

ENVIRONMENTAL RESEARCH FOOD SYSTEMS



TOPICAL REVIEW

The contribution of pulses to net zero in the UK

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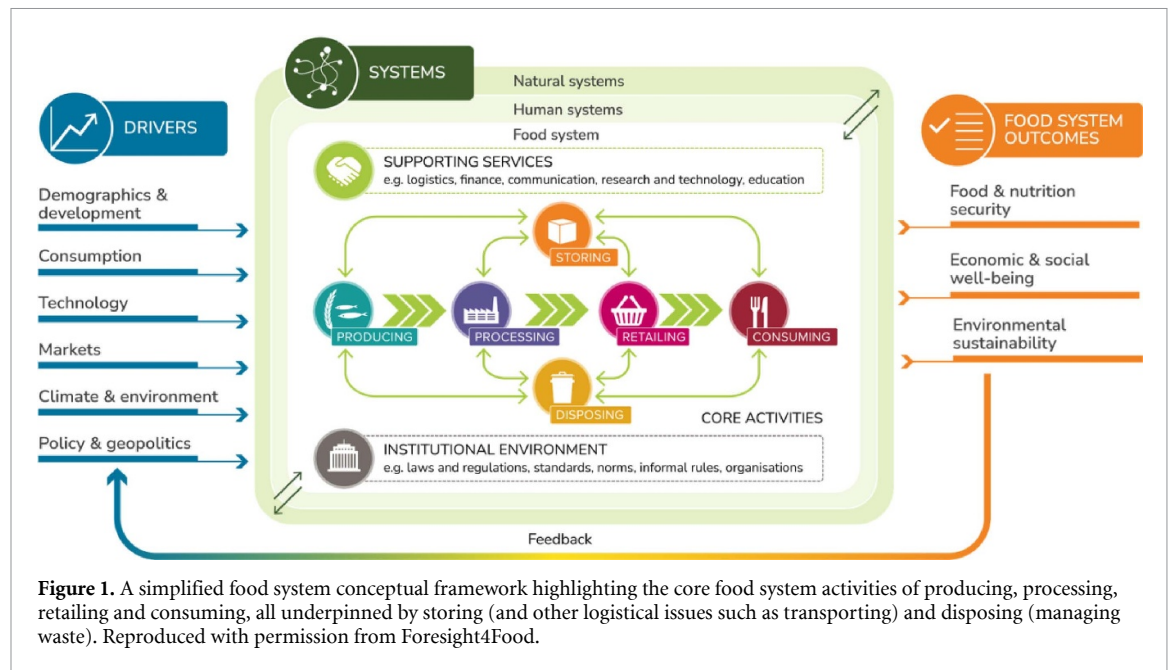
Abstract

The UK agrifood sector is estimated to be responsible for a quarter of the UK's territorial greenhouse gas emissions, making it a priority sector for the UK's net zero commitments by 2050. Pulses have been commonly identified as significant in driving emissions reduction throughout the value chain, whilst also delivering multiple co-benefits for biodiversity, soils, local economy, and human health. This review takes a food systems perspective on the potential of pulses to help achieve net zero in UK agrifood. It explores how pulses can increase the net zero impact of each of the key activities and their associated stakeholders: producers, processors and manufacturers, transportation and storage operators, consumers, and waste handlers. In so doing, the review contributes to a field which tends to focus on the two ends of the value chain (production and consumption), as these have been the areas of main interest to date. It thereby accentuates the 'missing middle' (what happens between the farm gate and the plate) in mainstream net zero discussions. While it identifies many opportunities in all food system activities along the entire value chain, it also discusses the significant social, economic and technological barriers to increasing the production and consumption of pulses in the UK. Knowledge of producing pulses has dwindled, yields are not economically competitive, the infrastructure to support processing lacks investment, and consumer behaviour is only slowly shifting towards a more pulse-rich diet. A coordinated shift is required across the pulse system to capitalise on the overall net zero opportunities from 'fork to farm'.

1. Introduction

Signatory countries of the Paris Climate Agreement are committed to limiting global warming to 1.5 °C above pre-industrial levels, and the Intergovernmental Panel on Climate Change scenario estimates that this will require global net zero emissions by 2050 (IPCC 2022). The agrifood system plays a major factor in this aim (Crippa *et al* 2021, Tubiello *et al* 2022). A series of diverse interventions is needed to bring global food systems within reach of net zero by 2050. Within countries' territorial boundaries, pathways to net zero food systems include large-scale adoption of low-emission practices, realising carbon sequestration potential, decreasing 2050 projected livestock production and deploying new-horizon technologies across food value chains (Costa *et al* 2022). Balancing greenhouse gases entering the atmosphere from the agrifood system with those being removed from the atmosphere by the system is essential to achieving net zero.

Currently, 11% of the UK greenhouse gas (GHG) emissions are from agriculture (Defra 2022a). The UK has legislated a net zero emissions target by 2050 in line with the Paris Climate Agreement (in accordance with section 1 of the Climate Change Act (2008), as amended). Whilst there is no government sectoral commitment established for agrifood, the National Farmers Union and British Retail Consortium have both set out a roadmap to achieve net zero by 2040 and the Climate Change Committee has detailed ambitious steps to reduce agrifood emissions by 64% by 2040 (CCC 2019, NFU 2019, BRC 2023). Of UK agricultural emissions, 56% is methane (CH₄) from ruminants (cows and sheep) and a further 31% is nitrous oxide



(N₂O) from artificial fertilisers (CCC 2019). In the IPCC Fifth Assessment Report, the global warming potential for a 100 year time horizon (GWP100) of CH₄ and N₂O are 28 and 265 times more potent than CO₂, respectively. Reducing ruminant CH₄ emissions and N₂O emissions associated with artificial fertiliser use are therefore top priorities in reaching agrifood net zero in the UK by 2050. Pulses are well placed to contribute significantly to reductions in both aspects.

The aim of this review is to highlight the potential that pulses have for contributing to the UK net zero agenda. We focus on the UK context specifically, i.e. those food system activities that are undertaken within the UK, to make a contribution to this agenda, and also to provide a background for further research within, for instance, the UK's 'Agri-food for Net Zero Network+' programme (AFN Network+ 2023).

The review is structured around a food system concept which encompasses a number of core 'activities' (figure 1). These activities are undertaken by 'actors' (people) working within an institutional environment and supported by a range of services. The ways in which actors conduct their activities are influenced by both interacting socioeconomic and biophysical 'drivers' operating within human and natural systems, and by their respective aims and objectives. Undertaking these activities leads to food system 'outcomes', which not only contribute to food security and other social welfare issues, but also GHG emissions and other environmental issues. Due to its dynamic system nature, these outcomes feedback to either enhance or dampen the drivers (figure 1).

A study by Williams *et al* (2010) found that, of the 250 Mt CO₂e from the UK agrifood system, 65 Mt CO₂e were located in the processing, distribution and end of life stage of food products. Nonetheless, net zero discussions generally focus on the role of agriculture and diets (i.e. the farm *and* the fork) so we also highlight the roles of those other food system activities after the material leaves the farm and before consumption (i.e. the farm to the fork). We specifically include these other activities as they are often the 'missing middle' in food system research (Hasnain *et al* 2020), and specifically on the potential for pulses to contribute to net zero. This oversight is significant as they provide the entry point into options for considering mitigation options. We therefore systematically review GHG emission and net zero opportunities across five main sets of food system activities in the UK:

- (i) Producing. This includes all aspects of growing the crop, i.e. the primary production.
- (ii) Processing. This includes manufacturing, i.e. all aspects of transforming the biomass of the crop into food products suitable for consumption.
- (iii) Transporting, storing and retailing. We combine these activities in the review as they are closely related in terms of GHG emissions and mitigation.
- (iv) Consuming. Here we include net zero issues related to diet, including substituting diet components and meal preparation.
- (v) Managing waste. All food system activities generate waste and opportunities for, and impact of minimising waste differ markedly depending on the given activity.

