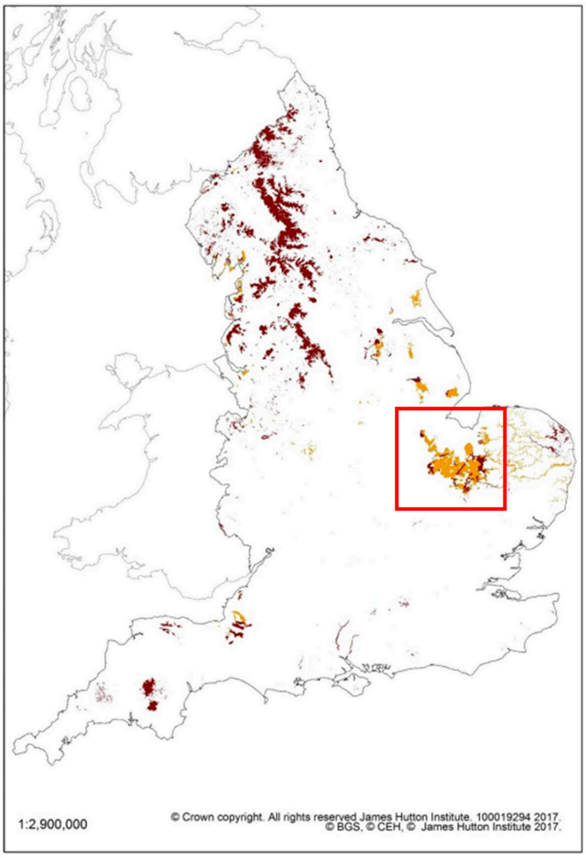

Figure 1. The approximate location of the Fens in the UK (red square), with deep peat in brown and wasted peat in orange [31,32].

2. Materials and Methods

The AgriFood4NetZero Network+ is an interdisciplinary, engaged research project funded by UK Research and Innovation (UKRI) to investigate plausible pathways and practical, open science to achieve net zero throughout the agrifood system by 2050. Within the Network+ are Champions with expertise in relevant issues and a board of early-career researchers (ECRs) with research interests related to the aims of the Network+. In March 2023, a workshop was held to review the state-of-the-art in land use science, peatland ecology, and socio-economic scenarios to identify key knowledge gaps and innovative pathways to a net zero agrifood future that would maintain the role of the Fens in food production. The workshop focused on four principal areas: (1) paludiculture (wetter farming) on agricultural peatlands, (2) the role of agricultural peatlands in C sequestration and food production, (3) the socioeconomics of peatland restoration, and (4) a case study of the Fens. Plenary lectures on each of these topics were given by invited speakers and discussed across five hubs. Participants included peatland and agricultural experts, academic researchers, ECRs, and members of organizations involved with the Fens (Natural England, Centre for Landscape Regeneration at the University of Cambridge, National Trust). Notably underrepresented were farmers and those involved in IDBs, something that has been identified as problematic by this essay (see Sections 3 and 4) and previous research. Attempts to remedy this and prevent such exclusion in the future are discussed in the following sections.

Each hub discussion was guided by five prompts: (1) current knowledge and knowledge gaps as to how current land use affects lowland peatlands, (2) how to define sustainable land management in the context of the Fens, (3) disparities between sustainable land management in general and when applied to the Fens, (4) prioritization of future work and actions, and (5) desired outcomes of the workshop. Discussions were focused on the environmental, economic, social, and technological implications of different scenarios seeking to transform land management in the Fens to achieve net zero GHG emissions while maintaining food production and achieving biodiversity net gain. Following each hub discussion, hubs provide feedback to the whole group, enabling a broad discussion between hubs and all participants in the workshop. **Following the workshop, key themes were drawn, and a draft document was produced and circulated to all workshop participants for comments. This manuscript was then revised, considering participant feedback, and again circulated for feedback to ensure that the multiple interests discussed during the workshop were represented in an accurate and balanced way. This second round of consultation allowed a final version of the manuscript to be drafted with all co-authors agreeing to the manuscript's conclusions and suggestions. These are discussed in the following sections.**

3. Results and Discussion

This discussion combines information from the plenary lectures and a synthesis of the main insights gained from the hub discussions held after each lecture.

