ELLEN MACARTHUR FOUNDATION

The big food redesign

TECHNICAL APPENDIX

This technical appendix provides detailed information on the calculations and modelling that underpin the conclusions and recommendations of *The big food redesign: Regenerating nature with the circular economy*. The scenarios modelled here form the basis of the design opportunities that comprise the circular design for food framework detailed in this study.

Section one provides an overview of the analytical framework and metrics used for the modelling.

Section two gives detailed context on the outcomes of the analysis for wheat, dairy, and potatoes.

Finally, all input data, assumptions, sources, and calculations for the modelling are detailed in section three.

This study was produced by the Ellen MacArthur Foundation, with analytical support from Material Economics to conduct the modelling detailed in this technical appendix.

MATERIAL ECONOMICS

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Contents

List of abbreviations

BAU	Business-as-usual
BIM	Biodiversity impact metric
CO_2e	Carbon dioxide equivalent
FMCG	Fast-moving consumer goods
GHG	Greenhouse gas
LER	Land equivalent ratio
LUC	Land-use change
MIG	Managed intensive grazing
NPV	Net present value
SOC	Soil organic content
UAA	Utilised agricultural area
USD	United States Dollar(s)

1. Analytical framework

Analytical framework

For this study, an analytical framework has been developed to quantify the environmental, food output, and farmer profitability outcomes of applying circular design for food. To do this, modelling was performed for four ingredients – wheat, dairy, potatoes, and sweeteners. These ingredients were selected based on three key criteria:

- **They represent a substantial agricultural footprint in the EU/UK.** Wheat, dairy, and potatoes collectively make up about 30% of Utilised Agricultural Area (UAA) in the EU and 22% of UAA in the UK
- **They are significant ingredients in most FMCG and retailer product portfolios.** All of the ingredients are typically amongst the top 10 ingredients sourced by volume, by major FMCGs and retailers
- **They represent a broad set of ingredient types, farming systems, and associated environmental challenges**

Based on the available literature, a set of practices and combinations of crops and/or livestock that support regenerative outcomes, as well as lower impact alternative ingredients, were selected for each ingredient. Importantly, these are illustrative and not intended to be a one-size-fits-all solution. The agricultural practices and crop/livestock combinations most appropriate for regenerating nature will vary significantly depending on context-specific factors, such as climate and soil types, and should be tailored to the needs of the specific location. As such, the quantified outcomes against the metrics assessed are expected to vary according to a farmer's given context; alternatively the same or similar outcomes might be achieved through the application of a different set of practices. The outcomes presented in this study assume contexts suitable for the practices and crops applied. This assumption holds true in many, but not necessarily all, UK and EU contexts.

The benefits of three scenarios were quantified for each ingredient and compared to the business-as-usual (BAU) impacts. The three scenarios assessed were:

1 Lower impact ingredients – shifting to conventionally grown alternative ingredients that have reduced environmental impacts and offer greater diversity
2 Better sourcing – growing the same ingredients using practices that support regenerative outcomes
3 Circular design for food – applying a combination of scenarios one and two

Opportunities to substitute wheat, dairy, and potatoes with upcycled ingredients were not analysed in the same way due to insufficient evidence. Quantified environmental and economic evidence for this is currently insufficient due to the relatively small-scale use of upcycled ingredients made from wheat, dairy, and potatoes, or for ingredients or products acting as suitable substitutes for these ingredients. Consequently, the evidence is lacking around established supply chains, buying models, and economies of scale for ingredient upcycling in this context. Instead, a different approach was taken to investigate the scale of the opportunity for upcycling by-products into sweeteners.

The diverse ingredients design opportunity described in the study was not included in the modelling as there is currently no appropriate metric available to quantify the many benefits of using diverse ingredients. The Agrobiodiversity Index for business could be used in the future, but this was not available when this study was conducted. Similarly to upcycled ingredients, many diverse ingredients are currently produced at a small scale and so face a number of the same issues in terms of the availability of accurate data.

Input data and proxies used in the modelling were gathered from a wide range of sources including: statistical databases, such as GLOBIO, PREDICTS, FAOSTAT, Eurostat, and Defra Statistics; the review of over 100 peer-reviewed academic studies, meta-studies, and publications; and interviews conducted with over 30 farmers, leading food industry stakeholders, academia, and those involved in project managing currently active regenerative pilot projects on farmlands in the EU, the UK, and North America.

1.1. Environmental impacts methodology

Two metrics were used to model environmental impact:

- **Net greenhouse gas emissions**
- **Biodiversity footprint (quantified in biodiversity weighted hectares)**

Each metric is expressed in terms of percentage reduction (%) compared to business-as-usual (BAU), here defined as conventional production of the example ingredient in EU/UK contexts during 2020. Calculations are based on farm-level impact and exclude the impacts caused by other steps in the value chain such as transportation or processing.

1.1.1. Net greenhouse gas emissions

The net greenhouse gas (GHG) emissions (tCO_2e) were calculated as follows:

- total GHG emissions released at farm-level to produce 1 tonne of food
- net of any increase/decrease in the amount of carbon sequestration from changing farming/crop dynamics and/or introducing new forms of vegetation, such as trees, onto farmlands
- net of any increase/decrease in GHG emissions associated with reduced/increased use of synthetic agricultural inputs through the implementation of practices such as reduced tillage and/or cover-cropping

Emissions figures for the evaluated ingredients only account for direct emissions at farm-level resulting from production. Figures do not include emissions associated with the initial land-use change (LUC) from unused land into crop/pastureland as the analysis is focused on the optimisation of existing agricultural systems in Europe, rather than the establishment of entirely new agricultural lands.

All GHG emissions in the study are evaluated using global-warming potential on a 100-year timescale (GWP_{100}). This is the most commonly used and accepted methodology for assessing the climate impact of warming gases. It should be noted that using GWP_{100} may both over- and understate climate effects, particularly those arising from shifts within and away from current livestock production systems. A notable alternative methodology is GWP*,[1,2] however this was not used in this analysis as it is not yet widely employed in the available literature and is not straightforward to apply to individual farms or supply chains in a clear and meaningful way.

Regenerative food production often increases soil organic content (SOC) over time until the soil is fully saturated. Reverting to more intense practices, such as conventional tillage, risks releasing some or all of the built-up SOC back into the atmosphere. In this analysis, the indefinite continuation of practices that support regenerative outcomes is assumed.

A common criticism of studies that show large increases in SOC after shifting from conventional to reduced tillage practices is that measurements are taken at an insufficient depth in the soil profile. For this study, results which include measurement at soil depths up to 30cm have been applied. The conversion of SOC figures to carbon dioxide equivalents (CO_2e) has been done using a conversion factor of 3.65 $tCO_2e/tSOC$.

1.1.2. Biodiversity footprint

There is currently no single, all-encompassing, and universally adopted metric to assess impacts to all levels of biodiversity (above/below-ground, genetic, ecosystem, and landscape). In this analysis, the University of Cambridge Institute for Sustainability Leadership's Biodiversity Impact Metric[3] (BIM) was used to quantify the biodiversity impact on farmland used to produce inputs to FMCG/retailer products. The BIM assesses biodiversity impact in terms of 'biodiversity weighted hectares' required to produce a given volume of a specific ingredient. It is based on three variables (see Figure 1):

The BIM is a useful proxy to quantify biodiversity impact from the agricultural systems used to produce defined volumes of the ingredients assessed. Three limitations should, however, be noted:

- it is relatively highly influenced by land use, with higher yielding crops more likely to get a lower score
- it is not suitable for comparing trade-offs across the three variables
- it is imprecise in terms of intensity scoring across specific farming practices, due to the current lack of conclusive scientific evidence around quantitative impact from a fully exhaustive set of farming practices

The latter of these limitations is addressed in this analysis through applying a precise set of intensity scores for the practices assessed, based on GLOBIO assessments as well as input gathered in expert interviews.

The STAR metric, which may be used to set Science-Based Targets in future, was considered as an alternative metric to BIM.[4] However, at the time of writing the dataset used to calculate the STAR metric was unpublished and so it was not possible to use this methodology for this study.

Figure 1: BIM calculation formula

Land usage		**Proportion of biodiversity lost based on intensity of land usage**		**Biodiversity importance of the land usage**		**Biodiversity weighted hectares**
Hectares required to produce the amount (tonnes) of commodity purchased in the source country	x	**Proportion of biodiversity** lost based on Mean Species Abundance (MSA) coefficients in relation to **intensity and type of land usage**	x	**Relative global importance of biodiversity** based on species richness and uniqueness in the **source country/region**	=	**'Weighted hectares'** (hectares weighted by biodiversity impact) required to produce given volume

1.2. Farmer profitability and total food output impacts methodology

The impacts on farmer profitability of each of the defined scenarios have been assessed at farm-level (including direct impacts on primary commodity prices). Potential economic implications for other parts of the FMCG/retailer value chain, such as processing, logistics, trading, and marketing have been kept out of scope due to their high dependency on company-specific capabilities and approaches.

The farmer profitability figures presented are for 'steady state', which is defined as the year in which the farm system reaches maturity: when yields and economic returns stabilise. This differs for each of the three ingredients that are the main focus of the study.

The analysis is focused on the most significant drivers of difference between the scenarios – aspects which would considerably alter costs, revenues, or investment needs compared to BAU – rather than attempting to present a comprehensive picture of costs and revenues. In select instances though, full baseline costs and revenues were modelled to showcase important changes in the total economic outlook for farmers. Therefore, the changes in profitability presented here should be considered high-level and indicative.

Costs following the implementation of the scenarios have been assumed to stay constant over time. In reality, these costs often decrease as farmers learn how to best optimise the new system.[5] It is also worth noting that individual farmer costs can be substantially reduced if a coordinated transition across multiple farm holdings is made, primarily thanks to enhanced economies of scale in the sourcing and pooling of equipment.

All economic values are presented in nominal USD terms, at average Q1 2021 currency levels. This includes producer prices, where the average price for the years 2015–19 has been applied. In effect, this means there are no assumed inflation or price premiums for regeneratively produced ingredients in the economic calculations affecting farmer revenues. No changes to existing subsidies have been included.

Depreciation is assumed to be linear over the lifetime of the asset in question, in line with standard accounting practices. For all machinery and infrastructure assets, the lifetime has been assumed to be 10 years. For tree investments in silvopasture systems a lifetime of 68 years (the average lifetime of the tree) has been assumed.

