UK Research and Innovation

Multifunctional Metrics: Rethinking sustainability in food systems

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About the AFN Network+

The AFN Network+ (UKRI Agri-food for Net Zero Network+) is a unique network of 3,100+ academics, researchers, third sector organisations, policy makers, and agri-food industry professionals from farmers to retailers.

Together, we are working to identify key research gaps that may be holding the UK food system back from transitioning towards a net zero UK by 2050, while also enhancing biodiversity and healthy ecosystems, nurturing livelihoods, supporting healthy consumer habits, and minimising the environmental impacts of overseas trade. Our findings will inform the next decade of research investments in this area by UKRI (our funder and the UK research councils umbrella organisation).

Alongside our core research, we run in-person and online events, produce topical resources, and give out hundreds of thousands of pounds of funding a year.

The AFN Network+ is coordinated by the University of East Anglia, University of the West of England, University of York, and University of Leeds, and is a £5m, 3-year project funded by four research councils; the Biotechnology and Biological Sciences Research Council, Economic and Social Research Council, Engineering and Physical Sciences Research Council, and the Natural Environment Research Council.

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While anthropogenic climate change is perhaps the most pressing threat to human society and environment, it is a common fallacy that it can be tackled independently of other crises we face, such as biodiversity collapse. For example, climate change accelerates biodiversity loss through habitat destruction and ecosystem disruption[1], and in turn, biodiversity loss reduces ecosystems' capacity to sequester carbon and adapt to climate impacts[2]. Similarly, social inequality undermines collective climate and environmental action, while climate change and environmental degradation disproportionately harms vulnerable populations.

Integrated approaches such as nature-based solutions offer several advantages. Agroecology and other circular, low-input farming systems demonstrate remarkable potential for carbon storage, biodiversity enhancement, and climate resilience while maintaining productive capacity and remaining within ecological boundaries[3],[4]. Crucially, they demonstrate both climate mitigation *and* climate adaptation potential, offering significant potential to improve the resilience of our food systems to environmental and impacts of climate change. By delivering against multiple outcomes, these approaches also facilitate policy coherence[5]. While land-sparing approaches which rely on the (sustainable) intensification of agriculture have an important role to play in a sustainable future for the food system, they cannot be relied upon to deliver needed ecological outcomes alone. The demands on land already exceed its availability in the UK, and biodiversity recovery cannot be achieved in isolated areas, requiring areas of low-intensity agricultural habitat for connectivity, landscape diversity, and ecological functioning[6].

However, these transformative approaches receive insufficient emphasis in policy development, research funding, and implementation support[7],[8]. Realising our climate and biodiversity goals requires balancing investment to recognise the role of farming systems that are supportive of natural processes, rather than ones that are prejudicial to them, or contribute to greater path dependency. This requires new frameworks for evaluating outcomes across multiple metrics, and governance structures at multiple scales that can coordinate across traditional sectoral boundaries. This paper argues that agroecology and circular farming practices such as agroforestry, crop-livestock integration, and low-input livestock systems warrant a much larger role in food system transformation than currently reflected in the research and policy landscape, due to their ability to deliver against multiple ambitions.

Part 2 of this report comprises a review of the evidence for three circular, low-input practices (agroforestry, crop-livestock integration, and low-input grazing of diverse swards) against the themes of: climate change mitigation and net zero; climate change adaptation; biodiversity; and financial viability.

[1] Pecl et al., 'Biodiversity Redistribution under Climate Change'.
[2] Weiskopf et al., 'Biodiversity Loss Reduces Global Terrestrial Carbon Storage'.
[3] Blaix et al., 'Agroecological Interventions Increase Biodiversity and the Potential for Climate Change Mitigation in Europe'.
[4] Altieri et al., 'Agroecology and the Design of Climate Change-Resilient Farming Systems'.
[5] Andrews et al., 'Putting Food in the Driver's Seat'.
[6] Kremen, 'Reframing the Land-sparing/Land-sharing Debate for Biodiversity Conservation'.
[7] F. and P., *Agroecologically-Conducive Policies*.
[8] Zeng et al., 'Agroecology, Technology, and Stakeholder Awareness'.

Introduction

As with all sectors and industries, there is an urgent need to decarbonise the food system, which is responsible for approximately a quarter of the UK's greenhouse gas (GHG) emissions[9]. Unlike other sectors, however, land has the unique capacity to not just mitigate harm by reducing greenhouse gas emissions; it can deliver tangible benefits through actively sequestering carbon and providing public goods such as clean water, healthy soils, and biodiversity.

There is already ample evidence demonstrating the harmful impacts that agricultural practices can cause along a range of metrics: direct and indirect greenhouse gas emissions from methane, nitrous oxide, and carbon dioxide; soil erosion and compaction; overuse of water, pollution of our waterways through oversupply of nutrients through animal manure and agricultural chemicals; and biodiversity decline. There are also competing demands for land, including but not limited to agriculture (which currently accounts for between 60 and 75% of the UK land area), development (including for housing), renewable energy, and nature restoration.

The practical question of which kind of farm practices facilitate outcomes such as the delivery of public goods is one part of the equation; the other, is how to do so whilst also supporting equitable access to nutrition for all and providing a viable income for the farmers involved.

Why resilience matters

The need to shift towards an equitable, productive, and sustainable food system requires embedding the principle of resilience at all stages of the supply chain. From a food security standpoint alone, the UK is self-sufficient in approximately 62% of its food, although for fruit and vegetables that figure is lower at 17% and 55% respectively[10]; many of the countries that we source from (such as Spain, from where we procure the highest proportion: 19%), are themselves increasingly vulnerable to the impacts of climate change[11]. Relying on imports to compensate for shortfalls in domestic production leaves us vulnerable to a range of risks.