3.1. Current Situation

As discussed, the drainage of peatlands for agricultural use and the provision of ecosystem services have resulted in sustained emissions of CO_2 into the atmosphere over past centuries. The Fens are incredibly important for UK food production; however, they produce a disproportionate share of the UK's food. Thus, one of the main challenges surrounding the future of the Fens is to maintain this crucial food production alongside the livelihoods of local communities while reducing soil loss, land subsidence, and CO_2 emissions from land use, ideally while also transitioning towards a situation where the sequestration of atmospheric CO_2 becomes possible.

3.2. The Role of Lowland Peatlands for Carbon Sequestration and Food Production

There are many ways in which lowland peatlands, including the Fens, could be managed more sustainably to reduce GHG emissions, such as complete or partial rewetting (see Section 3.2.1), paludiculture, and full restoration [28]. The complete, or near-complete, rewetting of agricultural peatlands may be required to move towards a genuinely net-zero landscape. The question of whether lowland agricultural peatlands should be completely removed from agriculture to achieve this was raised during the workshop; however, issues with the limited availability of water in the region, particularly in the summer months, which will be exacerbated by climate change [33], the complex nature of this water management, and the fact that there are very few food crops, if any, that could be grown under fully rewetted conditions mean that this is not a practical option for the region [5]. Furthermore, this would have significant negative economic and social implications for local communities and food self-sufficiency, where increased market demands would create a greater reliance on imported food, resulting in GHG emissions associated with displacement of food production and associated environmental degradation. The complete displacement of food production from agricultural peatlands is therefore not a sustainable solution.

The workshop subsequently focused on more practical and achievable solutions to the challenges faced. This included partial rewetting, which would involve continuing current farming with higher water levels and/or dynamic (i.e., seasonal) water level management, with some areas dedicated to complete restoration. This is in line with a report written by the Climate Change Committee [34], where 25% of lowland peat is proposed to be fully restored, while the CCC's 'Balanced Net Zero' report proposes the implementation of sustainable management (wetter management practices) on 75% of cropland on peat and rewetting 50% of grassland on peat by 2050 [34]. Given that croplands on peat are often drained to deeper depths (>100 cm) than what is required for cropping, implementing wetter management without shifting food production from peat areas could offer some emission reductions. For example, raising the average water table depth by as little as 10 cm could reduce carbon emissions by 3 t CO_2-eq ha^{-1} yr^{-1} dependent on peat depth [16]. There is also the potential for considerable emissions reductions through seasonal water management by raising the water tables through the winter months and continuing shallower drainage in the summer, although this remains to be tested. Evans et al. [35] state that 23–42% of CO_2 emissions occur between October and March. Although these practices offer some emission reductions, these areas will still remain a GHG source because drainage will still persist, as demonstrated by Schrier et al. [36], who showed that rewetted former agricultural peatland acted as a GHG sink, whereas peat used for agriculture with a comparatively lower water table still acted as a GHG source. It is also important to note that while wetter management generally reduces GHG emissions, there are potential trade-offs between reduced productivity, food production, and economic profitability.

To identify the most feasible options for how lowland peatlands can be managed for continued food production with decreased GHG emissions, it is crucial that discussions include perspectives from communities, farmers, local councils, food systems researchers, and water management experts. Understanding the current condition of peat at regional and local scales would enable farmers and policy makers to make more informed spatial choices relating to the management of agricultural peatlands. Remote sensing technologies, such as optical and radar, could be used to assist condition mapping by mapping wetness, vegetation greenness, motion, and the degradation status of agricultural peatlands [37–40]. This could then be used to support decision making on land use, crop selection, the allocation of subsidies, and more targeted restoration activities where appropriate. Furthermore, the use of models to predict the potential outcomes of different land use scenarios should account for any trade-offs and synergies associated with land use practices to enable farmers to transition in a viable way [41]. Models should also consider the scale at which land management should occur (i.e., regional, landscape scale, catchment level) for the most effective outcomes. When alternative management practices are established, farmers and potentially local councils should be supported in transitioning to a new system to enable change and reduce risk. Assurance from policy makers regarding the provision of long-term financial support would also be required.