2. Ingredient deep dive

Ingredient deep dive

2.1. Wheat

The analysis shows potential for a 30–80% reduction in GHG emissions and a 55% biodiversity footprint reduction across the three scenarios modelled for wheat production. Positive environmental impacts are reached in the circular design for food scenario, in which a shift to lower impact ingredients and practices that support regenerative outcomes is applied – effectively shifting from conventional, mono-crop farming systems into regenerative, multi-crop systems. The full GHG emissions reduction potential in the circular design for food scenario would be equivalent to a CO_2e reduction of approximately 62 million tonnes if extrapolated to total EU-27 wheat volumes.

2.1.1. Lower impact ingredients

A box of breakfast cereal has been selected as an example product in order to assess the impacts of a shift in wheat production. Using green peas as a substitute for wheat in the production of breakfast cereal has been the focus for these assessments. The green pea is already a proven product innovation in categories such as pasta and is currently being marketed by several FMCGs and retailers, albeit only in small volumes. Opportunities exist to expand its application to other categories in which wheat is currently a primary ingredient, such as breakfast cereals.

Environmental impact potential

Shifting the ingredient base in a box of breakfast cereal from conventionally produced wheat to conventionally produced green peas has the potential to reduce farm-level GHG emissions by 30–50%. This is the result of approximately 40%[6] lower per tonne CO_2e emissions and slightly higher yields for green peas (roughly 5.8 t/ha) compared to wheat (roughly 5.5 t/ha in EU-27).[7] This yield difference also contributes to reducing the farm-level biodiversity footprint by 5% as a somewhat smaller land area is required to produce equivalent product volumes. Additionally, green peas – like most other legumes – further support ecosystem health through their ability to fix nitrogen in the soil.

It is worth noting that green peas might not be the best choice of substitute ingredients in a UK context, where green pea yields are roughly 30% lower than the EU-27 average.

Economic implications

The main economic implication in a shift from wheat to green peas is increased ingredient costs from an FMCG/retailer perspective, as the per tonne price for conventional green peas is approximately seven times that of conventional wheat. This could lead to green pea breakfast cereal being marketed by FMCGs and retailers as a premium, niche product rather than as a direct alternative to regular wheat breakfast cereal.

2.1.2. Better sourcing

The set of practices that support regenerative outcomes assessed for wheat is one where a combination of intercropping and cover cropping has been applied, with crop residues retained on soil post-harvest. A key factor in the selection of this practice set is nitrogen fixation from leguminous inter-crops, and the way in which this practice can enhance drought resistance, due to minimised soil erosion from no-/minimum-tillage and year-round soil cover from cover crops. Drought resistance is likely to become increasingly relevant in a European context, due to the impacts of climate change, especially for Southern, Eastern, and Central European farmers,[8] who currently produce the large bulk (~85%)[9] of EU-27 wheat volumes.

Environmental impact potential

Shifting the ingredient base in a box of breakfast cereal from conventionally produced wheat to growing wheat with practices that support regenerative outcomes has the potential to reduce the farm-level GHG emissions by 40–60% and the farm-level biodiversity footprint by 20–30% at unchanged food volumes.

A recent US National Cover Crop Survey[10] found that five-year (2012–16) yield enhancement on fields managed with cover crops ranged from 1.3–11.6%, with an average five-year yield enhancement of 4.5%, in comparison with equivalent managed fields with no cover crops.

Importantly, the largest yield differences were noted in drought years.

Findings on the yield implications of no-/minimum-tillage are not as clear. If applying no-tillage on a standalone basis, yields have in many instances been reported to decline,[11] with the magnitude of decline varying substantially across temperature zones, climate, and crop types. Temperature wise, the most severe burden (~-15%) appears to typically be noted in tropical latitudes and the lowest burden in temperate latitudes (~-4%). No-tillage appears to perform best under rainfed conditions in dry climates, where it often matches conventional tillage yields. Root crops tend to be hit the hardest (~-20%+), while cereals – most notably wheat – suffer the least impact (~-2–3%). In all instances yield declines appear to reduce over time, hand-in-hand with ecosystem health enhancement and best practice methods coming into play. For wheat, yield increases of an average of 2% are typically noted 10 or more years after the transition from conventional to regenerative production is initiated.[12]

When applied in combination with complementary practices that support regenerative outcomes, minimum-/no-tillage appears to have the potential to increase yields. In years 10 onwards post-transition, combining no-tillage with complementary practices, such as cover-cropping and the retention of crop residue on field post-harvest, has been proven to boost yields up to around 20% compared with standalone no-tillage.[13] To quantify a proxy for wheat yield enhancement in steady state from the identified set of practices that support regenerative outcomes, a conservative, mid-single digit yield enhancement of 3–5% has been applied on top of the 2% average increase resulting from minimum-/no-tillage as an isolated practice. In total, the improved steady state wheat yield applied amounts to 5–7%. This proxy has been validated through several expert interviews and comparisons with evolving outcomes of wheat field pilots currently running in Italy and North America.

Over the course of a transitional two- to three-year period, the set of practices that support regenerative outcomes would typically have a low- to mid-single digit negative impact on yield, driven by the minimum-tillage aspect.

Minimum-tillage plays a central role in the potential for a shift to practices that support regenerative outcomes with the aim of reducing the GHG emissions of a box of breakfast cereal. By minimising soil disturbance, minimum-tillage enhances SOC sequestration capacity, with a positive sequestration cycle capturing approximately 1.1 tCO_2e/ha over the course of 10–15 years post-transition. The reduced use of external inputs further contributes to the reduction in GHG emissions.

The combination of minimum-tillage, the use of nitrogen-fixing legumes to enhance soil health and nutrients, and employing cover crops to provide year-round soil cover and act as a nutrient-enhancing crop residue when retained on the field post-harvest, contributes to higher on-field diversity and overall ecosystem health, as well as enabling the reduced use of synthetic inputs. The combined land usage reduction potential and beneficial ecosystem outcomes are thus key drivers of the biodiversity footprint reduction offered by this scenario.

Economic implications

From the perspective of an individual 100-hectare wheat farmer, shifting to a set of practices that support regenerative outcomes as described offers a nominal steady state net-value creation potential of approximately USD 13,000 per harvest or USD 130 per hectare (compared to a current approximately USD 25,000 per harvest or USD 250 per hectare average loss before subsidies for EU wheat farmers).[14] This comes after a transition period of approximately one to two years to break even and a ramp-up time of approximately 10 years to steady state. Lowered yield and increased capital expenditure (CAPEX) drive negative cash flow in the first year, with four years total payback time (both nominal and discounted with a rate of 4.5%). Net present value (NPV) for the total investment over 10 years is positive at discounting up to 50%+. Pay-off time could be further shortened if taking into account factors such as enhanced systems resilience, greening premium subsidies, and scope for a coordinated transition across multiple farmers (enabling, for example, shared equipment and pooled seeding purchases).

2.1.3. Circular design for food

The circular design for food practice set assessed for wheat is one where a combination of minimum-tillage, extensive intercropping with green peas, and cover-cropping has been applied. The sole difference when compared with the 'better sourcing' scenario assessed in section 2.1.2. is that green peas are treated as a cash crop and not simply an inter-crop, thus enabling more ambitious levels of intercropping and additional yield enhancements.

Environmental impact potential

Shifting the ingredient base in a breakfast cereal product line from 100% wheat sourced from conventional farms to a roughly 50:50 combination of wheat and green peas grown as inter-crops in a regenerative production system has the potential to reduce the farm-level GHG emissions by 60–80% and the farm-level biodiversity footprint by 45–55% at unchanged food volumes.

In addition to the beneficial yield dynamics from the practices used to support regenerative outcomes described in section 2.1.2. 'better sourcing', the circular design for food practice set benefits from the synergies of extensively intercropping wheat with green peas, which drive total system output roughly 50% higher (by weight) than for either when cultivated as a mono-crop using baseline practices.

Intercropping cereals and legumes has several synergistic effects, not least the ability of legumes, such as peas, to fix atmospheric nitrogen in the soil. Residual organic matter from the inter-cropped system is also higher in nutrients than a mono-crop would be, increasing the natural fertility of the soil in the long term.[15] The complementary growth cycles and morphology of wheat and peas increase their combined utilisation of the natural resources in the field. Complementary growth cycles mean their peak demands for resources such as nutrients, water, and sunlight are staggered, reducing competition between the two. Uptake of solar energy is also optimised by the different height and shape of the two crops.[16] Optimal usage means fewer resources are available for uptake by weeds, leading to natural weed suppression.[17]

Land equivalent ratios (LERs) – the ratio between the total output of an inter-cropped system compared to an equal land area of either mono-crop – are often shown to be high in studies of these systems. This is especially true for systems with limited external nutrient inputs, such as in organic farming, where LERs can reach very high levels[18] because of the relatively higher effects of legume nitrogen provision. However, even in systems with high external nutrient inputs, land efficiency ratios can reach high levels.[19] In this analysis, a LER assumption of 1.38 is applied, based on an average of 11 studies of wheat intercropping.[20]

It should be noted that primary crop yield is decreased in most cases of extensive intercropping, although some studies do show potential to increase yields of the primary crop, even without considering secondary crop yield.[21]

This yield decrease is made up for, however, by the secondary crop yield adding to the total system output. Therefore, in order to make economic sense, both crops in an inter-crop system must be marketable and the revenue generated by the secondary crop (in this case, peas) must at least make up for the lost primary crop yield (in this case, wheat).

As in the 'better sourcing' scenario, minimum-tillage plays the key role in the CO_2e footprint reduction potential of the circular design for food scenario, with additional marginal contributions from the reduced usage of external inputs. Added to these two factors is the potential to use a smaller area of land to produce equivalent food volumes. The combined result is a farm-level GHG emissions reduction of 60–80% compared to 40–60% in the 'better sourcing' scenario.

The biodiversity footprint dynamics in this scenario are similar to those at play in the 'better sourcing' scenario. However, further reduction of the footprint is enabled through the potential for an added 35–40 percentage points of total system output in steady state. The result is a farm-level biodiversity footprint reduction of 45–55% compared with 20–30% in the 'better sourcing' scenario.

Economic implications

From the perspective of an individual 100-hectare wheat farmer, an indicative analysis of the circular design for food scenario indicates that it offers up to approximately USD 200,000 in nominal steady state net-value creation per harvest, or USD 2,000 per harvest per hectare. As such, it offers the most compelling value potential across all wheat scenarios. Notably, circular design for food offers the potential for wheat farmers to become profitable (excluding subsidies) from year one post-transition, provided that a market for inter-cropped peas can be established – potentially giving leeway for repurposed flows of public financing. The key driver behind the substantially improved farmer economics is the use of inter-cropped peas as cash crops, which significantly enhances total food output from an unchanged land area (total food output enhancement of 34% in year one, reaching 49% in steady state) and offers additional revenue streams for the farmer. It is important to point out though that apart from harvesting dynamics, no additional costs resulting from a new infrastructure set up in order to market green peas have been incorporated in this assessment.