We rely on a network of globalised supply chains both for direct agricultural products, but also the raw materials required to produce them, such as ammonia for fertiliser. Chatham House illustrated this vulnerability in the 2017 report "Chokepoints and Vulnerabilities in Global Food Trade", noting that over half of internationally traded grain and fertilizer passed through one of three "chokepoints" in the global shipping system, a dependence which is predicted to increase in line with the growth in global trade[12]. The report suggested that there were three main areas of risks in regards to these global trade routes; i) climate change related hazards ii) security or conflict related hazards and iii) institutional hazards (such as the imposition of export controls). These hazards are exacerbated by increasing reliance on these routes, a chronic underinvestment in existing and alternative infrastructure and capacity, and of course, climate change, which increases the likelihood of supply chain disruption across all categories.

The UK food system is vulnerable to disruption globally (whether due to climate change impacts, geopolitical instability, or generic supply chain disruption), but it is also vulnerable domestically. The prioritisation of efficiency in supply chains has culminated in strategies that undermine their overall resilience to disruption, through mechanisms including "just in time" logistics and the consolidation of suppliers[13]. Such vulnerabilities were made starkly apparent by the COVID pandemic[14]. In contrast, by diversifying supply chains and growing the market share of SME producers and the role of regional supply chains we can increase the adaptability and resilience of our national supply chains[15]. Major retailers also have a role to play, by expanding product ranges to incorporate a wider variety of crops[16], sourcing from a greater number of producers, and proactively investing in robust risk mitigation strategies[17].

Government similarly should prioritise food system resilience to a much greater extent than it currently does, as there is a palpable lack of recognition of the vulnerability of our food system, with negligible reference to food in either the

[9] Hamish Forbes, Karen Fisher, Andrew Parry, *UK Food System GHG: Total UK Food & Drink Consumption Footprint and Pathway to a 50% Reduction by 2030*.
[10] 'UK Food Security Index 2024 - GOV.UK'.
[11] 'United Kingdom Food Security Report 2024: Theme 2: UK Food Supply Sources - GOV.UK', 2; 'Inspiring and Enabling Communities: The Integrated Local Delivery Model for Localism and the Environment', 2.
[12] Bailey and Wellesley, *Chokepoints and Vulnerabilities in Global Food Trade*.
[13] Garnett et al., 'Vulnerability of the United Kingdom's Food Supply Chains Exposed by COVID-19'.
[14] Ibid.
[15] *Food from Somewhere: Building Food Security and Resilience*; Gomez et al., 'Supply Chain Diversity Buffers Cities against Food Shocks'; 'Growing the Local Food Sector'.
[16] Azam-Ali et al., 'Diversifying the UK Agrifood System'.
[17] Hobbs and Hadachek, 'The Economics of Food Supply Chain Resilience'.

National Risk Register, or in the Government Resilience Framework[18]. Discussions of food security from a national perspective typically consider food security as a factor of production or global markets, and fail to reckon with nutritional inequalities as a result of income inequality; consequently, the policy levers that can increase food access in vulnerable populations (such as expanding eligibility and uptake of Healthy Start[19], or ensuring that everyone who is entitled to government support is in receipt of it[20]) are rarely considered as part of a strategy towards improving national food security.

What then, does a resilient food system look like? A 2022 analysis conceptualised resilience guided by four questions; *Resilience of what? Resilience to what? Resilience from whose perspective?* and *Resilience for how long?*. The writers proposed three qualities necessary for a resilient food system; robustness, recovery, and reorientation[21] and posit that the latter might be the most critical to resilience that is both profound and enduring, as it entails a proactive and voluntary restructuring, rather than minor adjustments. Given the degree of existing food insecurity in the UK, aspiring towards greater robustness and recovery is not in itself enough to ensure food security for all without reorienting our political and economic strategies to explicitly target nutritional inequality; similarly, if the UK fails to adequately re-orient in recognition and anticipation of climate change, we risk being grossly underprepared for the climatic and geopolitical conditions we are proceeding towards.

Clearly, the solution to a resilient food system is not as straightforward as simply ramping up domestic production. The UK's agricultural system is already oriented around principles of efficiency and productivity, and this has incurred a range of perverse outcomes particularly among environmental indicators. Extrapolated to a global scale, this has led to the environmental and health costs of food production greatly exceeding its market value and economic contribution[22]. In 2018 the Food and Agriculture Organisation suggested that our current productivity oriented trajectory was not inclined to lead to a reduction in world hunger, but that "significant undernourishment" was likely to still be a global issue in 2050, even if we were to increase agricultural output by 50%[23]. Within our current paradigm of efficiency, food waste and harmful agricultural practices are externalised and therefore 'cost effective', despite generating true costs for ecological and human health[24][25]. As long as we fail to accurately account for the social, and environmental outcomes of production, these negative externalities will inevitably continue to accumulate.

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[18] Lang, *Just In Case: Narrowing the UK Civil Food Resilience Gap*.
[19] 'Low Hanging Fruit: A Policy Pathway for Boosting Uptake of Plant-Rich Diets'.
[20] 'The Cost of Hunger and Hardship: Interim Report'.
[21] Zurek et al., 'Food System Resilience'.
[22] Benton and Bailey, 'The Paradox of Productivity'.
[23] *Chapter 5*, 5.
[24] 'The False Economy of Big Food and the Case for a New Food Economy'.
[25] Hendriks et al., 'The True Cost of Food'.