It is important to acknowledge the shortcomings of this work in living up to its own recommendations. Insufficient attention was given to the inclusion of farmers in the workshop, and their voices were therefore essentially absent from the discussions. The fact that we are not alone in this respect exacerbates rather than ameliorates the failing. Academic work has and continues to recognize the importance of including farmers in such discussions, yet repeatedly fails to do so. For example, the recent Power to the Peatlands conference in Antwerp issued a final declaration that referred to the 'massive economic and environmental harm' caused by drained peatlands, called for full re-wetting, and stated that land users, landowners, decision makers, NGOs, scientists, and entrepreneurs should act together and find common ground [42]. Yet, amongst the over 500 peat experts in attendance, there was only one farmer. In contrast, the farmer-led 2023 Fenland SOIL conference in the UK was attended by over 100 representatives from the farming sector, along with a similar combined total number of scientists, conservationists, and policymakers, offering hope that genuinely collaborative approaches are possible. Time and renumeration remain major barriers to inclusion; farmers are already overburdened with work without taking on additional labor in the form of research participation, especially given the fact that they are not usually financially compensated for their time, as opposed to the academics, policy makers, and employees of NGOs involved who engage in such work as part of their core employment and receive a salary for doing so. In addition, and perhaps related to the inequalities highlighted in the previous statement, trusted working relationships between farmers and academics remain difficult to foster and maintain, thus limiting opportunities for genuine, productive, and multidirectional engagement. We discuss possible ways to improve future engagement with the farming community in Section 4.

3.2.1. Paludiculture on Agricultural Peatlands

Paludiculture may offer a sustainable solution to managing agricultural peatlands in the future, although the evidence base for this is currently being developed. Paludiculture is a way of farming with higher water tables, meaning there is the potential to reduce CO_2 emissions and land subsidence while maintaining crop production [16]. Furthermore, a higher water table can also reduce the risk of fires during heatwaves, such as those that occurred in the Fens in the summer of 2022 [43], which are becoming more frequent as a result of climate change.

Under paludiculture management, water tables would be maintained at 10–20 cm below the surface, as empirical evidence indicates this is the optimal depth for reducing combined CO_2 and CH_4 emissions [35]. Lahtinen et al. [44] evaluated two paludiculture product systems: cattail (*Typha*) for construction board and common reed (*Phragmites*) for horticultural vermicompost using life cycle assessment, both of which resulted in considerably lower GHG emissions than current agricultural land use. Cattail was a net GHG sink of around 6 t CO_2-eq ha^{-1}, and reed was a net sink of around 3 t CO_2-eq ha^{-1} [44].

Over 80 crops have been identified as feasible for cultivation under paludiculture conditions [45], which include crops for bioenergy, construction materials, the horticultural industry, textiles, and food production. Throughout Europe, however, paludiculture crops are mostly cultivated for biomass or fiber production [45], demonstrating a lack of commercial paludiculture examples for food crops. This results in a lack of evidence relating to whether they could be grown at scale and what the market demands and financial viability would be [33].

In August 2022, the UK Government announced the £5 million Paludiculture Exploration Fund (PEF) to promote the use of peatlands for sustainable farming by overcoming barriers to commercial paludiculture [46]. A workshop was held in Cambridge in January 2023 to begin work within the PEF [47], which was notable for the attendance of a wide range of stakeholders. Following on from this, several projects have been announced that will begin work in 2023/2024 [48]. The challenges associated with paludiculture include water availability, suitable machinery and management, the potential displacement of food crops, and financial viability in comparison to conventional farming practices.

There is an urgent need to rethink the established practice of continuously draining the Fens, where excess water is pumped out to sea every winter and water shortages occur during most summers. If more water could be stored within the landscape during times of plenty, it would be available for redistribution and irrigation in times of need. This will require changes in legislation and regulation, investment in infrastructure, and realistic incentives for farmers to invest in reservoirs and change current hydrological modification and management practices. Water shortages in the Fens are not just a constraint on paludiculture. The same requirement for a comprehensive change to water management will be required to sustain even 'business as usual' arable farming, as well as the significant housing development that is projected for the region.