2.2. Dairy

The analysis shows potential for 40–100% GHG emissions reduction and 15–80% biodiversity footprint reduction across the three scenarios modelled for dairy production. Positive environmental impacts are reached in the circular design for food scenario where a shift to both lower impact ingredients and practices that support regenerative outcomes are applied, effectively turning conventional, mono-crop dairy farming systems into regenerative, multi-crop systems. The full potential GHG emissions reduction in this circular design for food scenario would be equivalent to a reduction of roughly 160 million tonnes of CO_2e per year if extrapolated to full EU-27 dairy volumes.

2.2.1. Lower impact ingredients

A carton of 'milky drink' has been selected as an example product in order to assess the impacts of a shift in dairy ingredients. While numerous substitutes could be in scope for this analysis – as illustrated by the many plant-based 'milky drink' options on the market today – the focus in this study is primarily on oat milk as it appears to offer the most substantial environmental benefits.

All substitution in this analysis has been calculated on a litre-by-litre basis. Although a nutrient-oriented perspective could have been taken (e.g., conducting the analysis on the basis of protein content in 1 litre of cow's milk vs. 1 litre of plant-based 'milky drink'), a volume-oriented perspective was selected for three reasons:

- A large share of 'milky drink' volumes in EU-27 countries and the UK is consumed for pleasure (e.g., in coffee or tea) rather than for its nutrient content
- Different choices of nutrients inevitably lead to highly diverging results, and there is no single nutrient that plays the most central role in the consumption of cow's milk
- A lot of the plant-based 'milky drinks' on the market contain nutrient supplements which put them on par with cow's milk

If applying a nutrient-based perspective, plant-based alternatives look less advantageous. This is the result of the generally higher protein content of cow's milk (by a factor of 2–3x) in comparison with most plant-based milks, so two to three times more plant production (and proportional cropland area) is required to match it protein-for-protein, affecting both biodiversity and GHG emissions.

No by-products created from dairy or oat farms have been considered in the total output calculations as it is challenging to set firm and objective boundaries for what to include in such calculations. It is important to acknowledge that beef output from dairy farms constitutes a highly valuable by-product, amounting to 5–10% of total protein output in the average EU-27 dairy system.[22]

Environmental impact potential

Shifting the ingredient base in 1 litre of 'milky drink' from cow's milk to oat 'milk' has the potential to reduce the farm-level GHG emissions by 80–99% and the farm-level biodiversity footprint by 70–80% at unchanged product volumes.

The per tonne CO_2e emission for oats are approximately 10 times lower than for dairy[23] with the difference further increased due to the substantial water content in 1 litre of oat 'milk' (oats constituting only 7–10% of the total ingredient base). Additionally, the theoretical yield for oat 'milk' (37.4 t/ha) is significantly higher than for cow's milk (7.3 t/ha), with the oat 'milk' yield again being significantly boosted by the water content.

The reduction in biodiversity footprint is entirely driven by the significant theoretical yield difference between the two ingredients, which results in a substantially smaller land area required to produce equivalent product volumes. From a land usage intensity perspective though, conventional cropland used for oat farming typically puts more pressure on biodiversity than pastureland.

Economic implications

The main economic implication of a shift from cow's milk to oat 'milk' is reduced ingredient costs from an FMCG/retailer perspective, as only 70–100g of oats are required to produce 1 litre of oat 'milk' and the per tonne price oats is less than half that of cow's milk.

2.2.2. Better sourcing

The set of practices that support regenerative outcomes assessed for dairy includes a combination of managed intensive rotational grazing (MIG), forage optimisation (the planting of a significantly more diverse set of grasses and crops on the pastureland), and light integration of silvopasture using walnut trees as they offer potential for new revenue streams and have been proven to grow well in many EU-27 and UK contexts.

The focus is therefore on the regenerative optimisation of grazing and pastureland dynamics, rather than assessing other aspects of conventional dairy farming systems, such as housing, external fodder, manure management, or supplements. There are three main reasons for this:

- There is a growing relevance in assessing the potential to generate environmental as well as economic benefits from optimised management of grazing in livestock systems
- Grazing on pastureland is an essential component of most conventional dairy farming systems in Europe, adopted by roughly 55% of EU-27 dairy farmers and more than 80% of UK dairy farmers[24]
- There is little debate that grazing, rather than housing or feedlot, is the preferred practice for animals when climate and weather conditions allow for it

Environmental impact potential

Shifting the ingredient base in a 'milky drinks' product line from conventionally produced cow's milk to more regeneratively produced cow's milk, in accordance with the practice set outlined above, has the potential to reduce the farm-level GHG emissions by 40–60% and the farm-level biodiversity footprint by 15–25% at unchanged product volumes.

The combined effects on forage growth and soil health from MIG and an optimised forage mix, alongside the carbon sequestration ability of trees planted onto pastureland, drive the reduced GHG emissions of this practice set. MIG stimulates forage growth – and thereby carbon sequestration – through a multitude of mechanisms. Most notable among these are optimised forage carbohydrate cycles, reduced shade on young and short forage, even manure distribution, and sufficient rest periods for soil and forage.[25]

What constitutes an optimal forage mix depends on the local context, but it typically entails a shift from three to four grass types to 15–17 grass and other plant types (such as legumes and clover) with complementary growth patterns and symbiotic traits. This broad spectrum of forage types is often established through broadcast seeding in the spring and autumn as well as out-feeding of hay on pastureland.

Studies have shown the potential for MIG and optimised forage mixing to enhance total pastureland forage yield by 20–100% depending on the baseline system. To provide for upside headroom rather than downside risks, an assumed forage yield enhancement of approximately 10% has been applied in this analysis. This also allows for the incorporation of sparse silvopasture (50–60 trees per hectare after initial planting, culled over time) onto 10% of pastureland without impacting the farm's ability to support an animal herd of unchanged size. In combination, the invigorated forage and trees are assumed to sequester 4.3 tCO_2e/ha per year.

The reduced biodiversity footprint is driven by improved ecosystem health outcomes from the high-diversity pastureland. Invigorated forage and soil typically influence beneficial insect and soil microbe populations, and rested paddocks provide undisturbed nesting habitats for native grassland birds such as sandpipers, bobolinks, and meadowlarks, which have been under significant pressure over the past 50 years.[26]

In addition to the GHG emissions and biodiversity benefits described above, the combination of MIG, an optimised forage mix, and incorporation of trees onto pastureland has been shown to optimise animal health as well as fuel per cow milk production capacity in several ways: enhanced physical fitness through increased movement, higher capacity to produce milk by being offered under-tree shade on days of heat, and boosted nutrient intake through an optimised forage mix. While acknowledging these additional benefits, this analysis considers them as upside opportunities rather than integrated components of the modelling.

Economic implications

From the perspective of an individual 100-hectare dairy farmer, the shift to practices that support the regenerative outcomes assessed offers a nominal steady state net-value creation potential of approximately USD 25,000 per year excluding timber sales, or USD 250 per hectare. It should be noted, however, that this comes only after a relatively lengthy transition period of roughly eight years to break even in nominal value terms and a ramp-up time of 10–15 years to steady state. Total payback time for the investments required to undertake the shift amounts to approximately 19 years (roughly 27 years in real value terms, applying a discounting rate of 4.5%). NPV for the entire investment is positive up to discounting rates of 7% per year.

2.2.3 Circular design for food

The circular design for food practice set assessed is one in which a combination of MIG, forage optimisation, and silvopasture has been applied. The sole differences compared to the set of practices that support regenerative outcomes described in 2.2.2. are that:

- The level of tree integration is significantly stepped up

(dedicating roughly 25% of farmland to trees, compared to roughly 10% in the 'better sourcing' scenario)

- The walnut harvest from trees is sold specifically for walnut 'milky drink' production purposes, implying that product innovation in FMCG/retailer 'milky drinks' product lines is a prerequisite for the shift to happen at scale

Environmental impact potential

The ingredient base in a 'milky drinks' product line could be shifted from 100% conventionally produced cow's milk to an approximate ratio of 60% cow's milk to 40% walnut 'milky drink' sourced from silvopasture systems that produce dairy and walnuts in ways that support regenerative outcomes. This has the potential to reduce farm-level GHG emissions by 80–100% and the farm-level biodiversity footprint by 55–65% at unchanged product volumes.

As in the 'better sourcing' scenario, the drivers behind the GHG emissions reduction are enhanced carbon sequestration capacity from invigorated forage and soil health alongside the integration of trees onto pastureland. The key difference is the more ambitious level of tree integration in this circular design for food scenario.

The reduced biodiversity footprint in this scenario is driven by the reduced land area requirements to produce unchanged 'milky drink' volumes and beneficial ecosystem health outcomes on the land area used. Mature walnut trees yield more 'milky drink' output per hectare (roughly 16 t/ha for walnut 'milk' compared to roughly 7.3 t/ha for cow's milk), which reduces the land area required to produce unchanged volumes of 'milky drinks' by approximately 28%.

Economic implications

While the potential for such substantial environmental improvement is compelling – not least the notion of a net-zero carbon future for dairy production in the EU/UK – it would not come without cost for farmers, reducing profitability compared to BAU over the course of 10–15 years. From the perspective of an individual 100-hectare dairy farmer, a nominal steady state net-value creation potential of approximately USD 15,000 per annum or USD 150 per hectare compared to BAU is not enough to make up for upfront investments and lost cow's milk profits. This is due to the investment needed to plant walnut trees and the reduction in cow's milk volumes resulting from the level of tree integration needed to reach a net-zero carbon footprint (the trees come at the expense of forage growth potential on pastureland, thus reducing the number of cows the farm can support).

The analysis indicates a net negative accumulated nominal cash flow of approximately USD 780,000 over the course of the transition period (years 1–11), and full payback only 60 or more years after the transition. Although cumulative nominal net-value creation after approximately 70 years is greater than USD 1.2 million when including timber sales in the specific case example assessed, NPV is only positive up to discounting rates of 2%.