We use the present participle form of the ‘activity’ words to clearly indicate these are what food system actors actually do (i.e. they are ‘doing’ words), and hence open to adaptation (Ingram and Thornton 2022). For example, ‘producing’ is what farmers can adapt, whereas ‘production’ is what farmers deliver.

For the initial literature search, four grain legume terms (‘pulses’, ‘beans’, ‘faba’, ‘legumes’) were combined with the key themes of this review (‘net zero’, ‘UK’, ‘GHG’, ‘life cycle assessment’, ‘food system’, ‘agriculture’, ‘processing’, ‘logistics’, ‘retail’, ‘consumption’). This search produced 193 papers. A second review was then conducted of papers cited in initial searches chosen by assessing the relevance of their title and keywords. A total of 105 from these two reviews are included in this work, along with a further 30 papers that provide supporting evidence. The literature search was limited to pulses grown for direct human consumption (excluding research into the pulses in the animal feed value chain) and only included papers from outside of the UK when contextually appropriate. For instance, examples in the South Asia context are the work of Kumar *et al* (2018) on the role of legumes in soil organic matter and carbon sequestration potential, or in nitrogen cycling (Kumar *et al* 2020).

2. Pulses in the UK

The term ‘pulses’ refers to a subset of annual grain legumes that are harvested mature as dry seed, for food, feed and sowing (FAO 2016). The most common pulses include dry beans (*Phaseolus* spp.), dry faba beans (often called field or broad beans, *Vicia faba*), dry peas (*Pisum sativum*), chickpeas (also known as Garbanzo beans, *Cicer arietinum*), cow peas (*Vigna* spp.), pigeon peas (*Cajanus cajan*), lentils (*Lens culinaris*) and lupins (*Lupinus* spp.). Not all legume crops are pulses, for example crops harvested immature, such as green beans and green peas, are classified as vegetables. Additionally, groundnuts and soybeans, which are harvested primarily for oil extractions, and fodder or cover crops such as alfalfa and clover, are not pulses. Pulses grown for seed, for grain (food) for direct human consumption or for animal feed typically occupy the same space in agricultural rotations and diverge postharvest into discrete value chains.

Producing pulses in the UK uses about 250 000 ha annually with the main crop being field (faba) bean, either winter-sown or spring-sown and occupying an average 193 000 ha for years 2020–2022 (Defra 2023). Very little field beans are used for human food domestically (<1000 tonnes) with over 99% used for animal feed, and human food quality beans are mainly exported to the Middle East and North Africa (LegValue 2019). The other important pulse crop in the UK is field peas (spring sown combining peas), occupying 57 000 ha in 2022, of which 10% of the 160 000 tonnes total yield was used for human food (Defra 2023). There is capacity to increase legume and pulse crops in arable rotations from the current 5% share to over 20%, significantly increasing the amount of pulses available on the UK market (NCS 2023).

According to the Family Food survey, 95 g of pulses were consumed on average per person per week in UK households in the year 2020/21 (Defra 2023) (table 1). Data is not available for breakdown of pulse types, except the separation of the popular processed meal of British-style baked beans (canned imported navy beans, cooked in tomato sauce) and canned peas (which are traditional eaten as mushy peas) from all other whole canned pulses (i.e. not categorised pulse varieties or where pulses are used as ingredients in processed food).

It is important to note the ‘mismatch’ between UK human consumption and production: current consumption is almost exclusively pulses that are not grown domestically. Therefore, current activities in the missing middle (between the fork and the farm) are primarily using imported pulses. The UK is reported to import about 200 000 t of pulses for human consumption (dry beans, chickpeas and lentils) through global partners per year (FAOSTAT 2021)⁴. Additionally, NHS Eatwell guidelines advise individuals to eat 80 g portion beans or pulses for ‘5 A day’ and to increase fibre intake (NHS 2024), with current consumption falling below this (table 1). Pulses are a key component of a balanced diet due to their high-protein content, as well as their richness in soluble fibre, folates, iron and zinc (Hall *et al* 2017), and their high fibre/protein creates satiation that helps to reduce consumption (Polak *et al* 2015). They are one of the most nutrient-dense food groups (rich in vitamins, minerals, potassium and B vitamins) with low glycaemic index carbohydrates, whilst having low fat (Didinger *et al* 2022). Nutritional research into pulses has demonstrated they reduce the risk of obesity (WHO 2022), cardiovascular disease (Jacobs and Gallaher 2004), and bad cholesterol (Bazzano *et al* 2011). It is therefore expected that there should be an additional increase in the consumption of pulse in the UK to meet future public health goals as well as net zero ambitions.

⁴ In 2021, the UK’s share of emissions from international shipping was included in the nation’s carbon budget and will now be required to contribute to the UK’s net zero target. However, aligned with territorial UK net zero, embedded emissions associated with overseas production are beyond the scope of this review.

Table 1. Quantities of pulses purchased for UK households (from Family Food Datasets, Defra 2023).

Pulse/bean variety	Purchase averages for pulses per person per week in 2020/21 (g)
Canned peas	14
78 g canned baked beans in sauce	40 ^a
Other canned beans and pulses	32
Dried pulses other than air-dried	9
Total:	95

^a Approximately 40 g of cooked beans are eaten when 78 g of baked beans in tomato sauce are consumed.

How then can increased domestic production (and consumption) of pulses contribute to a net zero agenda in the UK, and what gaps in research knowledge remain? To address these questions, this review is composed in three sections: (i) the net zero implications along the whole value chain of increasing pulses in the UK, (ii) the barriers to, and (iii) opportunities for, further producing and consuming pulses.

3. Net zero contributions

All activities along the pulse value chain have the potential for emissions reductions while producing pulses and minimising waste also have the potential for carbon sequestration. All activities can make a valuable contribution to UK net zero. These are discussed below and summarised in table 2 at the end of this section.

3.1. Producing

As legumes, pulses are able to rely fully or partially on nitrogen fixed from the atmosphere and have significantly lower requirement for applied nitrogen, thereby reducing emissions of CO₂ and N₂O associated with the manufacture and application of nitrogen fertilisers (Drinkwater *et al* 1998, Nemecek *et al* 2008). Additionally, pulse crops can have yield benefits on subsequent crops grown in the rotation (Preissel *et al* 2015, Stagnari *et al* 2017). Pulses are therefore considered valuable break crops in cereal and oil seed rape crop rotations, where they serve multiple purposes including improved soil organic matter (Kumar *et al* 2018), mobilising soil bound phosphorous (Nuruzzaman *et al* 2005), reducing pressure from weeds, pests and diseases (Munier-Jolain *et al* 2002) and improving soil structure (Watson *et al* 2017). These positive effects in the performance of crops following a legume (including pulses) are known as ‘pre-crop effects’ and are primarily due to the nitrogen effect (nitrogen carry over as residue) and the break crop effect (Notz and Reckling 2022). As a flowering crop, pulses also provide ecosystem services through increased biodiversity, attracting a diversity of wild pollinating insects (Bailes *et al* 2018, PGRO 2018). In addition to this, they can support farmers both in improving the overall productivity of their soils and diversifying their production and thereby making their farmers income more resilient to climate related crop failure (Ebert 2014, Warwick Crop Centre 2023).

Most life cycle assessment (LCA) studies on producing pulses focus on the impacts on intercropping, crop rotations and overall agricultural yield (Nemecek *et al* 2008, Costa *et al* 2022). From these, it is clear that optimisation of nitrogen cycles in pulse systems can reduce CO₂ emissions associated with fertiliser production, reduce N₂O emissions and improve soil fertility. Artificial fertilisers are more predisposed than biogenic nitrogen to nitrification, where nitrogen becomes highly mobile and escapes the rooting zone before the crop can absorb the nutrients (Robertson and Vitousek 2009, Squire *et al* 2022). In the UK it is estimated that around 50% of applied nitrogen is lost into the surrounding environment in this way (Defra 2020). In addition, the Haber–Bosch process of synthesising ammonia is highly energy intensive (Abberton 2010) so both the production and use of synthetic fertilisers account for about 5% of global emissions (Gao and Cabrera Serrenho 2023).