In addition to the issue of water shortages, there are also significant challenges associated with how farmers manage their water levels. Improved monitoring capacity is required, and there is a need to address the question of whether there is sufficient access to information to enable farmers to manage water levels effectively. Research into blanket bogs shows that water table monitoring is becoming more accessible through reductions in the cost of field instruments and the development of satellite radars [37,38,45,49], although the latter may be less practical on a day-to-day basis. How these methods would work in the context of agricultural peatlands is less well-known, and obtaining such information would require close collaboration between policy makers, researchers, farmers, and those responsible for water management.

Furthermore, it will be important to listen to and consult with farmers about the costs of implementing management changes on their land, the impacts on profits, the practices needed to maintain them, and potential support payments, particularly as farmers/land managers have identified that the most effective emission reduction mitigation measures for agricultural peat (i.e., paludiculture) at the farm scale are the most costly and impractical to implement compared to the less effective mitigation measures [5].

3.3. The Socioeconomics of Peatland Restoration

Engaging with and understanding the views of those that live in the Fens and value the local landscape is crucial, as is an understanding of the cultural value of the Fens. Networks have already been established to consider these aspects of landscape regeneration (see Section 3.3.2). The economic costs of agricultural peatland restoration are significant, but there are many potential funding mechanisms for this. Because market-driven approaches are dynamic, funding via subsidies or incentives can be perceived by farmers and local councils as uncertain. If public funding is involved, public support and a justification of the costs will be vital for success. The social value and economic costs of agricultural peatland restoration are, however, not fully understood. In 2016, a survey was conducted in Scotland to gauge how supportive members of the public are to peatland restoration [50]: a 'willingness to pay' indicator was used to determine the value the public placed on peatlands and therefore how much they would be willing to pay for peatland restoration, and whether this would be a sufficient amount to finance peatland restoration. The study found that the public's willingness to pay for peatland restoration ranged from GBP 127 to GBP 414 per hectare per year, depending on where the restoration occurred and the extent of improvement [50]. Further social research should be conducted to explore how and why Fenland communities interact with and value the landscape and to establish potential barriers to interaction with and appreciation of the Fens. Specifically, research into how different stakeholders (i.e., farmers, local communities, and tourists) value peatlands in ways other than for agricultural production and economic output, potentially conducted using scenario-type analyses, would be illuminating.

3.3.1. The Cultural Importance of the Fens

The rich natural and cultural heritage value of the Fens, the legends, folklore, archaeology, and biodiversity cannot be ignored [51,52]. John Clare, the celebrated nineteenth-century 'peasant poet' from the Lincolnshire Fen edge, felt that "the Fens are not a literary part of England" [53]. Over the last century, however, writers and other artists have found in the Fens a symbolic, beautiful, and contested landscape, artificial and yet fringed by some of England's wildest places [54]. Insights into how the cultural value of the Fens has changed over time and how and when current land use practices became accepted would be valuable. For example, there was staunch resistance to the drainage of the Fens in the 1640s and 1650s by the 'Fen Tigers'. This group consisted of local people who made their livelihoods from undrained wetland usage and resisted its drainage and enclosure [52,55].

3.3.2. The Role of Networks in Landscape Regeneration

Due to the complexities surrounding peatland regeneration, the diverse views and values of various stakeholders underpin the future management of the Fen landscape. External drivers of peatland management, such as climate change mitigation and intensive food production, can contradict the values held by local people, potentially creating conflict between communities and local and national governments. When making decisions on the management of the Fens, the interests of all communities and stakeholders should be considered, including the voices of marginalized groups and flora and fauna. Landscape decisions need to be inclusive from many different perspectives, and consideration needs to be given to how different voices can be best represented [56], including the farming community (see Section 3.2). Networks, such as Fenland SOIL, Natural Cambridgeshire, and The Centre for Landscape Regeneration at the University of Cambridge, facilitate this and allow critical issues to be raised [57–59]. Tenant farmers, for example, may be concerned about potential discrepancies between their tenancy agreements, which require them to keep land in good agricultural condition, and the incentives and funding requirements surrounding ecological restoration, which may result in breaches of tenancy agreements. In addition, it is difficult to predict how government policies will change in the future, making it difficult for farmers to make long-term land management decisions or investments, such as purchasing new machinery or creating water management infrastructure.