Circularity

Many of the environmental impacts in our food system are the result of our current linear practices, which rely on constant external inputs and generate waste products, both of which carry environmental impacts. This is facilitated by an economic ideology which makes it less cost-effective to embed circular principles throughout the value chain. Achieving sustainable food systems requires the incorporation of circular economy principles into Life Cycle Analysis-based assessments to better reflect the complexity and wider impacts of food production, consumption, and waste systems[26],[27]. The need for this is clear; from an agricultural inputs perspective, Europe has already exceeded the planetary boundary for nitrogen use[28], and it is estimated that 45% of nitrogen fertiliser isn't absorbed by plants, which is financially inefficient for farmers as well as damaging to the environment. Rock phosphorus is a finite resource that is being rapidly depleted, and is highly concentrated geographically, with 85% sourced from just five countries[29] while the emissions associated with the production of ammonia for nitrogen fertilisers carries a climate impact exceeding that of commercial aviation at 2.6 gigatonnes of carbon dioxide equivalent (CO2e) per year[30]. From an output perspective, current non-circular practices mean that valuable fertilizer from livestock systems is poorly utilised and unevenly distributed across the farming landscape, causing serious pollution and wasting nutrients[31]. There are a range of opportunities to increase circularity at all stages of the supply chain, from the utilisation of food waste, either directly as livestock or insect feed, or the use of manure as a feedstock for anaerobic digestion[32]. Enabling such developments can help the food system mitigate many of the impacts currently associated with food production, processing, transport, and consumption, and reduce emissions and demand for resources. Improving the efficiency of nutrient use and recycling is therefore critical to remaining within multiple planetary boundaries, and for reducing emissions. One study found that adopting fully circular practices in all parts of the food system would reduce agricultural land use by 71% and greenhouse gas emissions per capita by 29%[33]. While full circularity is not necessarily desirable or achievable, there is clearly potential for significant gains, even with existing technologies.

If we aim to reduce dependence on external inputs such as livestock feeds and synthetic fertilisers, and to incorporate greater principles of circularity into these systems, then we are led almost inevitably to the need for multifunctional landscapes.

Multi-functional land use

The demands on land in the UK exceed the total area of existing landmass, let alone what is ostensibly "available"[34]. Too often, issues such as biodiversity decline, climate change, health and nutritional access, and soil degradation are tackled and legislated for in disciplinary silos[3536]. Contributing to this issue is the fact that many models are generated that reflect the notion that land use is in-effect "zero sum", in that each unit of land is best dedicated to maximising one particular output, whether food, biodiversity restoration, housing, or more. However, this belies the reality that most land already delivers multiple outcomes[37], and ignores many of the possibilities that lie in recognising the potential for synergy in achieving many of our environmental, agricultural, and economic goals. Due to land availability constraints and competing demands for land use, it seems inevitable that siloed policy-making that centres around delivering individual outcomes is doomed to lead to policy incoherence and inefficient and perverse outcomes.

While it is undeniable that emissions need to be drastically reduced across all sectors, land can also deliver other positive outcomes in addition to decarbonisation and carbon storage from agriculture. According to the State of Nature 2019 report, 41% of UK species have shown strong or moderate decreases in abundance since 1970 while 27% of species have experienced strong or moderate decreases in distribution over the same period[38]. The UK government has committed to restoring 500,000 hectares of wildlife rich habitats outside of protected areas by 2042, alongside protecting 30% of the UK's land and sea by 2030[39]. Because biodiversity is difficult to model, it is not uncommon to

[26] Moores et al., 'Incorporating Circularity, Sustainability, and Systems Thinking into an Assessment Framework for Transformative Food System Innovation'.
[27] Lu and Halog, 'Towards Better Life Cycle Assessment and Circular Economy'.
[28] Steffen et al., 'Planetary Boundaries'.
[29] 'Q&A: What Does the World's Reliance on Fertilisers Mean for Climate Change? - Carbon Brief'.
[30] Ritchie et al., 'Breakdown of Carbon Dioxide, Methane and Nitrous Oxide Emissions by Sector'.
[31] Bujang and Lopez-Real, 'Composting for the Treatment of Cattle Wastes'.
[32] 'Guidelines on the Role of Livestock in Circular Bioeconomy Systems'.
[33] Van Zanten et al., 'Circularity in Europe Strengthens the Sustainability of the Global Food System'.
[34] King et al., *The Emerging Global Crisis of Land Use*.
[35] Abson et al., 'Leverage Points for Sustainability Transformation'.
[36] Andrews et al., 'Putting Food in the Driver's Seat'.
[37] Copping et al., 'Solar Farm Management Influences Breeding Bird Responses in an Arable-Dominated Landscape'.
[38] 'State of Nature 2019'.
[39] 'Nature Recovery for Local Authorities | Local Government Association'.

encounter land-use modelling that homogenizes the 65 broad habitat classifications in the UK Biodiversity Action Plan into categories such as arable land, grassland, and areas suitable for biodiversity restoration (or sometimes even just reforestation)[40]. However presenting land use as a dichotomy between nature and food production belies the role that low-intensity agriculture has played in the creation and maintenance of the varied habitats that historically characterise UK landscapes. We need land use models that are able to grapple with the complexities of multifunctional landscapes, and can recognise that food production and biodiversity restoration or ecosystem functioning are not zero sum, "as though food production cannot be woven into nature protection, and as though nature protection does not provide security and sustainability for food."[41]

Multi-functional approaches to land use are a more holistic approach, which can recognise the interdependencies and synergies between different activities and outcomes. Rather than viewing a unit of land as being suitable for only one "use", (whether that be arable agriculture, grazing livestock, forestry, biodiversity restoration, energy production etc) multifunctional land use describes a land use strategy which attempts to reconcile competing demands on land and to harness potential opportunities for synergy, while minimising trade-offs.

A multi-functional approach recognises that all land provides various market and non-market services, in ways that are not often measured or captured when considering their value; when we categorise land only according to its ability to deliver the primary "product" generated, we externalise the other positive outputs (services) but also negative impacts (disservices)[42][43], leaving an incomplete account for decision making. For example, an indoor poultry unit in the Wye Valley might be considered highly productive (and efficient) from a food production and emissions standpoint, but in terms of impact on local biodiversity and water quality the generated impacts may be harmful. If we focus our policy and research funding on single metrics (e.g. greenhouse gas emissions' intensity) believing that we can address others separately, we risk hitting the "target" of Net Zero, while missing the underlying point of food system sustainability[44]. We should be wary of building path dependency into a system that is already failing to deliver necessary outcomes.