The primary contribution to net zero associated with integrating more pulse crops into arable rotations is therefore the reduction in the use of nitrogen fertiliser both on the pulse crop and on the subsequent crop in the rotation. The quantity of nitrogen fixed by pulses in the soil is measured by the proportion of the crop nitrogen derived from atmospheric N₂, which varies depending on species from around 40% for common beans up to 75% for faba beans (Peoples *et al* 2009). In the pre-crop effect of pulses in non-organic European crop rotation fertilisation can be reduced by 60 kg N ha⁻¹ on average under maintenance of acceptable yields. Furthermore, the yield benefits are highest under low nitrogen fertilisation for subsequent crops with reduction in nitrogen fertilisation following pulses up to 31 kg ha⁻¹, and cereal yields up to 1.6 t ha⁻¹ higher

Table 2. Mapping the net zero (a) emissions reduction and (b) sequestration opportunities of increasing the prominence of pulses, broken down by food system activity.

	Producing	Processing and manufacturing	Transporting, storing, packaging and retailing	Consuming	Minimising waste
a. Emissions Reduction	<ul style="list-style-type: none"> • Reduced nitrogen use to grow pulse crops (Preissel <i>et al</i> 2015) • Reduced nitrogen use to grow subsequent crops in rotation (Peoples <i>et al</i> 2009) • Improved possibility for reduced tillage and reduced fuel usage (Nemecek <i>et al</i> 2008) • Reduced pesticide use due to a diversification of the crop rotation (Munier-Jolain <i>et al</i> 2002) • More diverse rotations decrease the emission associated with pesticides, diseases and weeds (Kumar <i>et al</i> 2020) • Less emission leaching from fertilisers (Drinkwater <i>et al</i> 1998) • Reduced soil carbon and nitrogen losses (Drinkwater <i>et al</i> 1998) • More efficient to directly eat pulses compared to feeding them to livestock (Davis <i>et al</i> 2010) 	<ul style="list-style-type: none"> • Minimal processing required when sold dry (Bandekar <i>et al</i> 2022) • Processed pulse products have lower environmental impact than equivalent meat products (Davis <i>et al</i> 2010) 	<ul style="list-style-type: none"> • Reduce transport emissions when grown and processed locally (Tidåker <i>et al</i> 2021) • Reduced energy usage and HFC emissions from cold chain logistics when replacing meat as ambient product (Bandekar <i>et al</i> 2022) • Shelf stable, so can use the most efficient modes of transport (Tidåker <i>et al</i> 2021) • Minimises waste as shelf stable; lowest contribution to food waste across all food categories (Bräutigam <i>et al</i> 2014) • Shelf stable so less energy used in storage • Resilient supply chain as dry stocks can be held (Parfitt <i>et al</i> 2010) 	<ul style="list-style-type: none"> • Reduced ruminant CH₄ emissions through displacing meat consumption (Harwatt <i>et al</i> 2017) • Positive health outcomes reduce economic and environmental burden of public health services (PGRO 2018) • High fibre/protein creates satiation that help maintain healthy body weight, reducing consumption (Polak <i>et al</i> 2015) • Reduction in noncommunicable disease (Alae-Carew <i>et al</i> 2022) 	<ul style="list-style-type: none"> • Anaerobic Digestion (Jensen <i>et al</i> 2012) • Pulse waste for biofuel (Jensen <i>et al</i> 2012) • Feed from pulse waste (Luzardo-Ocampo <i>et al</i> 2020) • Use of waste for novel isolate ingredients (Can Karaca and Nickerson 2022)
b. Sequestration	<ul style="list-style-type: none"> • Increased soil organic carbon (Kumar <i>et al</i> 2018) • Land use change to carbon capture from feed production (Röös <i>et al</i> 2020) 				<ul style="list-style-type: none"> • Crop waste used to add organic matter and nutrients to soil (Voisin <i>et al</i> 2014) • BECCS (Jensen <i>et al</i> 2012)

than in non-legume rotations (Preissel *et al* 2015). Similarly, Jensen (1997) found a nitrogen benefit of about 20 kg N ha⁻¹ from peas in a temperate European crop rotation, with Nemecek *et al* (2008) reporting a comparative life cycle analysis of crop cycles with and without pulses used no fertiliser on the pulse crop and a reduction of 23 kg ha⁻¹ for the subsequent crop. This resulted in 14% reduction in fossil fuel usage, which is significant given only one crop out of five crops was exchanged in the cycle, meaning the maximum potential reduction was 20%. These reductions are confirmed by an emissions assessment of four cereal-based cropping systems in Canada where the exchange of pulses for a crop within the rotation brought an average carbon emission reduction related to energy inputs of 15% (Lemke *et al* 2007). It is worth noting that in addition to the energy input reductions from fertiliser application, emissions reduction is also achieved by the reduction of fuel usage during tillage and nitrogen fertiliser application. Additionally, a greater diversity in crops reduces problems with weeds and pathogens and reduces the emissions associated with pesticide production and application (Nemecek *et al* 2008, Kumar *et al* 2020).

Further to the reductions in fossil fuel emission associated within agriculture inputs, pulses help sequester carbon through the formation of soil organic matter, thus significantly offsetting any emissions associated with N₂O (Bayer *et al* 2016). Practices that improve nutrient use whilst reducing tillage and increasing crop intensity can increase nitrogen availability. This can increase the quality and quantity of biomass which is then returned to the soil, thereby increasing overall soil organic carbon concentration (Christopher and Lal 2007). A study of the effects of a 35 year field trial of maize monoculture and pulse-based cropping on soil carbon levels and residue retention in Canada found a 40% greater quantity of carbon below the plough layer in a pulse-based rotation (Gregorich *et al* 2001). Furthermore, they found that soils under pulse-based rotation tend to be more 'preservative' of residue organic inputs than soils under monoculture. However, these effects are less clear in temperate UK weather conditions and with pulse rotations. One study of soil organic carbon under a common UK rotation of wheat/faba bean over 19 years found a lower level of accumulation than in a wheat monoculture in semi-arid conditions (Laudicina *et al* 2014). One issue is that soil carbon stocks are dependent on net nitrogen balance in the system. Thus, with pulse crops the majority of carbon sequestration potential is lost when the crop is harvested, and high amounts of nitrogen are taken off the field. For this reason, legumes used as cover crops, or green manure where residues do not leave the field, or as part of a foraged legume system, have more detectable beneficial effects on soil organic carbon (Stagnari *et al* 2017). Another issue is that the build-up of soil organic matter is affected by residue quality. Pulse residue generally has a lower ratio of carbon to nitrogen due to its nitrogen fixing rhizobia, resulting in more rapid decomposition (Watson *et al* 2017). There is a need for further research into legumes effects on soil carbon sequestration within temperate arable rotation to better understand the degree to which the increased production of pulses in the UK has the potential to sequester carbon in soils.

3.2. Processing and manufacturing

Compared to producing pulses, the processing and associated manufacturing activities are less well explored in studies of their GHG impact, constituting key aspects of the 'missing middle' in analyses. Processing involves cleaning, drying, sorting, splitting, milling, decorating and fractioning depending on the pulse, and bagging (Bandekar *et al* 2022).

For a ready-to-eat product, dry pulses need to be rehydrated after processing, usually through pressure heating in a salt brine, before being packaged in a steel or glass container. In this case, the production of packaging accounted for 70% of the environmental impact for all pulses studied, regardless of packaging or pulse type (Del Borghi *et al* 2018). In a Swedish instance, net home cooking emission was also negligible due to the country's renewable energy mix (Tidåker *et al* 2021). These life cycle assessments indicate that the primary environmental impact of the pulse value chain is under-researched, and further research into the 'missing middle' is needed to help make the scaling of pulse consumption a significant contribution in meeting net zero.