2.3. Potatoes

The analysis conducted shows the potential for 10–65% GHG emissions reduction and 10–50% biodiversity footprint reduction across the three scenarios modelled for potato production. Positive environmental impacts are reached in the circular design for food scenario, where a shift to a higher yielding and less vulnerable potato variety is combined with regenerative farming practices. The potential GHG emissions reduction in this scenario would be equivalent to a reduction of approximately 450,000 tonnes of CO_2e per year if extrapolated to full UK potato volumes.

2.3.1. Lower impact ingredients

A bag of table potatoes has been selected as an example product in order to assess the shift to lower impact ingredients as replacements for potatoes. While numerous potential substitutes exist for replacing potatoes in such product purposes, this analysis focuses on variety shifts. This sheds light on the potential environmental impact of shifting from some of today's most commercially successful potato varieties – of which several are relatively modestly yielding and vulnerable – to higher yielding and more pest-resistant varieties that are yet to reach commercial scale. Leading potato industry actors in Europe and North America are already moving in this direction, applying criteria relating to aspects such as yield, disease tolerance and/or resistance, drought tolerance, and fertiliser requirements in their variety selection.[27] It is still early days for many of the variety breeding programmes, however, and multiple stakeholders in the food system would need to mobilise around further efforts in order to leverage the full potential of diverse varieties for future environmental gains.

Environmental impact potential

Shifting the ingredient base in a bag of table potatoes from a conventionally produced, commercially proven all-purpose potato with modest yields and high need for agrochemicals to a higher yielding and more pest-tolerant variety has the potential to reduce the farm-level GHG emissions by 10–30% and the farm-level biodiversity footprint by 30–40% at unchanged product volumes.

Higher yield, and thus smaller land area requirement to produce equivalent volumes, is the key driver behind the reduced GHG emissions and biodiversity footprints in this design scenario. In BAU, one of the commercially dominant varieties in the UK (holding roughly 15% market share), which yields on average 40 t/ha, is used. The analysis considers a shift away from this variety to an alternative variety with proven average UK yields of approximately 62 t/ha.[28] While the latter variety has a higher CO_2e footprint on a per hectare basis, that is more than offset by the land area reduction resulting from its substantial yield.

An additional benefit to the alternative variety assessed is its higher pest tolerance and reduced need for fertilisers compared to the BAU variety. This implies potential cost savings and reduced environmental impact through a reduced use of agrochemicals. While acknowledging this as a highly relevant benefit, this analysis treats this as an upside potential rather than part of the quantitative modelling conducted due to a lack of statistically significant data.

Economic implications

From a farmer's perspective, shifting to commercially smaller scale varieties would not come without risks and costs. The risk of not finding buyers for all potato volumes is substantially higher when farming alternative varieties instead of commercially dominant ones. This highlights the importance of buyers, such as FMCGs and retailers, proactively sourcing alternative varieties to drive such a shift at scale. New varieties tend to carry higher seeding costs over the course of the first 10–30 years post-launch in order to compensate breeders. While higher yields (also on a per tonne seed basis), alongside lower land- and resulting machinery- and man-hour requirements, may compensate a substantial amount of this cost increase for farmers, it is still likely to result in either decreased margins or higher selling prices.

2.3.2. Better sourcing

The improved practice set assessed for potatoes includes a combination of reduced tillage, a mustard rotation used as green manure, leguminous cover crops, and animal manure organic amendment applied on a six-year-long potato rotation cycle. This specific set of practices has been selected as it offers the potential to resolve, at least partly, two of the key environmental issues with conventional potato farming: soil disturbance and carbon emissions typically caused by tilling and the heavy use of synthetic fertilisers and chemical pesticides (potato production in general requires almost twice the amount of pesticides per hectare compared to the average UK crop).[29]

In order to make the dynamics at play in this practice set as easy to grasp as possible, it has been assumed that the entire field would rotate into one new type of crop each year of the six-year-long rotation. Furthermore, it is assumed that the cover crops and animal manure used as organic amendment are applied solely in the potato year of the rotation, leaving practices in all other years at status quo (except for reduced tillage, which needs to be kept consistent across the full rotation in order to yield the benefits). In practice, different areas of farmland are often dedicated to different crops in the cycle, a preferable approach from a systems-resilience perspective.

Environmental impact potential

Shifting the ingredient base in a bag of table potatoes from potatoes conventionally produced to potatoes grown using the set of practices that support regenerative outcomes has potential to reduce the farm-level GHG emissions by 45–65% and the farm-level biodiversity footprint by 10–20% at equivalent product volumes.

All of the practices in the selected set have a proven ability to enhance SOC and reduce GHG emissions in steady state. Cover crops in the winter season have been shown to sequester up to approximately 3 tCO_2e/ha.[30] Manure used as an organic amendment has the potential to enhance soil carbon sequestration by anywhere between 0.2 and 5.1 tCO_2e/ha depending on local circumstances and application practices[31] and reduced tillage can further drive sequestration through reduced soil disturbance.[32]

Combining several of these practices likely limits their individual ability to drive carbon sequestration as there is a limit to the carbon storage ability of the soil. For this analysis a relatively conservative estimate of 2.3 tCO_2e/ha has been applied, based on data from the LATIS database.

Emissions are further reduced through the decreased need for external inputs. Green manure, cover crops, and organic amendment all provide nutrients to crops and reduce the need for synthetic fertiliser application. Mustard's ability to decrease levels of diseases and pests can also reduce the need for pesticides. In total, these effects are estimated to drive a combined emissions reduction of approximately 13% (0.8 tCO_2e/ha).

Added to this, a modest yield increase of approximately 5%, resulting from the incorporation of mustard used as green manure in the rotation, enables a small reduction in the land area required to produce equivalent food volumes, which further lowers the GHG emissions by roughly 3%. This assumed yield enhancement is below the yield improvement noted in studies where up to 25% uplift was found compared to a barley or soybean control rotation.[33] Based on input from experts with experience in similar field pilots in UK contexts, 5% has been deemed a reasonably conservative estimate.

The reduced biodiversity footprint is primarily a result of the slightly decreased intensity of land use driven by the reduced need for agrochemicals as well as reduced tillage. The smaller land area needed to produce equivalent food volumes also contributes to reducing the pressure on biodiversity (in biodiversity weighted hectare terms).

Economic implications
From the perspective of an individual 100-hectare potato farmer, the regenerative practice set assessed offers a positive nominal net-value creation potential of approximately USD 24,000 per potato harvest, or USD 240 per potato harvest per year. Break even comes at the first post-mustard potato crop in year seven, at which point profit increases come from increased yields and lower input costs compared to BAU. The key drivers of this are:

- Operating expenditure (OPEX) savings of approximately USD 30,000 in machine labour and fuel, resulting from the reduced tillage practices in the 'potato year' of the cycle,[34] and approximately USD 12,000 from reduced need for fertiliser input
- OPEX increases of roughly USD 6,000 from seeding and planting operations costs resulting from cover crop application
- OPEX increases and revenue losses from replacing barley with mustard used as green manure in the rotation. Here, a barley-based positive net rotation return of approximately USD 18,000 is assumed to be replaced with a mustard-based negative net rotation return of approximately USD 40,000, creating a total net negative impact of approximately USD 58,000 for the farmer in this rotation year
- Enhanced potato yields, which generate roughly an additional USD 46,000 in farmer revenues during the 'potato year' of the cycle

2.3.3. Circular design for food

The circular design for food set applied in this scenario is one in which a combination of reduced tillage, a mustard rotation used as green manure, leguminous cover crops, and animal manure used as organic amendment has been applied on a six-year-long potato rotation cycle. The sole difference when compared with the 'better sourcing' scenario assessed in section 2.3.2. is that the BAU potato variety is replaced with the higher yielding and more tolerant variety assessed in section 2.3.1. 'lower impact ingredients'.

Environmental impact potential
Shifting the ingredient base in a bag of table potatoes from the conventionally produced all-purpose potato applied in BAU to the higher yielding and more pest-tolerant variety grown using practices that support regenerative outcomes has the potential to reduce the farm-level GHG emissions by 45–65% and the farm-level biodiversity footprint by 40–50%, at equivalent product volumes.

The substantial reduction in GHG emissions is driven primarily (to some 75%) by the combined impact of cover crops, organic amendment, and reduced tillage, as described in section 2.3.2. Added to this is the decreased land area required to produce equivalent food volumes due to using a higher yielding variety and further enhancing its yield by approximately 5% from using practices that support regenerative outcomes.

Strong yield improvements, from the variety shift and application of practices that support regenerative outcomes, reduce the land required to produce equivalent potato volumes by approximately 40%. This is further enhanced by the lower farming intensity implied by reduced tillage and agrochemical use, pushing down the biodiversity impact to reach a total reduction of 40–50% (in biodiversity weighted hectare terms).

Economic implications
For an individual 100-hectare potato farmer, the circular design for food scenario offers a stronger potential economic case than either of the other two scenarios. It is estimated that it provides a nominal net-value creation potential of up to approximately USD 500,000 per potato harvest, or USD 5,000 per potato harvest per year, driven primarily by significantly higher yields compared to BAU. The break-even point, payback time, and cash flow profile are broadly similar to those outlined in the 'better sourcing' scenario described in section 2.3.2., owing to similar cost and revenue dynamics, with further enhanced revenues in potato years. Likewise, the dynamics of uncertainty around marketability and uptake of specialised varieties remain the same as for the standalone variety shift described in section 2.3.1. 'lower impact ingredients', meaning long-term contracts and buyer support may be needed to fuel this integrated shift, despite the very positive potential economic outcomes.

3. Detailed calculations

Detailed calculations

3.1. Top fast-moving consumer goods company and retailer agricultural footprint in the EU and UK

As major buyers of food, FMCGs and retailers have the opportunity and responsibility to play a critical role in catalysing a rapid transition towards a nature-positive system. For the three ingredients that are the main focus of this study, the sourcing footprint of the top 10 FMCGs and retailers in the EU and the UK accounts for approximately 25–40% of all EU volumes and 60–75% of all UK volumes. Total volumes of ingredients sourced are assumed to be proportional to the total sourcing footprint land area.