If we attempted to enhance the multifunctionality of more of our land, we might not see certain metrics maximised in the same way, but we could feasibly deliver greater benefits across a range of metrics. Well-designed agroforestry systems are prime examples; incorporating trees into agricultural land (whether grassland or arable) can increase carbon storage while providing food and supporting biodiversity and wider ecosystem functioning. Similarly, grazing sheep under solar panels can allow for energy production alongside food production, and, if managed well, greater biodiversity[45].

Issues with Monitoring and Evaluation

If we adopt a multifunctional approach to land use decision making then our approaches to evaluation must similarly become more holistic to account for the variety of positive and negative impacts incurred across a wider range of metrics. Our current strategies are not fit for this purpose. A range of approaches to food system sustainability are required to reach net zero; more intensive systems may be better able to adopt practices such as transitioning to renewable energy and precision agriculture, while others may more easily be able to reduce dependency on fossil fuels and emphasise nature-based solutions. This section examines the key challenges in current monitoring approaches, including limitations in carbon accounting systems, issues with data quality and modelling assumptions, problems of scale and system boundaries, and methodological choices that influence how environmental impacts are assessed and interpreted.

Limitations of Current Carbon Accounting Systems

While current carbon accounting systems might be suitable for more linear and intensive systems, they have several shortcomings when evaluating more complex and multifunctional farm systems, which are less replicable in lab environments. This carries implications for how accurately these systems are currently modelled, which in turn is used to support policy development. For example, the writers of the 7th Carbon Budget acknowledge that due to a paucity of data pertaining to regenerative agricultural practices, they were unable to include recommendations regarding these practices in their budget[46]; rather than leading to greater investment in research in these areas, there is a risk that policy

[40] Smith et al., 'Sustainable Pathways towards Climate and Biodiversity Goals in the UK'.
[41] 'Just in Case: Executive Summary'.
[42] Altieri et al., 'Agroecology and the Design of Climate Change-Resilient Farming Systems'.
[43] 'Discussion Paper 5.5: Ecosystem Disservices and Externalities'.
[44] Aubert, *Agroecology and Carbon Neutrality: What Are the Issues?*
[45] Copping et al., 'Solar Farm Management Influences Breeding Bird Responses in an Arable-Dominated Landscape'.
[46] *Climate Change Committee Answers Your Questions on Net Zero, Farming, Diets & Land*.

and research further sidelines these practices and systems by emphasising more well-understood interventions and failing to invest research capacity into under-researched areas, exacerbating our path dependency.

Data Quality and Modelling Assumptions

The quality of the data used to generate models is also important; the majority of models are not based on farm-level data but are broad extrapolations of oversimplified systems, which can undermine their use value in real-world settings. For example, a carbon calculator might model the emissions impact from the manure from an out-wintered cattle herd using data gathered from an intensive system in which they remain in a yard and produce slurry over winter, rather than an Adaptive Multi-Paddock (AMP) outwintered system in which their manure is deposited on pasture to decompose aerobically. These kinds of modelling decisions have significant implications for farmers or policy makers looking to make evidence-based decisions to increase sustainability.

Similarly, while it may make more sense to focus on the decarbonisation potential of intensive systems, rather than their likely negligible carbon storage potential, this is not the case for more extensive multifunctional approaches; on-farm carbon accounting doesn't typically account for offsets at the farm level, and could better account for the carbon storage potential of systems[47]. For example, the methane emissions from a herd might be accounted for in a carbon calculator, and baseline grassland sequestration levels discounted, but the added sequestration from improved grazing practices will typically not be accounted for. There is a need for better on-farm data for soil carbon storage to support more accurate modelling, and a need to develop more appropriate Life Cycle Assessments for agroecological and regenerative systems. This is particularly true for different grazing strategies which are rarely adequately represented in research despite increasing uptake among farmers, and their impacts on factors like agricultural productivity, and biodiversity or ecosystem functioning[48].

[47] Bretscher et al., 'Opportunities and Limitations of Farm-Level Greenhouse Gas Accounting Tools'.
[48] Norton et al., 'Identifying Levers for Change in UK Grazing Livestock Systems'.

Scale and System Boundary Challenges

The scale at which we evaluate the impacts of sustainability practices also matters. Decreasing the emissions intensity for a unit of a particular food as a product-level does not necessarily mean that overall emissions will decline if these gains facilitate increased consumption[49], nor that increasing productivity per unit area of land or animal will facilitate the availability of land available for other uses[50] [51]. The tendency for increased efficiency to lead to greater, rather than reduced, resource use is known as Jevons Paradox, and is of critical importance when increased efficiency is suggested as a solution to issues of resource use or emissions; without policy or financial levers in place that keep consumption at a steady (or decreased) rate, these gains are at risk of being rapidly subsumed by increased rates of consumption[52].

Similarly, although significant reductions in greenhouse gas emissions can and should be achieved by transitioning to renewable energy sources (whether to power the Haber Bosch process that allows the production of nitrogen based fertilisers, or in processing and transportation) this in itself is not an effective measure of increased sustainability; in order to avoid the pitfalls of Jevons Paradox we must reduce overall energy consumption. As highlighted in a 2025 report about sustainability in Australia's food system "In other words, no product in and of itself can ever be inherently sustainable regardless of quantity. It can only be so as part of a sustainable food system."[53] By reorienting our food system to be less dependent on fossil fuels (whether directly, as with diesel tractor use, or indirectly, from the production of animal feeds or fertilisers) we also have the added benefit of greater supply chain resilience, and open up opportunities for wider ecosystem health benefits[54].

Methodological Approaches: Attributional versus Consequential Life Cycle Assessment

The methodological choice between Attributional and Consequential life cycle assessment approaches influences how environmental impacts are quantified and interpreted in food systems, with implications for policy development and sustainability assessments. Attributional LCA (ALCA) allocates emissions based on average data and current production systems, providing a static representation of impacts at the product level. In contrast, consequential LCA (CLCA) considers system-wide effects of changes, such as shifts in production methods or consumption patterns, modelling the potential consequences of interventions[55] [56].