There have also been several life cycle assessments that compare the environmental impact, including GHG emissions, of pulse-based burgers and sausages with various other protein products (Davis *et al* 2010, Chaudhary and Tremorin 2020, Saget *et al* 2021b, Detzel *et al* 2022). As discussed below, incorporation of pulses into plant-based meat analogues will be essential to making convenient, healthy and palatable alternatives to processed meat products (Lemken *et al* 2019). As a result, there is a need to understand how these products compare to processed meat products and whether the desired emission savings in processing are achieved through supplementing meat with pulses in such products. Davis *et al* (2010) compared how introducing peas at various stages in the production of a meal (i.e. as livestock feed for pigs, as a partial replacement in a pork sausage and as a full replacement in a bean burger) affects environmental outcomes. They found that land use is significantly lower when peas partially replace or fully replace meat, but that in terms of energy usage there is negligible difference between the different products. This was because

refrigerated pork products were compared with a frozen bean burger and because the processing of the bean burger required significantly more energy than its alternatives. They concluded that there is a need for more energy-efficient processing of vegetarian products and non-frozen plant-based meat alternatives. The EU-Horizon 2020 project 'Protein2Food' used European sourced pulses to create extruded vegetable meat alternatives to create a nutritionally equivalent replacement for chicken meat (Detzel *et al* 2022). The project found that their faba bean and amaranth vegetable meat created 130 g CO₂-e per 100 g food product, translating to over 100 g CO₂-e reduced emissions vs high-performance chicken breast and over 200 g CO₂-e compared with conventional chicken. They concluded that such pulse products are an opportunity to significantly reduce dietary emissions, but also pointed to the need to reduce energy demands in the processing stage as well as optimise pulse farming towards higher and stable yields.

Two projects investigating the reformulation or replacement of beef burgers with a lentil alternative drew similar conclusions. In one Canada-based research paper it was found that a partial replacement of a lean beef burger with locally-sourced cooked lentils increased the nutrient density by 20% (notably with a 60 times increase in dietary fibre) whilst decreasing environmental footprints by 33% (Chaudhary and Tremorin 2020). Analysis by Saget *et al* (2021b) extended these findings by supplementing the carbon opportunity cost of land into a LCA of three burgers; Brazilian and Irish beef burgers, and a pulse-based vegetarian burger made from internationally sourced ingredients processed in the UK. They found that, when supplementing carbon opportunity cost, plant-based patties have a 77% smaller climate change burden. However, as in the above, the energy use in processing was found to be 8% more compared with the Brazilian beef patty. The results of multiple life cycle assessments of processed pulse alternative proteins indicate that the emissions from pulse based alternative meats are lower than their meat analogues, but that there remains a need to reduce the energy use in processing these novel products.

The final stage of processing dry packaged pulses requires rehydration (i.e. cooking). Differences in energy demand for cooking depends on pulse type and how it is rehydrated (stove-top boiling vs. pressure cooking) and relative efficiencies of cooking large quantities, however these were marginal differences in relation to the overall system-wide impact of pulses (Bandeekar *et al* 2022).

3.3. Transporting, storing and retailing

Transporting, storing and retailing are closely coupled food system activities and are frequently overlooked aspects in the food LCA studies (Burek and Nutter 2020) and constitute a major aspect of the 'missing middle'. As demographic transition and urbanisation continues, the transportation demands for food continue to increase. An increased 'food shadow', where increasingly urbanised populations demand more food from fewer farmers and more distant land, means food must be preserved for longer distances and times (Hammond *et al* 2015). An increasing amount of agrifood emissions will therefore come from transporting and storing food. Cold chain transportation is usually necessary for meat and dairy products, and a recent analysis from refrigeration in the UK food industry determined it contributed 3.2% of total emissions (Foster *et al* 2023). Unlike animal proteins, dry pulses can be stored and transported at ambient temperature (i.e. without cold chain logistics) over long time frames with minimal spoilage. Equally emissions from cold chain logistics are mitigated when pulses are eaten in place of other refrigerated products. An increase in protein supply that can be stored and transported at an ambient temperature will therefore become increasingly important in achieving net zero.

Transporting and storing food requires materials and energy for packaging, which can have high emissions. In 2015, packaging contributed about 5.4% (or 0.97 Gt CO₂-e yr⁻¹) of total food systems emissions (Crippa *et al* 2021). However, in one Swedish study, due to both Sweden's largely renewable energy supply and the use of Tetra Pak to package cooked pulses, the transportation of imported cans generated 59% of the GHG emissions of the product (Tidåker *et al* 2021). This supports research showing that, for plant-based foods which have relatively low GHG emissions from producing, transporting often becomes the largest single contributor to emissions (Sim *et al* 2007) demonstrating a clear benefit in producing pulses locally for reduced transport emissions. However, it is often not the 'food miles' themselves that have a significant impact, but the mode of transport used and the condition the food is in when it is transported that are most decisive. Whether pulses are transported dried or canned, and whether they are rail freighted or driven by truck create significant variance in their transport emissions (Tidåker *et al* 2021). As with processing and manufacturing, this LCA demonstrates that current research into pulses is often lacking the 'missing middle' of the food value chain analysis, and that understanding and optimising the processes between the farmgate, and the plate will be essential for the transition to more plant-based diets.

In another study Del Borghi *et al* (2018) showed that the packaging process contributed to 90% of the non-renewable energy demand due to the energy intensity of the materials used (steel or glass). They

suggested that a major GHG reduction can be made through the use of more environmentally-friendly packaging (paper or plastic), larger packaging formats, or optimally through a reusable glass bottle system.

Food retail is also a major source of GHGs, much of it due to refrigeration which has been estimated to be responsible for 43% of energy consumption by the retail/supermarket sector (Behfar *et al* 2018). Crippa *et al* (2021) estimated that GHG emissions from this sector increased by 4.2 times in Europe between 1990 and 2015. So, as for the transport and storing argument above, increased retail of dry or tinned pulses can substantially mitigate emissions if substituting for more perishable foods needed refrigeration.

3.4. Consuming

Replacing meat with pulses in diets has the potential to significantly reduce GHG emissions due to the cumulative net zero opportunities across all the food system activities discussed above.

The substitution of meat with pulses for net zero (and other environmental goals) has been the subject of many recent research papers (Vainio *et al* 2016, Harwatt *et al* 2017, Prudhomme *et al* 2020, Rösös *et al* 2020, Kozicka *et al* 2023). Earlier papers demonstrated that the production of 1 kg of protein from kidney beans required 'eighteen times less land, ten times less water, nine times less fuel, twelve times less fertiliser and ten times less pesticide in comparison to producing 1 kg of protein from beef' (Sabaté *et al* 2015), whilst another found that the emissions from ruminant meat can be up to 250 times higher than those of pulses (Tilman and Clark 2014). A 50% replacement of meat for beans in Sweden would maintain energy intake and most macro and micro-nutrient levels, whilst increasing dietary fibre and folate intake. This would reduce the environmental impact of Swedish diets by 20% and decrease land requirements by 23% (Rösös *et al* 2020). Similarly, a European wide assessment of three scenarios to increase the production of pulses in Europe found that emissions mitigation are much higher in the demand-side scenario where a large shift in human diet is paired with reforestation, than in a supply-side scenario where European legumes replace soy in feed mix (Prudhomme *et al* 2020). Whilst no such calculations have been made for the UK, it has been demonstrated that diversifying arable systems with pulses removes 10% of land from agricultural production, reduces emissions by ~10% and increases breeding bird populations by 177% whilst maintaining similar protein yields (Field *et al* 2016). These findings are in line with a wide range of research demonstrating that a transition from animal-based to plant-based proteins would reduce emissions, water use and land use, and benefit human health and biodiversity (Leip *et al* 2015). Thus, pulses will play a central role in transitioning diets for a net zero UK agrifood system whilst also providing excellent co-benefits for other environmental factors and human health.