Given the failure of this work to engage with the farming community at an early stage, we attempted to address this shortcoming by collaborating with a representative from Fenland SOIL on drafts of this essay. In addition, during the final stages of editing the manuscript, the lead authors were given the contact details of two farmers to approach for discussion and comment; however, due to the time frames imposed by academic publishing, it was not possible to include them. This reinforces the need for academics and farmers to engage at the early stages of workshop and research planning so that work can accommodate farming schedules and progress to mutually agreed time scales rather than attempting to impose academic time frames on farming collaborators. In addition, farmers engaged in research collaborations should be compensated appropriately for their time and expertise rather than being expected to undertake this on a voluntary basis. This will reassure farmers that the desire to engage is genuine and that academics take this commitment seriously rather than paying lip service to it.

In addition, while many academics and research centers are conducting research to explore alternative land management options, farmers are also actively engaged in exploring this at a more applied level. We suggest that further work be done to capture this practical work alongside the theoretical work so that the two approaches can be juxtaposed and synergies can be identified.

The Fens currently score poorly on many indicators of social health and wellbeing, such as the percentage of physically active adults and the number of children in low-income families [60]. One measure of the success of future management practices for the Fens will be the regeneration of the region for the benefit of those who live there. It will therefore be important to engage with local communities to establish what the wishes and aspirations of local communities are. Collaborating with the many community organizations in the area will facilitate the development of solutions with stakeholders, businesses, and residents. To develop appropriate solutions for peatland management and regeneration, we must facilitate effective knowledge exchange between the many diverse actors and networks who are involved in this decision making and ensure that all critical groups are involved in these discussions. Networks enable community members to be provided with the necessary information for decision making. In addition, while there are many members of the community who are actively engaged in this work, there are also many who are not, and so a focus on incorporating under-represented groups into networks and decision making would also be beneficial.

3.3.3. Case Study: The Centre for Landscape Regeneration at the University of Cambridge

As an example of the multi-disciplinary, engaged research that is vital to exploring how changes in land management across the Fens could work to reduce GHG emissions while considering all the other factors of importance to the region, participants heard about The Centre for Landscape Regeneration (CLR) [61]. The CLR is a new, interdisciplinary research centre that is focused on a holistic view of landscapes and evidence gathering to support decision making on land use. The CLR's primary aim is to provide an integrated knowledge framework and evidence base to support the regeneration of British landscapes for a range of benefits, including biodiversity recovery and climate change mitigation, while clearly considering socio-economic factors. The CLR is concentrating its first phase on the Cambridgeshire Fens; it will consider how it might be possible to reduce, and perhaps reverse, GHG emissions and the loss of lowland peat, manage water more effectively in the face of climate change, and allow typical Fenland biodiversity to recover whilst also allowing the landscape to remain a source of fresh food for the UK and sustain the farming, businesses, and communities that depend on the land. It will explore future potential landscapes via land-use scenario modeling that explores alternative land uses and examines the trade-offs between them. To achieve this, the CLR is collaborating with local stakeholders to understand their relationships with the landscape and to explore how their needs could be met by co-designing solutions to land use challenges.

Stakeholder networks are place-specific and, in the Fens, include farmers, the water industry, nature reserves, conservation non-governmental organizations, landowners, policy makers, local businesses, parish councils, and community grassroots organizations, as well as other peatland research projects that are being created as a result of recent funding. A simple systems analysis [61] analyzes the communications connections between these stakeholders and identifies key 'hubs' through which the flow of information is greatest. These include the farmer-led consortium Fenland SOIL, the charity Natural Cambridgeshire, and Future Fens, a project convened by the Environment Agency, Anglian Water, and Water Resources East. Each of these has a wide network of collaborating organizations and long-standing relationships of trust with community groups. Strong engagement with and through these hub organizations provides direct communication with most of the rest of the network and enables engagement with grassroots organizations in the most efficient way possible. The CLR provides a potential model for interdisciplinary environmental research, taking a holistic approach to landscapes and working closely with a wide range of stakeholders, communities, and researchers to explore a way forward in complex landscapes.