As there is very limited verified data available on the volumes of specific ingredients that individual FMCGs and retailers source, five types of data sources were used to conduct the agricultural footprint analysis:

- FAOSTAT[35] and Euromonitor[36] data on overall EU/UK volumes of specific ingredients and product categories
- Food waste flow data, primarily from Caldeira *et al.* (2019).[37] This, alongside Euromonitor data, has been key to identify and subtract all volumes which are not flowing via FMCGs/retailers
- Company-specific data on sourcing volumes for the ingredients in question, which was shared by several of the top 10 FMCGs and retailers in interviews. This confidential data has been highly valuable in conducting our detailed analysis
- Regional and/or country specific revenue figures for the years 2017–20 published by relevant FMCGs/retailers and/or by Statista,[38] Retail-Index,[39,40] and Rabobank.[41] This data was a key input to overarching EU and UK market share assessments, with relative market shares overlaid with the sourcing volume data gathered via interviews being used as a proxy for relative sourcing volumes across the top 10 FMCGs and retailers
- Industry press, such as the *Grocer*[42]

Wheat

As wheat is primarily sold to be used as an ingredient in other food products, and FMCG products (and own-label products) are sold by retailers, the market shares held by retailers overlaid with volume data gathered in interviews have been key in assessing the wheat sourcing footprint. The UK market share was estimated based solely on the top 10 retailer shares, as no individual FMCG holds a larger wheat market share than the top 10 retailers in this highly concentrated retailer market.

In the EU, the market share was estimated based on top eight retailer market shares, alongside the wheat market share held by Nestlé and Barilla. The volumes sourced by Nestlé and Barilla are larger than those sourced by the top 9–10 retailers in the EU, so referring solely to retailer market shares would understate the sourcing footprint. The top 10 retailer list in the UK includes: Tesco, Sainsbury's, Asda, Morrisons, Aldi, Marks & Spencer, Coop, Lidl, Waitrose, and Iceland.[43] The top eight retailer list in the EU includes: Schwartz, Carrefour, Aldi, Tesco, Edeka, Rewe Group, Auchan, Leclerc, Metro, and Sainsbury's.[44] Nestlé[45] and Barilla[46] wheat data has been sourced through company websites and Statista.[47]

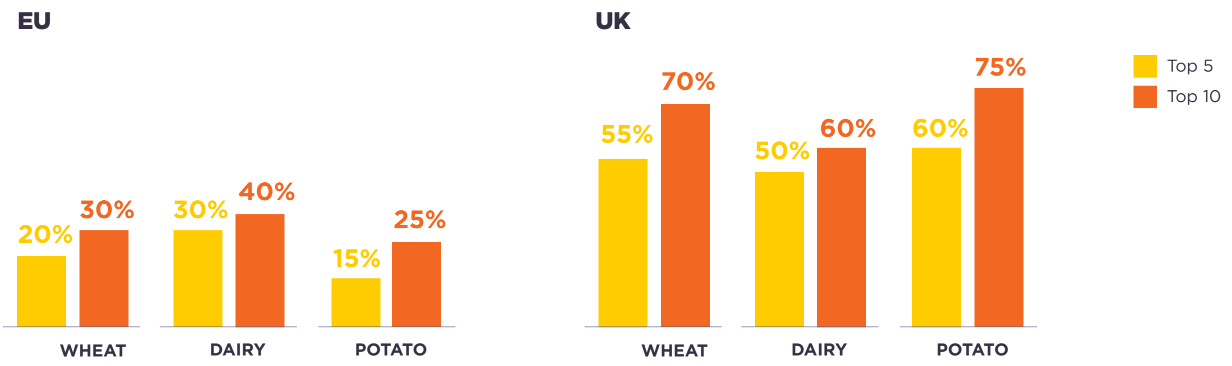
Dairy

Market shares held by the top 10 FMCGs and dairy cooperatives, overlaid with volume data gathered through interviews, were key in assessing the dairy sourcing footprint. The UK market share was estimated based on Statista[48] data and industry press,[49] while the EU market share was estimated based on Rabobank data.[50] The top 10 FMCG and dairy cooperatives list in the UK includes: Arla, Müller, Ornua, Dairy Crest, Meadow Foods, Dale Farm, Yeo Valley, Glanbia, First Milk, and County Milk.[51] The top 10 FMCG and dairy cooperatives list in the EU includes: Nestlé, Lactalis, Danone, Freisland/Campina, Arla, Unilever, Deutches Milchkontor, Sodiaal, Savencia, and Müller.[52]

Potatoes

For potatoes, the volumes and market share of top FMCGs and retailers in the EU and the UK was gathered through interviews. Market share data from Retail-Index[53] further complemented the analysis. The top 10 FMCG and retailer list for potatoes in the UK includes: PepsiCo, McCain, Tesco, Sainsbury's, Asda, Morrisons, Aldi, Marks & Spencer, Coop, and Lidl.[54] The top 10 FMCG and retailer list for potatoes in the EU includes: Schwarz group, Carrefour, Aldi, Tesco, Edeka, Rewe Group, Auchan, Leclerc, Metro, and Sainsbury's.[55]

Figure 2: Top 5-10 FMCGs' and retailers' share of food volumes
Selected ingredients, estimations based on market data

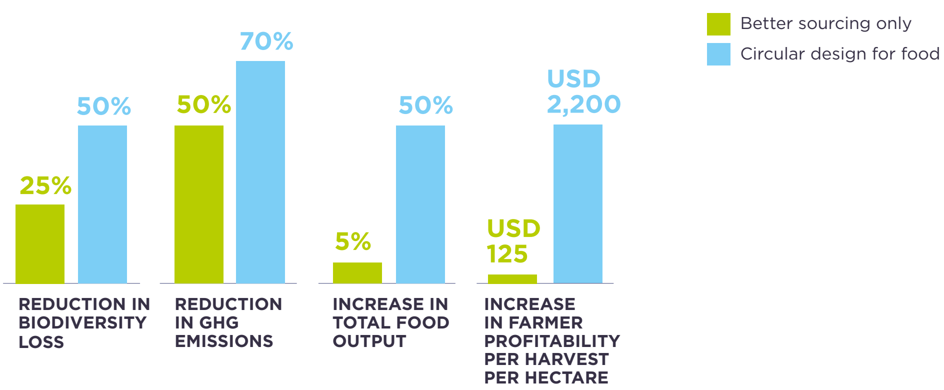


3.2. Wheat – Detailed results and input data

Table 1: Assumptions on ingredients and production methods for different wheat scenarios

Scenario	Ingredient and production method
BAU	Wheat, conventionally produced
Lower impact ingredients	Green peas, conventionally produced
Better sourcing	Wheat, grown using practices that support regenerative outcomes: intercropping with clover and other leguminous crops, minimal-tillage, cover crops, and residue retention as green manure
Circular design for food	Wheat and peas inter-cropped (50:50) and using other practices that support regenerative outcomes: minimal-tillage, cover crops, and residue retention as green manure

Figure 3: Wheat
Circular design for food offers significant benefits versus better sourcing of current ingredients alone



3.2.1 Environmental impacts

Table 2: Net GHG emissions for wheat

Scenario	Total (tCO_2e/t)	% change compared to BAU	Comment
BAU	0.65	N/A	UK data used as a proxy for EU-27 Direct production emissions, excluding downstream and LUC-related emissions. Based on 3.6 t/ha[56] A comparison of GHG emissions from UK field crop production under different agricultural systems
Lower impact ingredients	0.40	-38.5%	Based on data for green peas[57]
Better sourcing	0.32	-50.8%	Emissions reduced by 0.6 tCO_2e/ha through reduced need for fuel and fertilisers.[58] Additionally, soil carbon sequestration assumed at 1.13 t/ha per year based on an average of estimates from multiple studies: - 1.69 tCO_2e/ha,[59] comparing no-till to high-tillage, 4.61 MgC/ha in the top 30cm of soil over 10 years, converted to CO_2e p.a. - 0.91 tCO_2e/ha,[60] comparing cover-cropping to no cover crops, using specific data for wheat from Figure 3. (0.25 MgC/ha p.a., converted to CO_2e) - 0.77 tCO_2e/ha,[61] minimum-tillage combined with field pea cover crop for wheat production (0.21 t/ha p.a., converted to CO_2e)
Circular design for food	0.20	-69.2%	Average of green peas and wheat GHG emissions, reduced linearly with increased yield and land efficiency ratio (emissions assumed to correlate with land area, rather than total yield) Assuming same sequestration rate as in 'better sourcing scenario'

Table 3: Biodiversity impact (BIM) for wheat

Scenario	Metric	Value	Comment
BAU	Total food output (t/ha)	5.53[62]	
	Land use (ha/t)	0.18	Calculated from yield
	x		
	Proportion of biodiversity lost	0.9	'Intense cropland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.115**	
Lower impact ingredients	Total food output (t/ha)	5.76[63]	
	Land use (ha/t)	0.17	
	x		
	Proportion of biodiversity lost	0.9	
	x		
	Biodiversity importance of land area used	0.705	
	=		
	Total BIM score (biodiversity weighted hectares)	**0.110**	
	% change compared to BAU	**-4.3%**	

Scenario	Metric	Value	Comment
Better sourcing	Total food output (t/ha)	5.89	A +6.5% yield increase estimated in steady state from implementation of selected practices that support regenerative outcomes[64]
	Land use (ha/t)	0.17	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.7	'Light intensity cropland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.084**	
	% change compared to BAU	**-27.0%**	

Scenario	Metric	Value	Comment
Circular design for food	Total food output (t/ha)	8.39	4.09t wheat + 4.30t green peas. A +6.5% and +7.5% yield increase in steady state for wheat and peas respectively, from practices that support regenerative outcomes.[65] Yield further enhanced by extensive intercropping system (land efficiency ratio of 1.39 used)[66] Using numbers for the first 1–5 years after transition for year 1, and 10+ years after transition for year 10 and beyond. Using average yield increase from the application of two synergistic practices as compared to only one to approximate yield effects from synergistic practices. Values for year 2–9 are linearly interpolated
	Land use (ha/t)	0.12	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.7	'Light intensity cropland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.059**	
	% change compared to BAU	**-48.7%**	

3.2.2. Farmer profitability and food output impacts

Table 4: Input data used to calculate change in farmer profitability for wheat[67]

Scenario	Data point	Value	Comment
BAU	Average wheat yield in EU-27	5.53 t/ha[68]	Average for EU-27 countries across the years 2015–19
	Average wheat price in EU-27	184.8 USD/t[69]	Average for EU-27 countries across the years 2015–19
	Baseline cost: seeds	91.9 USD/ha[70]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘seeds’ – EUR 76.3
	Baseline cost: fuel and energy	121.2 USD/ha[71]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘motor fuels and lubricants’ and ‘energy’ – EUR 100.6
	Baseline cost: machinery and maintenance	83.3 USD/ha[72]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘machines and buildings upkeep’ – EUR 69.1
	Baseline cost: fertilisers	186.0 USD/ha[73]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘fertilisers’ – EUR 154.4
	Baseline cost: pesticides	152.3 USD/ha[74]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘crop protection’ – EUR 126.4
	Baseline cost: other costs	635.5 USD/ha[75]	Average value for 2018, EU-28 from EU cereal economics report, table on p.21 Including ‘water’, ‘wages paid’, ‘contract work’, ‘other specific costs’, ‘depreciation’, ‘interest paid’, ‘rent paid’, ‘other specific costs’, and ‘other direct costs’ – EUR 527.5 (unchanged in analysis)