3.5. Minimising waste

Total food waste in the UK amounts to 12.8 million tonnes a year, with the waste occurring pre-farm gate alone accounting for 10% of UK agricultural GHG emissions and enough to feed 6.4 million people three meals a day for a year. Of the waste produced, 80% came from meat and animal products, 8% came from roots, tubers and oil crops, 8% came from fruit and vegetables, and 4% came from cereals and pulses (WWF-UK 2022). Non-perishable food such as pulses have similarly been shown to have the lowest waste of all food types (Bräutigam *et al* 2014, Jeswani *et al* 2021). Therefore, increasing the proportion of UK grown pulses in diets can potentially translate to a reduction in overall waste in the system.

Nevertheless, food value chains still generate waste (Parfitt *et al* 2010), and for pulses, especially at the producing and processing activities. If valorised, this waste can contribute to net zero goals. On UK farms burning crop residue (CR) is strictly licensed (Defra 2021). Instead, CR from pulse crops is typically reinvested in the soil, which provides the benefits of the pre-crop effects (Notz and Reckling 2022). While pulse CR is not appropriate for human consumption it can also be used as biomass for biofuel and anaerobic digestion (Jensen *et al* 2012). By 2050, 15% of global energy requirements will be supplied by bioenergy (IEA 2022). Bioenergy is a key net zero energy supply because it can be integrated into existing combustion systems, and as the CO₂ released is of biogenic origin, it is therefore of overall lower climate forcing potential than that from fossil fuels. The combination of bioenergy and carbon capture and storage (BECCS) is currently one of the most scalable negative emissions technologies and plays a central role in IPCC plausible net zero pathways (IPCC 2022). However, harvesting pulses leaves less CR than that from cereals, meaning the relative economics are less favourable and overall quantities from cereals make it a preferred feedstock (Jensen *et al* 2012). Further, CR from pulses are of higher nitrogen content than cereals and contribute more to soil organic matter formation than cereal residues when ploughed in or left on the surface. This contribution of carbon sequestered would be reduced if the residue is harvested for bioenergy (Voisin *et al* 2014), as well as reducing the pre-crop effects if removed.

In some cases, pulse crops graded unsuitable for human food (for example field beans with bruchid damage), despite losing the premium, can be diverted into the animal feed value chain (Jones 2021).

Additional to this divergence from human food, a further 25% of post-harvest pulse waste occurs in processing in the form of husk, powder, broken and shrivelled pulses (Bandekar *et al* 2022). Anaerobic digestion is increasingly being employed across the UK to generate green energy from such waste (Jensen *et al* 2012), although there are legitimate concerns that an increase in subsidies for aerobic digestion may lead to energy crops displacing food crops (Allen and Hammond 2019). There is therefore further need for research and development of novel uses for pulse waste products in the UK.

4. Barriers to uptake

The main barriers to uptake relate to producing, processing and manufacturing, consuming and minimising waste.

4.1. Producing

Barriers for increasing the area used for producing UK pulses are multifaceted. Interventions to increase the production of pulses in the UK will need to address not only the barriers of increasing production of what is already grown (i.e. dry field beans and dry peas), but equally the barriers to producing novel pulse crops. Interventions also need to and establishing the extent to which it is possible and desirable for UK production to contribute to its own pulse demands (Luyckx 2023).

Defra performed an evaluation of the potential for crop diversification in the UK including grain legumes for both human and animal feed value chains. Crop suitability (the prevalence of UK adapted varieties), the ease of cultivation based on a lack of agronomy experience and evidence, and economic potential of market and yield were the main barriers perceived for shortlisted pulse crops (Defra 2022c). Shortlisted pulse crops evaluated to make no contribution towards net zero (table 3) were assumed to replace existing imports on such a small scale that any gains from production *per se* would be negligible. Only pulses already widely grown in the UK (field bean, yellow pea and Carlin pea) were assessed to ‘certainly’ contribute to increased productivity, sustainability and net zero goals (table 3).

Fundamentally, available seed of varieties of pulse crops that are adapted to thrive in UK growing conditions are a prerequisite for UK production. The state of knowledge and resources of diverse (non-traditional) pulse crops in the UK is comprehensively described by Defra (2022c). Researchers at Warwick Crop Centre have used conventional breeding to develop dry common bean varieties adapted to UK conditions that are quick cooking, making them more amenable to consumer needs (Warwick Crop Centre 2023). However, such breeding programmes (especially by conventional means) require long-term commitment and therefore reassurance that a profitable market will exist (PGRO 2018), thus requiring wider systemic shifts to be in play.

New precision breeding techniques also provide the opportunity to create novel pulse cultivars more suited to the UK agrifood system, with desirable agronomic, nutritional and culinary qualities, increasing both desirability or production and consumption. The recently-passed ‘Genetic Technology (Precision Breeding)’ Act (UK Government 2023) promises to accelerate crop improvement efforts using these techniques. The technologies are also low cost, contributing to a democratisation of plant breeding that could catalyse innovation. Precision breeding programs could increase breeding cycle efficiency, produce earlier maturity, improve seed set and make harvesting easier through reducing the risk of lodging and pod shatter (Howell and Abhimanyu 2023). However, many pulse crops that are grown, or have potential to grow, in the UK (for example the commonly grown field bean (*V. faba*) or novel crop dry bean (*P. vulgaris*)) are currently non-edited legume species, meaning genome-editing approaches are yet to be developed for these species despite the fact that whole-genome data is widely available (Baloglu *et al* 2022).

Defra’s 2022 annual ‘Farm Practice Survey’ indicated that the proportion of farmers that consider emissions an important factor in decision making on their land, crops and livestock was 64%, of which 58% stated that they were currently taking action to reduce their emissions (Defra 2022c). Of the actions taken, the greatest increase from 2020 to 2022 was the use of pulses in arable rotation which increased 26%–32% of holdings, indicating a surge in interest in the crop. The primary reason for inaction against climate change by UK farmers was that they are unsure of what to do to reduce emissions due to conflicting information (44%) and that they believe action is not necessary because their farm does not produce emissions (36%).

By far the most important limiting factor identified across a range of studies of farmers decision making is the economics of crop production. In general, there is a prioritisation of short-term profitability and business survival over long term actions to reduce emissions and adapt to climate change (Wheeler and Lobley 2021), often referred to as the ‘productivist’ mindset. A meta-analysis of UK farmer behaviour research found that market or compliance-based rewards were vital to incentivising short term changes to business practices and that farmers attitudes towards adopting environmentally beneficial produce was dependent on whether there was a sufficient market for the product (Rose *et al* 2018).

Table 3. Workshop assessment of potential for draft shortlist grain legume/pulse crops to contribute to increased productivity or sustainability, or achieving net zero, in diverse cropping systems. (1 = potential increase, 0 = no change, −1 = make worse, blank = unknown). From Defra (2022c), p 106.

Grain legumes and pulses	Productivity	Sustainability	Net zero
1. Vicia bean	1+	1+	1+
2. Yellow pea	1+	1+	1+
3. Carlin pea	1+	1+	1+
4. Soya bean ^a	1+	1+	1+
5. Lentil	0	1++	1
6. White lupin	0	1	0
7. Navy bean	−1	1+	0
8. Chickpea	−1	1+	0
9. Narrow-leaved lupin	−1	1	1
10. Yellow lupin	−1	1	1

^a Soy is not considered a pulse if grown as an oilseed crop.

Unlike cereals and oil seeds, which have received decades of policy and research focus leading to high and stable yields, most pulses are still a niche crop in the UK (PGRO 2018, Defra 2022c). As a result, they have received minimal commercial, research and policy investment, leading to lower and less stable yields, as well as volatile supply and demand, and inaccurate reporting. The security of a contract that had reasonable expectation of cosmetic standards and quality, as well as payment for growing a fixed area rather than a certain tonnage, were highlighted as essential in offering farmers risk security when producing pulse crops (PGRO 2018). For many farmers introducing pulses, particularly for the human market, represents an economic risk without a high enough return to be sufficiently motivational.