While ALCA is useful for understanding emissions intensity under existing conditions, it may not adequately capture the broader implications of decisions intended to reduce environmental impacts. For instance, a switch from soybean meal to rapeseed meal in pig diets may appear to reduce land use under ALCA, but CLCA can show that the change might lead to increased emissions due to market-mediated effects[57]. When extrapolated to a food system level, attributional approaches risk perpetuating the dynamics described by Jevons Paradox by presenting efficiency improvements at the product level without accounting for effects that may ultimately increase total environmental impacts. Consequential assessments in contrast, attempt to model these feedback effects, though they require assumptions about market responses and system boundaries that introduce different types of uncertainty[58].

The choice of methodology can influence policy conclusions, particularly regarding interventions aimed at improving resource efficiency or reducing environmental impacts. Attributional findings may support policies focused on improving per-unit performance, while consequential findings may highlight the importance of policies that address total consumption levels or system-wide effects. Both methodologies face limitations in capturing the full complexity of food system sustainability; attributional approaches may not account for important indirect effects or system responses, while consequential approaches involve greater uncertainty in modeling and behavioral responses[59]. In light of this, relying solely on ALCA may be insufficient when evaluating strategies for emissions reduction, especially if these strategies are expected to drive more transformation change. By combining both attributional and consequential

[49] 'Re-framing the Climate Change Debate in the Livestock Sector: Mitigation and Adaptation Options - Rivera-Ferre - 2016 - WIREs Climate Change - Wiley Online Library'.
[50] Ewers et al., 'Do Increases in Agricultural Yield Spare Land for Nature?'
[51] McNicol et al., 'Net Zero Requires Ambitious Greenhouse Gas Emission Reductions on Beef and Sheep Farms Coordinated with Afforestation and Other Land Use Change Measures'.
[52] Kremen, 'Reframing the Land-sparing/Land-sharing Debate for Biodiversity Conservation'.
[53] Nelson et al., *Towards a State of the Food System Report for Australia*.
[54] 'Fixing Nitrogen: The Challenge for Climate, Nature, and Health'.
[55] Dominguez Aldama et al., 'Allocation Methods in Life Cycle Assessments (LCAs) of Agri-Food Co-Products and Food Waste Valorization Systems'.
[56] Finnveden et al., 'Recent Developments in Life Cycle Assessment'.
[57] Van Zanten et al., 'Attributional versus Consequential Life Cycle Assessment and Feed Optimization'.
[58] Weidema et al., 'Attributional or Consequential Life Cycle Assessment'.
[59] Ibid.

approaches, it becomes easier to assess not only the current state of emissions but also the likely outcomes of proposed changes, providing a more robust basis for policy and planning.

Livestock and Land Use

In modelling exercises, researchers often use simplified extremes to show potential upper bounds of land-sparing and climate mitigation outcomes versus a business-as-usual approach, typically for illustrative rather than prescriptive purposes. However there has been comparatively little modelling of the implications of a default livestock system, in which feed-food competition is eliminated, and animals are fed only on pasture, as part of crop-rotations, or on by-waste-, or co-products[60]. From a food waste perspective, while there are benefits to reappropriating food waste as livestock feed, there are significantly greater environmental benefits accrued from avoiding the production, processing, and transport of wasted food in the first place[61]. The "Food Use Hierarchy" advocates for priority being given to avoiding waste in the first place, followed by utilising it for humans, then by livestock, composting, and finally, anaerobic digestion.

Due to monogastric animals' inability to effectively convert forage, and their ability to efficiently convert food-waste, there is a case to be made for prioritising food waste (whether directly, or indirectly as larvae feed) towards this sector, rather than towards ruminants, who can be effectively reared off of crop-residues and grassland alone. Analyses of production efficiency using Feed Conversion Ratios (FCR) typically find that grass-fed livestock are the least efficient converters of feed (requiring the greatest volume of food to produce a kilogram of product) with farmed salmon and poultry being the most efficient. However, if comparing the quantities of human edible protein required to produce a kilogram of animal source foods, rather than simple volume, the relationship is reversed, and grass-fed ruminant products are the most efficient[62]. Furthermore, grass-fed livestock may also contribute to other positive outcomes, such as improved soil health, that more intensive systems cannot.

Similarly, a study of dairy cattle on different feed regimes suggested that cows fed on more digestible feeds (i.e. soya meal) were more carbon efficient per kg of milk production, whilst cows fed a greater proportion of grazed forage were more carbon efficient per hectare of land[63] (and relied on fewer external inputs) making the sustainability case for one system over another less clear cut than we are typically led to believe.

Wageningen's Circular Food Systems project found that a diet that included some animal source foods from purely default livestock (i.e. those fed from pasture or by-, waste-, or co-products), was more efficient from a land-use perspective than a purely plant-based diet, due to the elimination of feed-food competition combined with the utilisation of land and resources that would otherwise not be used to generate food for humans[64]. In this way, rearing livestock from low-opportunity cost feedstuffs (pasture and crop residues in the case of ruminants, and by-, co-, and waste products for monogastrics) presents an opportunity to partially decouple animal agriculture from at least its arable land base, while delivering other benefits.