Scenario	Data point	Value	Comment
Better sourcing	Total food output	+7%	**Yield increases over time** due to gradually improving soil health and learning effects, going from a ~4% loss to a **~7% increase compared to BAU** over ~10 years
	Investment: no-till drill	160.5 USD/ha (year 1)[76]	Average per-hectare cost for four different farm sizes presented in Epplin (2007), Table 3
	Savings: fuel and energy	-45.4% (-55.1 USD/ha)[77]	From implementation of conservation tillage and cover crops, compared to conventional practices. Average of savings from soybeans (48%) and corn (43%), using data from tables 3 and 4. Expressed as a ratio to better reflect European fuel and energy prices
	Savings: machinery and maintenance	-68 USD/ha[78]	From implementation of conservation tillage and cover crops, compared to conventional practices. Average of savings from soybeans (34 USD/acre) and corn (21 USD/acre), using data from tables 3 and 4, sum of 'repairs', 'machine hire', and 'equipment'. Investment cost for new machinery for no-till assumed to depreciate over ten years
	Savings: fertilisers	-9.3 USD/ha (Roughly -5%)[79]	From implementation of conservation tillage and cover crops, compared to conventional practices. Average of savings from soybeans (10.3 USD/acre) and corn (-2.8 USD/acre), using data from tables 3 and 4, sum of nitrogen (N), phosphorus (P), potassium (K), and 'other' fertiliser categories. Cross-referenced with survey data for Spring wheat farmers from SARE (2020)
	Cost increase: cover crops	+59.2 USD/ha[80]	From implementation of conservation tillage and cover crops, compared to conventional practices. Average cost increases from soybeans (22.9 USD/acre) and corn (25.1 USD/acre), using data from tables 3 and 4, sum of 'cover crop seed' and 'cover crop planting'. Cross-referenced with survey data from SARE (2020)
	Year in which steady state is reached	10	Year in which the farm system reaches maturity: when yields and economic returns stabilise

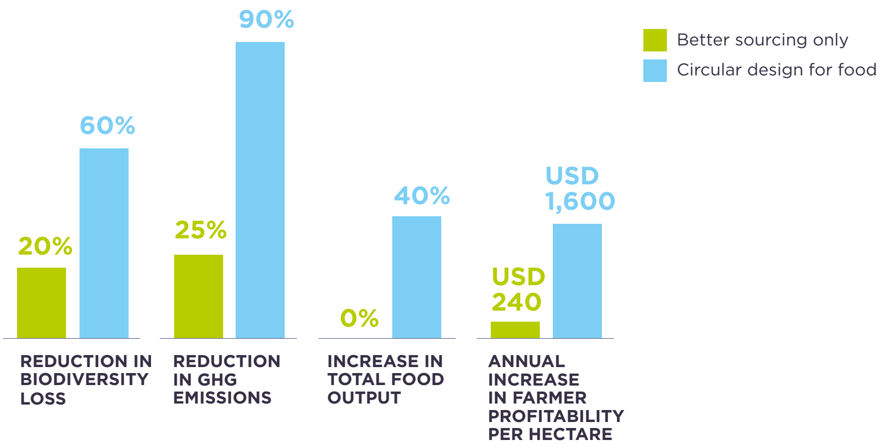
Scenario	Data point	Value	Comment
Circular design for food	Total food output	8.39 t/ha	4.09t wheat + 4.30t green peas A +6.5% and +7.5% yield increase in steady state for wheat and peas respectively, from regenerative production[81] Yield further enhanced by extensive intercropping system (land efficiency ratio of 1.39 used)[82]
	Average green pea yield in EU-27	5.76 t/ha[83]	Average for EU-27 countries across the years 2015–19
	Average green pea price in EU-27	184.8 USD/t[84]	Average for EU-27 countries across the years 2015–19
	Cost increase: crop sorting, separation, and losses from intercropping	+27.7 USD/t[85]	From increased complexity of operations in an inter-cropped system. Additional costs of 15 EUR/t for sorting and separation processes, and 8 EUR/t for additional product losses in processing
	Year in which steady state is reached	10	Year in which the farm system reaches maturity: when yields and economic returns stabilise

3.3. Dairy – Detailed results and input data

Table 5: Assumptions on ingredients and production methods for different dairy scenarios

Scenario	Ingredient and production method
BAU	Dairy (cow's milk), conventionally produced. Cattle are grazed for part of the year with their diet supplemented by hay and conventionally produced cereals
Lower impact ingredients	Oat milk, made using conventionally produced oats
Better sourcing	Dairy produced using practices that support regenerative outcomes: Managed Intensive Grazing (MIG), sowing of diverse grazing forage, and walnut silvopasture on 10% of land area. Walnuts are sold but not used in the same food products
Circular design for food	Dairy and walnuts produced using practices that support regenerative outcomes: Managed Intensive Grazing (MIG), sowing of diverse grazing forage, and walnut silvopasture on 25% of land area. All the outputs of the system – dairy and walnuts – are used in the same food product line (such as silvo, see p55 of the study)

Figure 4: Dairy
Circular design for food offers significant benefits versus better sourcing of current ingredients alone



3.3.1 Environmental impacts

All data and sources underlying results depicted in figures 5 and 11 in the main study are presented below. Protein adjusted figures are shown in orange, for illustrative purposes. Note that protein is just one nutrient provided by milk, and diverse plant-based milks have very different nutritional profiles.

Table 6: Net GHG emissions for dairy

Scenario	Total (tCO_2e/t)	% change compared to BAU	Protein adjusted total (tCO_2e/t)	Comment
BAU	1.190[86]	N/A	35.7[87]	N/A Protein adjusted total GHG emissions are expressed tCO_2e per tonne of milk protein produced, and based on 33.3kg protein provided by 1 tonne of dairy milk
Lower impact ingredients	0.009	-99.2%	0.9	Using only emissions from oat production (excluding processing and other inputs) of 0.12 tCO_2e/t and 77g oats per litre of milk drink (see below) Protein adjusted total GHG emissions are expressed tCO_2e per tonne of oat protein produced, and based on 129kg[88] protein in 1 tonne of oats, 10g/l of protein in a typical carton of oat milk and assumed 77g oats per litre of oat milk
Better sourcing	0.6043	-49.2%	18.1	Emissions partially negated by 4.3 tCO_2e/ha from enhanced carbon sequestration (see below). Calculated based on LATIS data (see below), adjusted for a lower ratio of tree integration (10% land coverage) Assuming 50% of sequestration comes from land practices (so not scaled with trees) and 50% from silvopasture (so scaled linearly with a factor of 0.4) Protein adjusted total GHG emissions are expressed tCO_2e per tonne of milk protein produced, and based on 33.3kg protein provided by 1 tonne of dairy milk

Scenario	Total (tCO_2e/t)	% change compared to BAU	Protein adjusted total (tCO_2e/t)	Comment
Circular design for food	0.108	-82.1%	4.3	Emissions from cow's milk production reduced from ~17% lower stocking and production rate Emissions further negated by 6.0 additional tCO_2e/ha (regenerative rate minus BAU rate) from enhanced carbon sequestration (see below). From LATIS database, milk production using holistic management grazing and silvopasture at 25–30% land coverage ratio, 6.1 t/ha minus BAU rate of 6.0 t/ha[89] Protein adjusted total GHG emissions are expressed tCO_2e per tonne of walnut protein produced, and based on 155kg[90] protein in 1 tonne of walnuts, 12.5g/l of protein in a typical carton of walnut milk and assumed 81g oats per litre of oat milk

Table 7: Biodiversity impact (BIM) for dairy

Scenario	Metric	Value	Comment
BAU	Total food output (t/ha)	7.29	Calculated based on EUROSTAT and FAOSTAT
	Land use (ha/t)	0.137	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.7	'Intense pastureland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.068**	

Scenario	Metric	Value	Comment
Lower impact ingredients	Total food output (t/ha)	37.4	Using 2.89 t/ha oat production and 77g oats per litre of milk drink
	Land use (ha/t)	0.027	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.9	'Intense cropland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.017**	
	% change compared to BAU	**-75.0%**	
Better sourcing	Total food output (t/ha)	7.29	Same total food output as in BAU, assuming increased forage from MIG and optimisation is offset by silvopasture land use and shading effects
	Land use (ha/t)	0.137	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.55	Midpoint between 'intense pastureland' and 'light pastureland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.053**	
	% change compared to BAU	**-22.1%**	

Scenario	Metric	Value	Comment
Circular design for food	Total food output (t/ha)	10.06	(6.04t cow's + 4.03t nut) 5.87 t/ha cow's milk, reduced from 'better sourcing' due to an additional 15% tree coverage Additional 3.90 t/ha from walnut milk, using nut yield of 0.31 t/ha (25% of the 100% tree density figure of 1.27 t/ha) and 81g walnuts per litre of milky drink
	Land use (ha/t)	0.099	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.4	'Light pastureland'
	x		
	Biodiversity importance of land area used	0.705	Average for EU-27
	=		
	Total BIM score (biodiversity weighted hectares)	**0.028**	
	% change compared to BAU	**-58.8%**	

3.3.2. Farmer profitability and food output impacts

All data and sources underlying results depicted in figures 11 and 15 in the main report are presented below.