In a small UK trial a FlexDraper[®] header was used for successful harvest of UK adapted dry bean varieties (Baynes and Smith 2023). Despite the versatility of innovative equipment for harvesting (VanKoughnet 2014, 2015), investment in new equipment is often not viable for smaller enterprises, and alternative models such as co-operative ownership or contracting out the harvesting would often be required to avoid bearing the full cost burden (Holloway and Ilbery 1996).

There are also technological barriers related to registered agriculture inputs for pulse crops in the UK. A potential consequence of increasing overall pulse cropped areas is an increase in the incidence of pest and diseases associated with pulse crops, which is exacerbated by the lack of new (and loss of existing) registered pesticides (Howell and Abhimanyu 2023). Currently, the levels of pulse production in the UK are not high enough to warrant the time and economic investment into registering new pesticides. Investment in agronomy research, as well as a wider demand for pulses will therefore be critical for the development of inputs needed to support increased producing. When technological barriers such as these are combined with a lack of knowledge support and poor financial returns, they can form a sufficient set of barriers to prevent farmers from introducing pulse crops.

A wider consensus amongst the literature is that it may be problematic to place too much responsibility on the decision-making behaviour of individual farmers, given that their decisions are restrained by wider systemic factors and influenced and constructed within the context of social norms. Whilst it is important to understand the motivations and attitudes of farmers in relation to farming practise, it is important not to lose sight of the need to stimulate wider social change, necessitating actions from organisations, policy makers, funders and the public (Rose *et al* 2018). As has been previously discussed, structural barriers such as the price competitiveness of crops, the need for guarantees from processing companies and access to technology markets become effectively debilitating for farmers who may otherwise wish to grow pulse crops. These interactions between social, environmental and technical factors that prevent any one actor within the system from adopting new practices have been identified by several authors as generating technological 'lock-ins' (Magrini *et al* 2016, Lemken *et al* 2017, Cusworth *et al* 2021).

Lock-ins describe situations in which technological innovation has been focused on a specific system, at the expense of alternatives, leading to a path dependence on the selected system. As a result of this path dependence, even when the system becomes financially, environmentally or socially unsustainable, there is an inertia that prevents individuals within the system from changing technology. In the case of pulses, the post-war productivist drive in Europe coalesced around research and investment focused on genetic engineering of specific crops for productivity and agrochemical management. This had the effect of driving out minor crops, environmentally beneficial practises and alternative modes of agricultural management (Magrini *et al* 2016, Zander *et al* 2016, Cusworth *et al* 2021). This socio-technical regime has displaced knowledge of traditional farming practices, created monocultures with unmatched yields and reduced trade and consumption to just a few crops that are dependent on artificial inputs. The only solution to breaking

out of this lock-in is through a coordinated shift from inter-connected sectors across the food system to a more sustainable system such as the increased production of pulses. Therefore, to understand the barriers to increasing pulse production, there is a need to look beyond the producer and understand the specific restraints in place for every actor within the pulse value chain, in order to design a systemic innovation (Midgley and Rajagopalan 2020) toward increased pulses.

4.2. Processing and manufacturing

As was highlighted at the end of the previous section, the wider systemic barriers that constrain the choices available to farmers are equally shared by processors and manufacturers, who are similarly restricted by economics, technology, public policy and international trade. There are two main reasons for this.

First, in the UK there already exists a very competitively priced and stable supply of plant proteins in the form of pulses from North America. Without significant subsidies for research into breeding programs, these imports significantly undercut the price of domestic pulse production (Howell and Abhimanyu 2023). Whilst UK pulses have a competitive edge in terms of transportation costs and potential import tariffs, often they cannot be sufficiently dried in the field due to shorter, wetter growing seasons, meaning that high capital investment in technology, specifically drying and storage facilities, may be necessary. Furthermore, despite farmers wanting the security of a contract in order to consider producing beans, the current structure of the UK pulse market does not allow this. The market works through intermediaries between growers and processors, who store and trade imported grains on a weekly basis (Howell and Abhimanyu 2023). As a result, processors have no capacity to carry stock and have no direct contact with producers, making a contract arrangement unlikely. This is reflected in research into the pulse-based food industry in Europe and the US, where it was identified that most producers had little concerns for the environmental benefits of pulses and were not interested in establishing relationships with wheat suppliers who could integrate pulses into their rotation. Instead pulses are treated as commodity crops by processors and manufacturers, meaning that growth in the plant-based processed food industry in recent years has not resulted in an increase of pulse cultivation in countries consuming the products, but an increase in imports and the dominance of soy as a product ingredient (Lascialfari *et al* 2019). As with producers, manufacturers are therefore also locked into a system dependent on trade of high yield crops (soy from the US), which makes consideration of any other socio-technical arrangement prohibitively expensive.

Second, whilst opportunities have arisen for the creation of pulse-based products, largely driven by consumer concerns for health and the environment, manufacturers paradoxically appear to be unwilling to advertise the environmental benefits of their products. In interviews with a variety of manufacturers, Lascialfari *et al* (2019) also identified that in order to stimulate demand and avoid discouraging consumers, manufacturers exclusively market products based on their novel ingredient and avoided mentioning pulses nutritional and environmental benefits. They conclude that this condition was due to a failure of institutions to proactively communicate on sustainable and healthy diets. Without this coherent messaging, consumers and citizens fail to draw connections between their purchasing actions and the environmental and health consequences of their actions, meaning they are not motivated to change their food behaviours. Thus, as with producing pulses, the ability to encourage behavioural change towards net zero practices is constrained by a wider political atmosphere of non-intervention in individuals' choices.

4.3. Consuming

General consumer barriers to increasing pulses in diets are related to personal factors including convenience and preparation time, lack of knowledge and familiarity with pulses and pulse-based recipes, concerns over digestive issues and flatulence, and a perception of pulses as food for the poor. These outweigh structural factors such as price and availability (Jallinoja *et al* 2016). Recent UK research found that consumer attitudes are particularly aligned with the need for pulses to be convenient, cheap and shelf stable, mostly likely due to the association of pulses as baked beans. This is equally reflected in identified barriers to consuming more pulses specifically related to preparation time, knowledge and difficulty of cooking pulses (Henn *et al* 2022).

Public attitude surveys indicate that willingness to consider a reduction in meat consumption generally has grown in the UK from 34% in 2014 (Dibb and Fitzpatrick 2014) to 65% of people surveyed in 2020 (Eating Better 2020). However, the percentage of those who had reduced their meat intake in the past year was substantially lower at 21% in 2020 (Eating Better 2020, Alae-Carew *et al* 2022), showing that there is a disconnect between intention and action.

Consumer behaviour research has been undertaken to understand how a higher translation of individuals' intentions to consume less meat into action can be achieved. In a meta-analysis of 38 studies into consumer perceptions of protein intake and sustainability, a trend was identified that consumer awareness of the environmental impact of meat production is very low and that willingness to reduce meat consumption is also very low (Hartmann and Siegrist 2017). Whilst their analysis argues that more research needs to be

done to understand how consumers can be motivated to eat more plant protein and less meat, they conclude that improving consumers knowledge of the environmental impacts of dietary choices will be critical. They note it is therefore necessary to increase general awareness of the environmental consequences of meat consumption, whilst simultaneously addressing the multiple other motivations for reducing meat intake.

4.4. Minimising waste

In the UK, the primary barrier to preventing waste of pulses is the power imbalance between growers and big retail. The concentration of power amongst a small number of large retailers allows them to dictate the terms of engagement with growers, meaning they often burden farmers with both food waste and the associated costs. The primary causes of waste caused by retail are cosmetic standards, overproduction to meet demands, failure to market seasonal gluts, order cancellations and alterations and low price offers (Porter *et al* 2018). As discussed earlier, the pressure exerted on growers by retailers lead to a risk aversion around producing new crops, as growers cannot afford to front the cost of an unsuccessful harvest (Holloway and Ilbery 1997). The unequal balance of power in market infrastructure therefore creates a barrier to pulse crop adoption through the potential burden of waste. To accelerate the adoption of pulses in the UK, supermarkets will have to be front and centre in conversations about creating new value chains for UK pulse crops. Equally, the creation of secondary markets for valorising pulse waste will be essential for providing a financial safety net for all those taking on the risk of new pulse products (Cordis 2017, Can Karaca and Nickerson 2022).