However "releasing" land from agriculture is in itself sufficient to deliver benefits. The FFCC's 2019 report 'Farming for Change' noted three issues associated with a land-sparing approach's prioritisation of off-farm biodiversity over on-farm biodiversity. First, the fact that in a UK context, an "irreplaceable" share of biodiversity is either wholly or partly dependent on low-input agricultural practices. Secondly, in the same way that emissions intensity, rather than reductions in absolute emissions, are often a hallmark of sustainable intensification, we see a similar emphasis on resource or input efficiency in regards to the use of pesticides, herbicides, and fungicides in these systems; however, this belies the fact that even efficient use of biocides can have detrimental impacts on critical biodiversity markers and habitats. Third, it ignores the fact that biodiversity within agricultural landscapes supports productivity of these areas in the long-term through the provision of ecosystem services[65]. Similarly, Kremen's seminal 2015 paper on the "land sparing/land sharing" debate suggested the dichotomy unhelpfully frames the issue as a zero-sum equation, when in fact both approaches are needed for a robust strategy for biodiversity restoration. Indeed, dramatic declines in insect populations are recorded even within protected areas, suggesting that land-sparing approaches alone will not be sufficient to arrest, let alone, reverse, biodiversity loss[66]. Kremen argued that hospitable matrices (as provided by land-sharing approaches) surrounding protected areas were critical to the success of these "land sparing" areas, both by

[60] Van Zanten et al., 'Defining a Land Boundary for Sustainable Livestock Consumption'.
[61] World Wildlife Fund, 'Driven to Waste'.
[62] Wilkinson, 'Re-Defining Efficiency of Feed Use by Livestock'.
[63] Bell et al., 'The Effect of Improving Cow Productivity, Fertility, and Longevity on the Global Warming Potential of Dairy Systems'.
[64] van Zanten et al., 'Opinion Paper'.
[65] 'Farming for Change: Charting a Course That Works for All'.
[66] Hallmann et al., 'More than 75 Percent Decline over 27 Years in Total Flying Insect Biomass in Protected Areas'.

"buffering" them from the impacts of more developed areas, and by providing connectivity between areas necessary for the viability and dispersal of populations[67].

Additionally, the concept of carbon or biodiversity leakage is a critical consideration when designing a land use strategy. For example, while the European Deforestation Regulation will prohibit importing commodities such as soya through the EU that are not verified to be deforestation free, compound feeds will not be within scope of the regulations, which may result in misleadingly favourable carbon accounting for intensive systems. Similarly, if we incentivise the "release" of land from food production for biodiversity restoration or afforestation without a rigorous implementation framework, we risk inadvertently causing "biodiversity leakage" in other countries to compensate for reduced production domestically[68]. Researchers at Cambridge warned that we should be "much more cautious about restoring natural habitats on currently productive farmland in less biodiverse parts of the world" such as the UK, and suggest that the concept of leakage has to be more robustly embedded in policy making to avoid displacing production to less enforced, but more biodiverse, regions of the world.

Clearly, we need a holistic approach to land-use and agricultural decision-making, and a framework for evaluating sustainability which is both multiscalar and capable of recognising a wider range of benefits and disservices.

The role of Agroecology

Agroecology as a term is often used in different ways, whether to describe a set of practices, principles, or more comprehensively to refer to a wider agricultural and social movement with strong roots in Latin America and Sub-Saharan Africa and an explicit focus on food sovereignty[69-70]. Not only this, but the IPCC's 2019 special report[71] identified agroecology as a form of sustainable land management with both climate adaptation and mitigation potential.

Circularity is a core principle in agroecology, and the synergies between the two concepts (due to their alignment on many areas including the reduction of external inputs, the re-valorisation of "waste" products, and integration of ecological processes with agriculture) is already well documented[72-73]. Compared to other approaches which may perpetuate inequalities, agroecology's explicit focus on social and community benefits, including food sovereignty, can mitigate its risk of corporate co-optation. Agroecology is also highly compatible with a multi-functional approach due to its emphasis on diversification and working with ecological systems. Rather than emphasising productivity, it has a stronger focus on yield stability through greater crop diversification, improved soil and nutrient management through practices such as crop-livestock integration, and improved agrobiodiversity through reduced use of agrochemicals and increased proportion of semi-natural vegetation[74].

Agroecology also has a strong evidence-base suggesting that it is facilitative of food security[75] and long-term system resilience[76] due to its systems-level, multi-disciplinary, and transformational nature. An FFCC's report from 2021 suggested that agroecology in a UK context could contribute to healthier diets, improved biodiversity, and a 35-55% reduction in agricultural emissions compared to 2010 levels[77]. But these concepts inherently challenge the foundations of our current agri-food system and so may contribute to agroecology's relatively slow uptake in policy and research within a UK context. While the practices examined in Part 2 of this work are not inherently agroecological, they can be features of an agroecological system, if embedded in a democratic and participatory governance framework.

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[75] Bezner Kerr et al., 'Can Agroecology Improve Food Security and Nutrition?'
[76] Gliessman, 'Transforming Food and Agriculture Systems with Agroecology'.
[77] 'Farming for Change: Charting a Course That Works for All'.

Alternative frameworks

Principles of circularity are central to more "low-tech" and "tacit knowledge intensive" solutions such as agroecology. But they are also foundational to a range of sustainable food futures, including those that emphasize the role of technological innovations in sustainable intensification. If they are centred around and complementing of human needs[78], technological innovations have a significant role to play in future sustainable food systems, particularly in terms of facilitating circularity, and impact monitoring. However, technological innovation without consideration of the wider food system context risks decarbonising systems that are prone to other deleterious environmental and social impacts, and may increase path dependency for systems that are generally unsustainable and unjust[79].

Despite this, there is a significant disparity in investment levels between nature-based farming practices and "business as usual" approaches, with the Global Alliance for the Future of Food estimating that over $630 billion is invested in agricultural subsidies, but only 1.5% of this is targeted towards sustainable or agroecological interventions[80]. Similarly, a recent evaluation of nature-based vs technology-based solutions in the livestock sector by FAIRR found that nature-based solutions have the potential to deliver almost 40% of the mitigation required to reach 2030 climate targets, along with significant nature co-benefits, although they currently receive lower levels of investment than technological approaches[81]. It additionally noted that disproportionate investment in technology-based solutions created further lock in and path dependency for these systems, rather than facilitating a plurality of production types to improve resilience.