Table 8: Input data used to calculate change in farmer profitability[91] for dairy (figures expressed on a per-year basis unless otherwise stated)

Scenario	Data point	Value	Comment
BAU	Average dairy yield in EU-27	7.29 t/ha[92]	Calculated from total dairy production along with total pasturing area from EUROSTAT, summing 2016 data for EU-27, categories: 'specialist dairying (calculated with standard output)' and 'cattle-dairying, rearing and fattening combined (calculated with standard output)' totalling 20.9 Mha of UAA
	Average dairy price in EU-27	375.2 USD/t[93]	Average for EU-27 countries across the years 2015–19
Better sourcing	Total food output	7.29 t/ha	Same yield as in BAU, assuming increased forage from MIG and optimisation is offset by silvopasture land use and shading effects
	Tree coverage ratio	10%	10% of land covered with walnut trees
	Investment: MIG infrastructure	25 USD/ha (year 1)[94]	'Baseline scenario' from Wang *et al.* (2018). Scenarios range from 7.4 USD/ha to 173 USD/ha by different estimations Investments cover, e.g. additional fencing, water piping, and water troughs. MIG investments mainly in fencing, water systems, and paths to enable more rotations; depreciated over a 10-year lifetime
	Investment: black walnut tree planting	907.7 USD/ha (year 1, at 10% density)	Based on economic case study from the University of Missouri[95] Original value of 1,815 USD/ha assumed to represent a 20% land coverage ratio[96] Further sources: Johnson (2011); Dubeux *et al.* (2015)

Scenario	Data point	Value	Comment
Better sourcing	Cost increase: tree maintenance	215.4 USD/ha (at 10% density)	Based on economic case study from the University of Missouri[97] Original value of 1,077 USD/ha assumed to represent a 20% land coverage ratio,[98] and to represent 40% maintenance costs (pruning, etc.) and 60% harvesting costs (for hand harvest) Further sources: Johnson (2011); Dubeux *et al.* (2015)
	Cost increase: nut harvesting	323.1 USD/ha (at 10% density)	Based on economic case study from the University of Missouri[99] Original value of 1,077 USD/ha assumed to represent a 20% land coverage ratio,[100] and to represent 40% maintenance costs (pruning, etc.) and 60% harvesting costs (for hand harvest) Harvesting costs scale linearly over time with nut yields, from 0 USD in year 1–4 up to full 323 USD in year 13 Further sources: Johnson (2011); Dubeux *et al.* (2015)
	Walnut yield, from 10% tree density	0.23 t/ha (including shells) (at 10% density)[101]	Average for EU-27 countries across the years 2015–19 is 2.29 t/ha with shells Yield including shells used to match price data Yield scaled linearly with tree density (10%) for calculations
	Walnut yield timings	First yield in year 5. Full yield from year 13. Timber harvest year 68[102]	Yield scaled linearly from year 5 to year 13, after which yield is assumed constant per hectare until tree end-of-life and timber harvest in year 68 after planting
	Average walnut price in EU-27	3,486 USD/t (including shells)[103]	Average for EU-27 countries across the years 2015–19

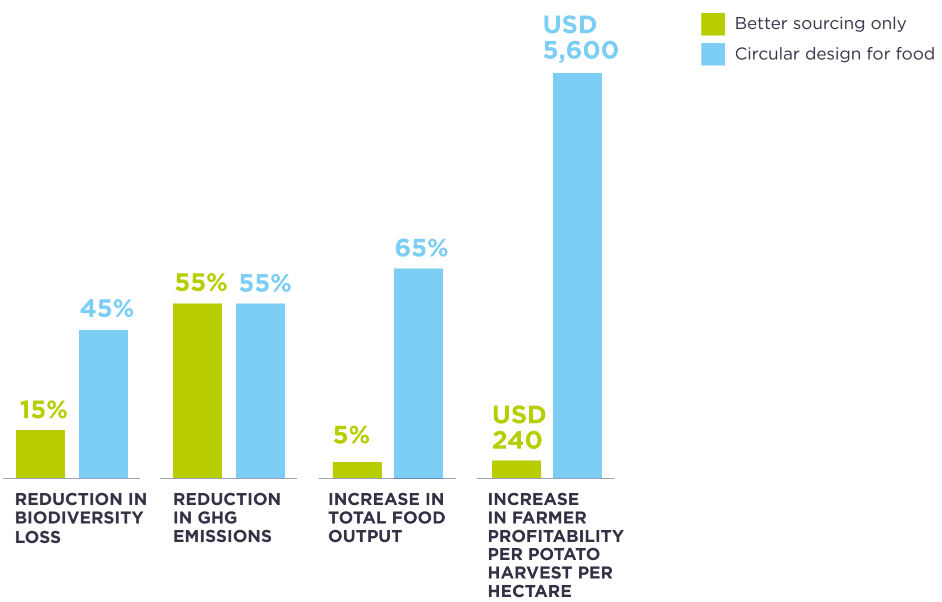
Scenario	Data point	Value	Comment
Better sourcing	Walnut timber revenue	11,100 USD/ha (at tree maturity after 60–70 years)[104]	Based on economic case study from the University of Missouri, referenced by Savanna Institute (2018) Original value of 22,200 USD/ha assumed to represent a 20% land coverage ratio, based on Godsey (2003)
	Year in which steady state is reached	13	Year in which the farm system reaches maturity: when yields and economic returns stabilise Walnut trees have reached 'full fruiting yield', thus steadily providing a stable level of revenue generation up until the end of the lifetime of the trees
Circular design for food	Total food output	10.06 t/ha	(6.04t cow's + 4.03t nut) 5.87 t/ha cow's milk, reduced from 'better sourcing' by an additional 15% tree coverage
	Tree coverage ratio	25%[105]	Additional 3.90 t/ha from walnut milk, using nut yield of 0.31 t/ha (25% of the 100% tree density figure of 1.27 t/ha) and 81g walnuts per litre of milky drink 25% of land is covered with walnut trees
	Costs, investments, nut and timber yields	Various	Scaled from the values in 'better sourcing' above using the 25% land coverage ratio (compared to 10% land coverage ratio in 'better sourcing' scenario) Tree CAPEX (i.e. tree plants; no substantial equipment investments needed) depreciated, and timber yield allocated across, tree lifetime (~60–70 years)
	Year in which steady state is reached	13	Year in which the farm system reaches maturity: when yields and economic returns stabilise Walnut trees have reached 'full fruiting yield', thus steadily providing a stable level of revenue generation up until the end of the lifetime of the trees

3.4. Potatoes – Detailed results and input data

Table 9: Assumptions on ingredients and production methods for different potato scenarios

Scenario	Ingredient and production method
BAU	Potatoes, conventionally produced
Lower impact ingredients	High-yielding, disease-resilient variety of potato, conventionally produced
Better sourcing	Typical potato variety produced using a set of practices that support regenerative outcomes: organic amendment with cow manure; crop rotation including mustard, which has disease-suppressant properties and is ploughed into soil as green manure; low-tillage
Circular design for food	High-yielding, disease-resilient variety of potato that is grown using the same set of practices used in 'better sourcing'

Figure 5: Potatoes
Circular design for food offers significant benefits versus better sourcing of current ingredients alone



3.4.1. Environmental impacts

All data and sources underlying results depicted in figures 7 and 12 in the main study are presented below

Table 10: Net GHG emissions for potatoes

Scenario	Total (tCO_2e/t)	% change compared to BAU	Comment
BAU	153	N/A	Based on 6.1 tCO_2e/ha from LATIS database.[106] Based on 153.5 kg/t multiplied with above average potato yield. Similar to the figure of 145 kg/t from Moudrý *et al.* (2013)[107]
Lower impact ingredients	121	-20.9%	Emissions per hectare partly scaled with increased yields, whereas some fractions stay constant (and thus decrease per tonne of output). Calculated by scaling portions of potato emission constituent factors with increased yields, based on Moudrý *et al.* (2013)[108] Factors assumed to increase with increased yields: fertilisers (26%) + seeds (17%). Factors assumed to stay constant with increased yields: field emissions (37%) + pesticides (2%) + agrotechnical operation (19%)
Better sourcing	72	-52.9%	Emissions from fertilisers (26% of total) and pesticides (2% of total) decreased by 50% and 25% respectively Additionally, soil carbon sequestration of 2.3 tCO_2e/ha from using practices that support regenerative outcomes, based on LATIS database[109] Using data from LATIS database, for potato production employing reduced tillage along with organic amendment. Sequestration from reduced tillage continues during non-potato years, but is not explicitly attributed to potato production GHG emissions per hectare partially scaled with increased yields, same as high-yielding resilient potatoes

Scenario	Total (tCO_2e/t)	% change compared to BAU	Comment
Circular design for food	71	-53.6%	GHG emissions per hectare partially scaled with increased yields, same as high-yielding resilient potatoes Same emissions reductions and soil carbon sequestration (2.3 tCO_2e/ha) as in the 'better sourcing' scenario Calculated by scaling portions of potato emission constituent factors with increased yields, based on Moudrý *et al.* (2013)[110] Factors assumed to increase with increased yields: fertilisers (26%) + seeds (17%) Factors assumed to stay constant with increased yields: field emissions (37%) + pesticides (2%) + agrotechnical operation (19%) These emissions are reduced by the same factors as in 'better sourcing' scenario (reduced fertiliser and pesticide use, enhanced soil carbon sequestration)

Table 11: Biodiversity impact (BIM) for potatoes

Scenario	Metric	Value	Comment
BAU	Total food output (t/ha)	39.5	Average potato yields in UK, 2015–19[111]
	Land use (ha/t)	0.025	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.9	'Intense cropland'
	x		
	Biodiversity importance of land area used	0.43	Average for UK
	=		
	Total BIM score (biodiversity weighted hectares)	**0.0098**	

Scenario	Metric	Value	Comment
Lower impact ingredients	Total food output (t/ha)	62.3	Based on expert input on yields of specialised, high-yielding variety
	Land use (ha/t)	0.016	Calculated from total food output
	x		
	Proportion of biodiversity lost	0.9	'Intense cropland'
	x		
	Biodiversity importance of land area used	0.43	Average for UK
	=		
	Total BIM score (biodiversity weighted hectares)	**0.0062**	
	% change compared to BAU	**-36.7%**	
Better sourcing	Total food output (t/ha)	41.5	Yield increase of +5% over baseline, conservative estimate based on multiple sources
	Land use (ha/t)	0.024	Calculated from yield
	x		
	Proportion of biodiversity lost	0.8	Midpoint between 'intense cropland' and 'light cropland'
	x		
	Biodiversity importance of land area used	0.43	Average for UK
	=		
	Total BIM score (biodiversity weighted hectares)	**0.0083**	
	% change compared to BAU	**-15.3%**	

Scenario	Metric	Value	Comment
Circular design for food	Total food output (t/ha)	65.5	Based on expert input on yields of specialised, high-yielding variety
	Land use (ha/t)		Calculated from total food output
	x		
	Proportion of biodiversity lost	0.43	Average for UK
	x		
	Biodiversity importance of land area used	0.8	Midpoint between ‘intense cropland’ and ‘light cropland’
	=		
	Total BIM score (biodiversity weighted hectares)	**0.0053**	
	% change compared to BAU	**-45.9%**	

3.4.2. Farmer profitability and food output impacts

All data and sources underlying results depicted in figures 7 and 12 in the main study are presented below.