4.5. Interlinked barriers

The above discussion notes the set of barriers preventing an increase in the consumption of locally grown pulses, despite their multiple benefits, constitute a socio-technical lock-in. Every stakeholder in the system requires confidence in a wider social and systemic shift to change their own business practise. Breeding programs need confidence in a stable market for new crops to invest in long term programs, both to improve yields of current crops and to research crop diversification. Equally, agricultural input producers need sufficient demand for pulse-based products before developing and registering new agrichemicals. Farmers need adoption of new crops to be de-risked through agricultural extension services, guaranteed purchase contracts and stable primary and secondary markets for the pulses they grow, as well as motivation to take on this risk through a sense of a wider socio-economic shift. Processors equally need investment into infrastructure to store and process home-grown legumes, competitive pricing for UK grown pulses compared with imports and most importantly they need confidence that environmental credentials will be a valuable sales point for their products. This can only be met if there is more publicly available information about the multiple benefits of pulses and more attempts to communicate these to consumers. Finally, this messaging will only influence behaviour if pulses are accessible, affordable and convenient, requiring both efforts to increase agricultural yields and investment into developing new pulse-based products.

5. Increasing net zero impact

In recent years, a series of socio-economic, environmental and cultural shifts have coalesced to create favourable conditions for increasing the prevalence of pulses in the UK agrifood system to meet net zero goals. The increased cost of fertiliser associated with the ongoing war in Ukraine is leading to farmers seeking alternative ways to increase the productivity of their land. Recent and persistently high levels of cabbage stem flea beetle have also made growers seek alternatives break crops to oilseed rape (such as the faba bean), due to consecutive failed harvests (Howell and Abhimanyu 2023). Reliance on imported soybean meal for animal feed (and it is sometimes questionable provenance) is leading to shifts in plant protein sourcing (Luyckx 2023). Furthermore, the use of offsetting has come under increased public scrutiny, raising suspicions of inaction, unaccountability and greenwashing, and causing companies to look for solutions to reducing emission within their supply chains. Finally, market trends reflect a reduction in the consumption of meat products and increasing consumer demand for meat alternatives and novel plant protein products (see section 5.3). All of these factors are combining to set the conditions for a shift to an increase in producing and consuming pulses as a contribution to the UK's net zero goals. While it is acknowledged that endeavours to increase the prevalence of pulses in the UK will require coordinated action across the entire value-chain (Iannetta *et al* 2021, UKRI 2022, Lovegrove *et al* 2023), the main opportunities lie in the producing, processing and manufacturing, consuming, and minimising waste activities.

5.1. Producing

Recent research into producing UK pulses has presented several opportunities for increases whilst sustaining yields and helping to achieve net zero. One such line of enquiry is intercropping, where two or more crops are grown on a single piece of land simultaneously (usually in alternating strips). Research into cereal-pulse

intercropping as part of the ReMIX project has demonstrated that the practise can increase regional protein supply whilst reducing inputs, such as fertiliser and pesticides (Holt *et al* 2021). Furthermore, intercropping produces positive interspecies interactions by causing the increased acquisition of soil derived nitrogen in cereals and reducing the use of soil derived nitrogen in the pulse, thereby increasing the reliance on symbiotic nitrogen fixation (Rodriguez *et al* 2020, Tripathi *et al* 2021, Weih *et al* 2021). However, for these methods to be widely implemented further research needs to be done into harvesting and post-harvest separation of crops as well as the legislative framework and agronomic support for farmers in implementing these new farming methods.

Finally, several opportunities to offer farmers the economic support they need to produce novel pulse crops are emerging. As the UK continues to remodel its agricultural subsidies after leaving the EU, there is huge potential to further incorporate funding for public goods, of which producing pulse crops for their environmental and human health benefits could play a central role (PGRO 2018). Private investment into sustainable farming is also becoming increasingly common through a variety of avenues including ecosystem services, nature-based solutions and landscape enterprise networks. Increasingly, small and medium UK enterprises (for example Wildfarmed and Hodmedods) are working with farmers, often in collaboration with agronomists, to financially support the implementation of sustainable farming practices. Finally, viable secondary markets for non-food grade pulses are emerging that will allow farmers to recoup some of the costs of less successful harvests.

5.2. Processing and manufacturing

One of the opportunities for using pulses and pulse derived protein isolates is in the growing market for 'Plant Based Meats' (see sections 3.2 and 5.3). In addition, a range of studies have tested how pulses can be covertly incorporated into existing and novel foods products as a 'health by stealth' approach to increasing their consumption. Pulse proteins possess functional properties that play an important role in food formulation and processing, such as solubility, water and fat binding capacity, and foaming (Boye *et al* 2010). As a result a wide range of research has explored how pulses can be used in a variety of different processed products including dairy products (Mefleh *et al* 2022), extruder snacks (Tas and Shah 2021) and as a glutinous wheat replacement in various pastas (Petitot *et al* 2010), breads (Lovegrove *et al* 2023), and baked products (Noorfarahzilah *et al* 2014, Sozer *et al* 2017). The premise behind many of these studies is that using pulses in familiar products and analogue meal structures helps to circumvent key barriers to their increased uptake such as unfamiliarity, undesirability and the need to devote time to cooking and developing new cooking skills (Alae-Carew *et al* 2022).

Whilst the majority of these research projects are primarily motivated by improved health outcomes, they also have positive net zero outcomes through fostering a stable high-volume demand for pulses and pulse ingredients. One study estimates that if a 25% faba bean composite bread reaching a 10% market share in the UK would generate demand for a further 50 kt of faba bean per annum, driving widespread, favourable land use change and a concomitant 11% drop in CO₂-e emissions per loaf (Lovegrove *et al* 2023). In this way, a focus on establishing supply chains for pulse-enhanced staple products would create favourable conditions to produce more pulse-based products in the UK. Sales of savoury snacks in the UK retail market were around £3.9 billion in 2017 (Tas and Shah 2021), so even a small increase in the pulse content of these products could significantly increase the size of the UK pulse markets.

5.3. Consuming

The UK market for plant-based products, driven by shifting diets away from meat, is already having macro-level effects on food system value chains. One in four consumers regularly buy plant-based meat and dairy alternatives (AHDB 2019), mostly due to ethical and environmental concerns (Jallinoja *et al* 2016). A recent YouGov survey found that 14% of UK adults identify as flexitarian and an additional 15% have diets that avoid meat (apart from fish) (YouGov 2023). Due to their high protein content (21%–40%), pulses are a key ingredient in many plant-based 'meats', which allow consumers to reduce their meat consumption without having to change meal structures, sacrifice convenience, gain new cooking skills or lose nutritional value, all of which have been identified as barriers to dietary change (see section 4.3). This was reflected in a recent Straits Research study, where 40% of consumers said they would like more plant-based alternatives to meat and dairy (Vegconomist 2023). Individuals consuming plant based alternative foods increased from 6.7% in 2008–2011, to 13.1% in 2017–2019, with the largest increases amongst Millennials and high earners (Alae-Carew *et al* 2022). Large retailers and big brands have developed bean-based product ranges that respond to the joint demand for plant based alternative meats and easy to prepare food, such as Kraft Heinz new 'Beanz Liberation' range (Woolfson 2021). The major UK supermarket Sainsbury's has recorded a 65% increase in its plant-based products year on year, and anticipated that 25% of the UK population will be

vegetarian by 2025 (Sainsbury's 2019, Nicholson and Jones 2023). This would have a significant net zero impact.