4. Conclusions and Prospects

There is a clear need to focus on the practicality of how GHG emissions in the Fens can be reduced while ensuring continued food production and considering the needs of Fenland communities. When considering changing land management practices or land use, views, ideas, and input from farmers are clearly important. It will therefore be crucial to establish what information and support farmers require before suggesting any changes to land use management. This is something that many of the researchers involved in the workshop discussion and writing of this essay are actively addressing (e.g., with the CLR and Fenland SOIL). Research must be responsive to the needs and constraints of farmers, other land managers, and wider communities and incorporate their practical knowledge rather than attempting to impose 'top-down' academic solutions that cannot be implemented within commercial farming systems. Two-way communication with farmers and stakeholders is key to ensuring that any changes are acceptable and feasible for Fenland communities and businesses. Research needs to listen to communities to provide an understanding of what drives behavior change in the Fens, barriers to change, and how drivers and barriers differ between diverse Fenland stakeholders. This information, combined with modeling approaches and community engagement, will be important for developing future scenarios and understanding how they would be received by different groups within Fenland communities. This would be constructive in developing an evaluation framework to reflect the socioeconomic and ecological value of the Fens, identify the trade-offs of continuing or reducing GHG emissions, investigate the factors influencing this, and develop management strategies for future peatland use. In addition, workshop participants identified areas where specific transdisciplinary peatland research is needed, with academia, industry, and stakeholders collaborating to explore how changes in land management across the Fens could work to reduce GHG emissions while considering all the other factors of importance to the region. This research should include:

(i) an estimate of the GHG emissions reduction that can realistically be delivered from agricultural peatlands to achieve net zero emissions by 2050.
(ii) the environmental (including GHG emissions), economic, and social implications of removing lowland peatlands from agricultural production and/or the adoption of alternative production systems.
(iii) whether efforts on GHG emissions mitigation and C sequestration would be better focused elsewhere so that food production can continue on lowland peatlands.
(iv) the levels of food production (for human consumption) that would be achievable if farming management prioritized a reduction in GHG emissions.
(v) how a transition to more seasonal farming, integrated with wetter management practices, could offer a potential solution.
(vi) how removing some agricultural peatland from conventional farming and instead using it for paludiculture would impact biodiversity, financial viability, and human food self-sufficiency.
(vii) what a localized, mosaic approach to land management could look like for the Fens, considering the pressures of ensuring food production, supporting biodiversity, reducing GHG emissions, and supporting the socio-economic wellbeing of the region.

The workshop participants acknowledged the scale and significance of this challenge and the importance of ensuring involvement and support from local communities, farmers, and businesses. Continued collaboration and an engaged conversation will be vital.

Author Contributions: Conceptualization, H.B.; Methodology, I.L.L., C.O. and V.T.; Funding acquisition, H.B.; Investigation, I.L.L., C.O. and V.T.; Project administration, I.L.L., C.O. and V.T.; Supervision, H.B.; Writing—original draft, I.L.L. and C.O.; Writing—review and editing, H.B., I.L.L., C.O., V.T., A.V.B., P.B., B.D. (Brenda D'Acunha), B.D. (Beth Delaney), H.D., C.D.E., K.J.F., J.A.F., R.M.F., L.E.F., G.H., J.K., R.M., F.R.M., P.N., S.E.P., M.H. and J.M.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the UKRI AgriFood4NetZero Network+, grant number EP/X011062/1. The Centre for Landscape Regeneration is supported by the Natural Environment Research Council (NERC), grant number NE/W00495X/1.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors wish to thank the AgriFood4NetZero Network+ for providing funds for the organization of the workshop. Further thanks to R.M.F. and H.D. for organizing in-person hubs at Newcastle University and the University of Cambridge, respectively, and to C.D.E., L.E.F., J.K., P.N. and S.E.P. for giving plenary lectures at the workshop.

Conflicts of Interest: The authors declare no conflict of interest.

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