Table 12: Input data used to calculate change in farmer profitability[112] for potatoes (All figures are per potato harvest, unless otherwise stated)

Scenario	Data point	Value	Comment
BAU	Average potato yield in the UK	39.6 t/ha[113]	Average for UK across the years 2015–19
	Average potato price in UK	235 USD/t[114]	Average for UK across the years 2015–19 Same price used across the board for all varieties in this analysis
	Baseline synthetic fertiliser cost	134.1 USD/ha[115]	Based on table 8 in Pedersen *et al.* (2005), taking the average of all countries in the study Summing values for N, P, and K fertilisers
	Baseline pesticide cost	204 USD[116]	Based on table 8 in Pedersen *et al.* (2005), taking the average of all countries in the study Summing values for ‘herbicide’, ‘fungi- and insecticides’, and ‘treatment for withering, desiccant’
Better sourcing	Total food output	41.5 t/ha	Yield increase of +5% over baseline, conservative estimate based on multiple sources
	Cost increase: cover crops	59 USD/ha[117]	From table 17 in Wale *et al.* (2015), summing costs for seeds and additional drilling (GBP 28 and GBP 15 per hectare, respectively)
	Cost increase: mustard crop rotation	580 USD/ha[118]	Based on table 4 in Larkin and Halloran (2014), comparing increased costs for applying mustard as a green manure of 403 USD/ha to the (lost) net rotation return for a barley control rotation (which produces net revenues of up to 177 USD/ha)

Scenario	Data point	Value	Comment
Better sourcing	Cost savings: reduction in machinery and labour costs from reduced tillage	-301 USD/ha[119]	From table 18 in de Tourdonnet *et al.* (2007), referencing the use of conservation tillage vs. conventional tillage for potato production in Germany
	Cost savings: fertiliser use reduction from regenerative production	-50%	Estimate based on discussion with experts[120] Green manure, organic amendment, and cover crops all show potential to naturally increase nutrient availability for potatoes Equivalent to a 67 USD/ha reduction based on above baseline As examples of fertiliser replacement from selected practices, see e.g., Wale *et al.* (2015),[121] Curless, Kelling, and Speth (2004)[122] for cover crops, El-Sayed, Hassan, and El-Mogy (2015)[123] for organic fertilisers and McGuire (2003)[124] for fumigation through incorporation of mustard
	Cost savings: pesticide use reduction from regenerative production	-25%	Estimate based on discussion with experts[125] From application of mustard as a naturally disease-suppressing rotation crop Equivalent to a 51 USD/ha reduction based on above baseline
	Year in which steady state is reached	7	Year in which the farm system reaches maturity: when yields and economic returns stabilise Assumed to be during the second potato rotation in a six-year cycle, i.e. in year 7, as the benefits from mustard as green manure, cover crops, etc. are realised by then

Scenario	Data point	Value	Comment
Circular design for food	Total food output	65.5 t/ha	Based on expert input on yields of specialised, high-yielding variety
	Cost increase: proprietary potato seeds	852 USD/ha	Based on expert figures[126] Estimating a total seed cost for a modern proprietary variety of 1,534 USD/ha (using a seed rate of ~2.5 t/acre), compared to a conventional variety seed cost of 682 USD/ha (using a seed rate of 2 t/ha)
	Year in which steady state is reached	7	Year in which the farm system reaches maturity: when yields and economic returns stabilise Assumed to be during the second potato rotation in a six-year cycle, i.e. in year 7, as the benefits from mustard as green manure, cover crops, etc. are realised by then

3.5. Upcycled sweetener calculations

Sugar crops are one of the largest crops produced by volume, with around 2.2 billion tonnes of sugar beet and sugar cane combined produced each year.[127] These and other sweeteners are widely used in food products. The potential size of the opportunity was quantified for four food by-products which can be upcycled to produce ingredients that satisfy the property of sweetness that sugar cane and sugar beets primarily provide currently. These by-products were selected as there are some great examples of companies transforming the by-products into sweeteners to make the most of the food that we already grow. The many benefits of using upcycled ingredients are outlined in the 'Upcycled Ingredients' section of the main study.

Fruit by-product
The solid by-product of producing fruit juice and low cosmetic grade fruit (often referred to as 'ugly fruit') can be upcycled into sweeteners.

Table 13: The scale of opportunity if global fruit by-products were upcycled into sweeteners and used in food products

	Data point	Value	Calculation
A	Yield of sweetener from 1 tonne fruit by-product	0.33 tonnes[128]	-
B	Global apple production (five-year average, 2015–19)	84,722,559.8[129]	-
C	Global apple production % used for processed products	28%[130]	-
D	Solid by-product by mass (%)	25%	-
E	Global apple juice by-product yield	5,824,675.99 tonnes	AxBxC
F	UK + EU ugly apples	962,100.00 tonnes	-
G	Total global volume of fruit by-product	6.7 million tonnes	E+F
H	Total yield of fruit by-product sweetener	2,262,258.44 tonnes	GxA
I	Average area of land required to produce 1 tonne sugar (mean for sugar beet and sugar cane)	0.1229 hectares	-
J	Spared land if all fruit by-product were upcycled and used to replace sugar	264,111.97 hectares	HxI
K	Country with similar land area	Luxembourg (258,600 hectares)	-

Crop residues

Crop residues, such as leaves and stems, are by-products that are left over after harvesting cereals and other annual crops.

Table 14: The scale of opportunity if global crop residues were upcycled into sweeteners and used in food products

	Data point	Value	Calculation
A	Global volume of by-product	2.802 billion tonnes[131]	-
B	Moisture content wheat straw	5.5%[132]	-
C	Dry weight of global cereal crop residue	2,647,890,000.00 tonnes	Ax(1-(B÷100))
D	Sweetener yield per tonne residue (dry weight)	0.45 tonnes[133]	-
E	Total yield of glucose syrup sweetener from global cereal crops	1,191,550,500 tonnes	CxD
F	Global glucose syrup demand	17,000,000 tonnes[134]	-
G	Percentage total theoretical yield required to supply global demand for glucose syrup	1.4%	(F÷E)x100

Cacao fruit pulp
Cacao fruit pulp is one of two by-products of producing chocolate (the other is the cacao shell). Cacao fruit pulp can be upcycled into sweeteners.

Table 15: The scale of opportunity if global cacao fruit pulp production (a by-product of chocolate production) was upcycled into sweeteners and used in food products

	Data point	Value	Calculation
A	Global volume of cacao beans	5.183 million tonnes[135]	-
B	Cacao fruit % = bean	25%	-
C	Cacao fruit % = pulp	25%	-
D	Global volume of cacao fruit pulp by-product	5.183 million tonnes	Equal ratio to A
E	Yield of cacao pulp sweetener from 1 tonne of cacao fruit	0.004 tonnes[136]	-
F	Global theoretical yield of cacao sweetener	20733.6488 tonnes	DxE
G	Sugar in standard 70% dark chocolate bars (100g)	27g (0.000027 tonnes)[137]	-
H	Cacao sugar in 100g bar of typical 70% dark chocolate, which replaces 100% of sugar – all ingredients made from cacao fruit	15g (0.000015 tonnes)[138]	-
I	Number of theoretical 70% dark chocolate bars that could be made from global cacao fruit pulp production	1,382,243,253.33	F÷H
J	Total sugar saved by replacing sugar with total theoretical cacao pulp sweetener yield	2,488 tonnes	(I÷H)xG

Coffee cherry

Coffee cherries are a by-product of producing coffee beans. It is the fleshy fruit part of the plant. Typically, it is left to rot in fields, where it becomes a source of methane emissions and mycotoxin pollution to soil and waterways. Unlike the other upcycled ingredients, coffee cherry is not strictly upcycled into a sweetener, but rather into a flour that can be used to partially or completely replace conventional ingredients like wheat flour. Coffee cherry flour has flavour-enhancing properties and when used in the ingredient mix, it significantly reduces the need for added sugar in sweet products.

Table 16: The scale of opportunity if global coffee cherry production (a by-product of the coffee industry) were upcycled and used in food products

	Data point	Value	Calculation
A	Global volume of by-product	20.5 million tonnes[139]	-
B	Global methane emissions from coffee cherry left to rot	16.6 million tonnes CO_2e[140]	-
C	Fuel used for transatlantic flight	3.61 tonnes[141]	-
D	GHG emissions per tonne fuel	3.15 tonnes CO_2e[142]	-
E	GHG emissions of transatlantic flight (Boeing 737-400, London to New York, 926km)	11.37 tonnes CO_2e[143]	CxD
F	Equivalent number of one-way transatlantic flights	1,459,789.83 transatlantic flights	B÷E
G	Equivalent number of return transatlantic flights	729,894.91 return transatlantic flights	F÷2

Endnotes

1 Introduced by Allen *et al.*, *A solution to the misrepresentations of CO_2e emissions of short-lived climate pollutants under ambitious mitigation* (2018)

2 Lynch *et al.*, *Demonstrating GWP*: a means of reporting warming-equivalent emissions that captures the contrasting impacts of short- and long-lived climate pollutants* (2020)

3 CISL, *Measuring business impacts on nature* (2020)

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5 Soil health partnership, Environmental Defense Fund, and K-Coe,Conservation's impact on the farm bottom line (2021)

6 Audsley *et al.*, *How low can we go? As assessment of greenhouse gas emissions from the UK food system and the scope to reduce them by 2050 WWF-UK and the Food Climate Research Network* (2009); Carlton *et al.*, *A comparison of GHG emissions from UK field crop production under selected arable systems with reference to disease control* (2012)

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24 van den Pol-van Dasselaar, A., Hennessy, D., and Isselstein, J., *Grazing of dairy cows in Europe: an in-depth analysis based on the perception of grassland experts* (2020). Note: the vast majority of these farmers do combine grazing with housing the animals to varying degrees, primarily during colder seasons

25 Undersander, D., *et al.*, *Pastures for profit: a guide to rotational grazing* (2002)

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28 Expert call input

29 Garthwaite, D., *et al.*, *Pesticide usage survey report 284 – arable crops in the United Kingdom 2018* (2018)

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41 Rabobank (2020)

42 The Grocer (2019)

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44 Statista (2017)

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55 Retail-Index (2019)

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67 Does not take into consideration any potential cost premiums or subsidies for regeneratively produced ingredients. The profitability of the 'lower impact ingredient' scenario was not modelled

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