However, in order for dietary guidelines to have a noticeable net zero effect, they need to be used to guide other policies, such as educational interventions. One such intervention is the use of home economics education at schools to promote a positive image of plant protein meals and teach young people how to cook with new ingredients. Equally, public information campaigns can be used to educate consumers about the health and environmental benefits of pulses, and to raise public awareness about health and environmental issues related to high levels of meat intake (Jallinoja *et al* 2016). Moreover, these campaigns need to go further than government advice and must involve a whole host of non-state actors that not only educate consumers about pulses, but also change their perception of pulses through making them desirable food, associated with pleasure and fulfilment, rather than a vegetarian compromise (Jallinoja *et al* 2016). Such an approach was taken by the UN in 2016 with the 'International Year of Pulses' and has more recently been led by 'Beans Is How', an advocacy campaign that uses celebrity chefs, food journalists and social media campaigns to promote pulse based recipes and rebrand pulses as desirable future foods (Beans Is How 2023).

Studies into how additional information influences consumer preferences for pulses and pulse-based products agree that when consumers are informed of positive health or environmental impact this increases their intention to consume the product (Röös *et al* 2020). Some studies find that positive health outcomes are a stronger motivation for eating less meat compared with environmental reasons (Tobler *et al* 2011) and others identified that when consumers were informed of both environmental and health benefits this further increased their intention to consume the product (Henn *et al* 2023). Positive messaging about the environmental (including net zero) and health benefits of pulse consumption should therefore be focused and strengthened by government messaging, food research and industry advertising and branding to align consumer intentions more closely with consumer decisions.

National nutritional guidelines can also be used to determine procurement through institutional food services (such as schools, hospitals, public sector offices and prisons). Unlike private sector hospitality services, institutional food services offer opportunities to directly influence consumers' eating habits because choice is limited. Further, guests are often described as 'captive' (Magrini *et al* 2021) and the food that is served can be directly influenced by government policy. In the UK, the newly introduced 'dynamic procurement system' aims to make it easier for small and medium sized enterprises to fulfil public procurement contracts, creating potentially stable demand for novel pulses grown in the UK (Eveleigh 2023).

5.4. Minimising waste

Waste in the form of powder, husk, broken and unprocessed pulses can be up to 25% of the total pulse weight processed (Patras *et al* 2011). Producing more pulses in the UK could therefore create opportunities for a variety of new industries and products from the waste during processing and manufacturing, furthering net zero aims by increasing economically viable side streams. Several studies have identified the potential to isolate nutrients such as proteins, fibres and fatty acids from this waste, that could be used as functional ingredients in food products to improve their nutritional value (Niño-Medina *et al* 2019, Luzardo-Ocampo *et al* 2020, Can Karaca and Nickerson 2022). This has the potential to create new market value for pulses by presenting a viable alternative market for harvests that do not meet food grade standards. There is also potential to use by-products from pulse rehydration, such as the use of the salt brine (known as aquafaba) as a foaming and emulsifying agent, that could serve as a low environmental impact replacement for egg white in food products (Buhl *et al* 2019). However, a recent LCA of two types of mayonnaise, one using egg and one aquafaba concluded that the overall environmental footprint of the pulse equivalent product was in fact higher (Saget *et al* 2021a). This demonstrates the need for further research into how and when novel pulse-based replacements of animal products achieve the net zero aims they intend. Finally, extracts from pulse by-products have the potential to be used in cosmetics such as moisturisers and anti-itching agents, as well as fibrous material to be used in biodegradable packaging (Tassoni *et al* 2020). The EU project LEGUVAL put forward a series of novel suggestions for the 3 million tonnes of pulse waste produced every year on farms in Europe (Cordis 2017). The project was able to extract an 80% purity protein from the waste, which was then turned into biodegradable plastic plant pots (Cordis 2017). In both instances there is a lack of research connecting the extraction of by-products from the leguminous waste with the use of by-products in new value-added products.

In addition to pulse waste for human consumption, there is great potential for on-farm pulse waste to be repurposed as feed. The WWF's Future of Feed report (Cottee *et al* 2022) highlights the importance of using food waste as animal feed and scenarios to understand the feed-food competition related to increased pulses production in the UK have been carried out in a recent report 'Soy No More' (Landworkers Alliance 2024).

5.5. Ways forward

Whilst increases in producing and consuming pulses offers an immediate reduction in carbon emissions, interventions to reduce the emissions associated with the ‘missing middle’ of the pulse value chain are also important. The most pressing of these improvements will include optimising the transportation emissions of pulses through local production and using the most efficient means of transportation; identifying and scaling the most energy-efficient packaging designs for whole pulses and pulse products, including scoping the potential for packing reuse schemes; and reducing the energy demands associated with producing novel plant-based meat alternatives. These innovations in pulse and pulse-based ingredients will need support through research funding and innovation grants.

Public procurement could also be a key leverage point for systems change: through creating a stable demand for pulses and pulse-based products, enabling the economies of scale that make product prices competitive, increasing consumer access to pulse products, educating consumers about the multiple benefits of pulses, shifting social norms around the role of meat in diets and signalling a clear policy direction related to diets and the net zero agenda. Lessons could be learned from a series of well-funded research projects in Europe (e.g. LegValue, Legumes Translated, LegumePlus, ReMIX), Australia (CILR) and Canada (Pulse Canada). These have bolstered the production of pulses in many locations, closed yield gaps, improved public awareness of the environmental and health benefits of pulses, increased domestic consumption and strengthened exports of pulses from each of the regions (Balázs *et al* 2021). In particular, the Canadian model of public funding for public good has been hugely successful in building a large sector of the economy (PGRO 2018), leading to Canada becoming the largest pulse exporter in the world and the number one supplier of UK pulses for human consumption. There is a real opportunity for the UK, and other countries worldwide, to invest in similar programs, allowing them to contribute to net zero goals whilst creating new enterprise opportunities and improving public health outcomes.

Current socio-economic and ecological conditions in the UK are beginning to create an informal enabling environment. For farmers, fertiliser price hikes, the cabbage stem flea beetle, increased concern for soil health and buyers seeking alternatives to soy are all creating opportunities for producing pulses, whilst research into intercropping and precision breeding promise to make yields stable and competitive with other crops. Similarly, for processor and producers, there is a clear increased demand for plant protein products as well as increasing investor scrutiny over supply chain emissions that is creating opportunities for pulses and pulse by-products to be incorporated openly or covertly into an entire range of products and ingredients.

6. Conclusions

It is clear that when looking across the value chain, pulses have a valuable contribution towards a net zero UK agrifood system. For growers, increasing pulses in the rotation not only reduces emissions associated with fertiliser, pesticide and tillage, and under the correct conditions increase soil carbon. Equally, for processors and manufacturers the incorporation of pulses and pulse derived ingredients into products is a low-cost solution to reducing the carbon footprint of various consumer products, with simultaneous benefits such as improved nutritional value, reduced gluten content and GMO/soy free credentials. Producing and eating more pulses in the UK will also contribute to net zero goals in transportation, storage and food waste through greatly shortened food miles and long shelf-life. Finally, for consumers, pulses are a highly nutritious alternative to meat that can significantly increase the net zero value of diets.

However, the UK currently produces negligible/limited quantities of pulses that are consumed by the UK population, and barriers to consuming traditional varieties and producing those currently imported are significant. Increasing UK production to meet current demands for pulses could impact beyond the UK agrifood system, provided a scale is met (which cannot be done without support) and assuming displacement of higher carbon imports. In a scenario of increased UK demand for pulses for human consumption because of dietary trends continuing to shift away from meat and dairy, net zero contributions could increase but vary depending on whether this demand was met by UK production or via global imports. Furthermore, these changes to the food environment—specifically to the availability, affordability and visibility of pulses and pulse-based products—will only shift consumption patterns when accompanied by a coordinated set of public information campaigns and educational interventions to inform consumers about the choices they make. Yet the UK is still lacking a formal enabling environment through clear policy direction, provision of capacity building, incentives for greater diverse pulse production and support for food sector innovation that would encourage long-term investment throughout the supply chain.

Demand for pulses in the UK is increasing and needs to be met. While there remain questions of ultimate magnitude or scalability within the UK, there is clearly potential across all food system activities for pulses to contribute to UK net zero.

Data availability statement

No new data were created or analysed in this study.

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