A 2017 analysis of leverage points for sustainability transformation supported this concern, with the authors arguing that "many sustainability interventions target highly tangible, but essentially weak, leverage points (i.e. using interventions that are easy, but have limited potential for transformational change). Thus, there is an urgent need to focus on less obvious but potentially far more powerful areas of intervention."[82] They proposed a research agenda based on systems thinking that emphasise more truly transformational sustainability interventions based on "reconnecting people to nature, restructuring institutions and rethinking how knowledge is created and used in pursuit of sustainability." Similarly, Gliessman's "Five Levels of Agroecological Transition" conceptualises a pathways towards agroecological transformations in the food system, from 0 (no integration) to level 1 (arguably our current position, *"Increase the efficiency of industrial and conventional practices in order to reduce the use and consumption of costly, scarce, or environmentally damaging inputs"*) to level 5; "*build a new global food system, based on equity, participation, democracy, and justice, that is not only sustainable but helps restore and protects earth's life support systems upon which we all depend*"[83].

The ways we determine value from an economic perspective also have a role to play in supporting a transformation to a sustainable and equitable food system. In 2021, The Dasgupta Report suggested that biodiversity and ecosystems underpin economic activity, but that current economic models fail to account for nature's value adequately. It also laid out the relationship between our economic activity and biodiversity decline, and emphasised the limitations of using GDP as a measure of economic success, in favour of a more "inclusive" model of wealth, which includes natural and human capital[84]. The FFCC's 2025 report Paying the Price similarly identified growth as a poor framework for a nutritious and just food system, stating "The foundations of [that] growth are the country's resources, its human, social and natural capital. Pushing for ever-cheaper food at any cost has whittled away these pillars of common prosperity."[85] A truly sustainable transition for our food system requires far more than simply finding "green" versions of existing practices, yet current strategies and measures of value do not reflect the wider benefits we should be seeking from our food system. Perhaps it is necessary to "reorient" towards new frameworks such as the Wellbeing Economy, which is oriented around producing the outcomes such as human and ecological wellbeing, rather than using GDP growth as a proxy measure[86]. Other complementary approaches like the United Nations' call for the adoption of "Beyond GDP"[87] frameworks, and the philosophy of *Buen Vivir* as enshrined in the constitutions of Bolivia and Ecuador[88] offer potential pathways for redefining prosperity by placing wellbeing, environmental flourishing, and social equity at the heart of policy making and governance.

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[78] Anderson and Maughan, '"The Innovation Imperative"'.
[79] Ehrenfeld et al., *Searching for Sustainability: No Quick Fixes*.
[80] 'Public Climate Finance for Food Systems'.
[81] 'Climate and Nature-Based Interventions in Livestock | FAIRR'.
[82] Abson et al., 'Leverage Points for Sustainability Transformation'.
[83] Gliessman, 'Transforming Food and Agriculture Systems with Agroecology'.
[84] Dasgupta, *The Economics of Biodiversity*.
[85] 'Paying the Price Cheap Food, Big Business and the Cost to Farming and Food Security'.
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[87] *Valuing What Counts*.
[88] 'Chapter 6, The Climate Crisis: South African and Global Democratic Eco-Socialist Alternatives on JSTOR'.

Governance

Governance, like agroecology, is a term that can encompass a variety of practices and structures; sometimes a set of regulatory frameworks, sometimes a dynamic process of multi-stakeholder collaboration, or as an approach to shaping equitable, resilient and sustainable food systems. The 2025 Local Food Growth Plan (LFGP) argues that governance's social and environmental impacts serve as a crucial driver of holistic food system transformation that can address food insecurity, economic inequality and climate impacts[89]. Regardless, without greater policy coherence to enable synergies between sectors, we may continue to experience the impacts of misaligned policies and funding[90].

The Local Food Growth Plan and Professor Kevin Morgan's *Values for Money* report argues that public procurement deserves particular attention due to its potential to deliver social, economic and environmental outcomes. Although it can comprise a small fraction of public spending (1% in the case Wales according to the report) it has a social and environmental impact that vastly exceeds its financial footprint, suggesting that procurement practices that integrate social value and well-being goals can yield a "triple dividend" of healthier diets, enhanced community wealth and more resilient local economies[91]. Emphasising healthier and sustainable diets through public procurement also improves nutritional access for some of the most vulnerable groups in society; school children, those in hospitals and care homes, and the incarcerated.

Circularity can also serve as a core principle within effective governance for sustainable food. Public procurement strategies can support the development of shorter supply chains, reduce food waste, and return value to local food economies, while providing a reliable market for agroecological producers[92-93]. Like agroecology, which challenges extractive logics, a values-based procurement agenda challenges the conventional "race to the bottom" approach that prioritises low cost at the expense of quality and sustainability. By embedding well-being and social value within procurement criteria—such as re-weighting tenders to favour local provenance and sustainability—governance can build on the synergies between environmental stewardship, social justice and economic resilience.

The LFGP also stresses the need for a broader reorientation of the food system towards local and regional priorities. Some local authorities have begun to adopt regional food growth plans and invest in mid-scale infrastructure—such as regional processing facilities and food hubs—that facilitate the circular flow of resources within local food networks. These initiatives mirror the effect of agroecology in stabilising yields through diversified cropping systems, but at the governance level, through stabilising supply chains through regionalised, collaborative approaches.

From a land use perspective, the Food Farming and Countryside Commission (FFCC) developed a Multifunctional Land Use Framework in recognition of the fact that there is little collaboration between different sectors and no current overarching national strategies that attempt to harmonise land use to deliver optimum outcomes. The Food Farming and Countryside Commission's Multifunctional Land Use Framework (MLUF) is a process for decision making around land use that attempts to reconcile the multiple competing demands on land; by identifying synergies in terms of desired outcomes, and providing a cross-departmental framework for decision making that incorporates all stakeholders, from communities, policy makers, infrastructure planners, and landowners[94]. Key elements of the FFCC's Multifunctional Land Use framework is meaningful stakeholder engagement (beyond mere consultation), devolved decision-making, and cross-departmental working to ensure decision making is synergistic rather than at best disjointed, or at worst, counterproductive.

London's Good Food Local report similarly highlights the transformative role of governance when it is embedded in inclusive food partnerships. These partnerships prioritise local knowledge and diversity and cultural inclusion, moving beyond the confines of cost-based procurement to shape a more equitable food system, aligning with agroecological principles[95]. The London councils in the report have pursued ambitious policies ranging from enshrining the Right to Grow, and the establishment of community gardens supported by training and resources, initiatives that ensure vulnerable populations such as the elderly have access to nutritious food in sociable community environments, and supporting local food economies. The report suggests that councils that align food policy with public health, climate and economic priorities in these integrated approaches are better positioned to meet the challenges of urban food insecurity and environmental degradation.

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89 'Growing the Local Food Sector'.
90 Andrews et al., 'Putting Food in the Driver's Seat'.
91 Morgan, *Values for Money: Public Sector Food Procurement in Wales*.
92 'Growing the Local Food Sector'.
93 'Good Food Local'.
94 'The Multifunctional Land Use Framework The Key to Better Land Use Decisions'.
95 'Good Food Local'.

Integrated Local Delivery (ILD) frameworks in the UK is a governance approach that embraces a systems-level reorientation towards circularity, social value and environmental resilience. ILD is built on the premise that cross-sectoral collaboration and locally driven decision-making are critical for addressing the interconnected challenges of climate adaptation, food security and health. ILD functions at the lowest relevant administrative level (such as town or parish), uses local stakeholders and capacity, and aims to maximise the impact of public funds by delivering across multiple objectives; It follows a six-stage process that can be applied to multiple scales and any aims or contexts[96]. Such approaches demonstrate the potential of governance to act as a foundational enabler of more equitable, regional, and resilient food systems. They reinforce the notion that governance is most effective when it is participatory, place-based and explicitly values-driven, creating the conditions for transformative food system change rather than entrenching "business as usual" paradigms[97].

However, as with agroecology's barriers to adoption in mainstream contexts, governance approaches face significant challenges in scaling up and embedding these principles. Funding and capacity constraints, incoherent policy environments, and misaligned incentives often impede efforts, particularly when aiming to reorient the system in line with these social and environmental goals. Collaboration is crucial to ensure alignment between policy areas such as health, the environment, and agriculture[98-99], and at multiple scales, such as at a national and municipal level[100-101]. Beyond policy coherence however, is a need for effective monitoring and evaluation, the allocation of responsibility for the delivery of outcomes[102] and transparency of goals, processes, and outcomes to the wider public[103].

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[98] Bateman et al., 'How to Make Land Use Policy Decisions'.
[99] Andrews et al., 'Putting Food in the Driver's Seat'.
[100] Monticone et al., 'Identifying Food Policy Coherence in Italian Regional Policies'.
[101] Coderoni, 'Key Policy Objectives for European Agricultural Policies'.
[102] Nelson et al., *Towards a State of the Food System Report for Australia*.
[103] Andrews et al., 'Putting Food in the Driver's Seat'.

Conclusion

Although circular principles can be adopted into our existing value chains, a truly circular food system requires a more fundamental reorientation. In an increasingly chaotic geo-political and climatic environment, adopting low-input and circular agricultural practices may become increasingly inevitable, either as a deliberate strategy to mitigate climate change or as a necessary adaptation to its impacts[104][105]. Beyond mere agricultural practices, we must emphasise inclusive and coherent governance systems to ensure that the benefits of such systems are experienced equally.

The transformation of the UK's food system represents one of the most complex and urgent challenges of our time, requiring us to navigate the interconnected demands of climate mitigation, biodiversity recovery, food security, and social justice simultaneously. Our current trajectory, characterised by linear practices, efficiency-oriented metrics, and siloed policy approaches, is fundamentally inadequate for addressing the scale and complexity of these challenges. The evidence presented suggests that the solution lies not in incremental improvements to existing systems, but in a fundamental reorientation towards principles of circularity, multifunctionality, and resilience. Agroecological approaches and multifunctional land use strategies offer pathways that can deliver multiple benefits across environmental, social, and economic metrics, whilst also building the adaptive capacity necessary to navigate an uncertain climatic future.

Realising this transformation requires more than single-issue solutions; it demands a shift in how we conceive of success in our food system. As long as we continue to externalise environmental and social costs, prioritise narrow efficiency metrics over system-wide resilience, and fail to account for the full spectrum of outcomes delivered by land, we will remain locked into patterns that undermine both human and ecological wellbeing.

The urgency of this transformation cannot be overstated. Climate change, biodiversity collapse, and increasing geopolitical instability are already reshaping the conditions within which our food system operates, and these pressures will only intensify. The choice is not whether to transform our food system, but whether to do so proactively and equitably, or to have transformation imposed upon us through crisis and collapse. By embracing circularity, multifunctionality, and agroecological principles now, we can build resilience whilst delivering the environmental and social outcomes our society needs.

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Credits

Charlotte Wheeler

Charlotte has worked in the agricultural sector for the past decade+, as a farmer and in academia. As Champion, she worked for Pasture for Life, as Research Officer, synthesising relevant research for a farming audience, as well as working on an inter-organisational project on the development of local and alternative supply chains. Charlotte is interested in exploring the role that agroecology can play in contributing to the UK food system's resilience to climate change, and the synergies between low-input farming, biodiversity restoration, and equitable, just food systems. She currently works as a consultant for Agriculture and Environment Policy Consultant at ICF.

AFN Network+

The AFN Network+ (UKRI Agri-food for Net Zero Network+) is a unique network of 3,100+ academics, researchers, third sector organisations, policy makers, and agri-food industry professionals from farmers to retailers. Together, we are working to identify key research gaps that may be holding the UK food system back from transitioning towards a net zero UK by 2050, while also enhancing biodiversity and healthy ecosystems, nurturing livelihoods, supporting healthy consumer habits, and minimising the environmental impacts of overseas trade. Our findings will inform the next decade of research investments in this area by UKRI (our funder and the UK research councils umbrella organisation).

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