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Economic potential of energy crops in Scotland

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1 Executive summary

1.1 Background

The generation of energy from organic matter, such as plants, is called bioenergy. The Update to the Climate Change Plan (CCPu) identifies the significant role that bioenergy could play in delivering Scotland's legally binding commitment to achieve net zero by 2045. This could be achieved whilst also supporting a green economic recovery from the effects of the Covid-19 pandemic and a just transition that creates jobs and supports people and rural communities.

To meet this expanded role for bioenergy in Scotland, a scaling up of domestic biomass production would be required. The UK Climate Change Committee (CCC) highlighted the opportunity for domestic production as a key pillar for delivering the CCPu ambition.

This research examines the economic potential of perennial energy crops (PECs) for farmers and land-managers, as well as the wider economic implications. The three PECs considered are miscanthus, short rotation coppice (SRC) and short rotation forestry (SRF).

1.2 Key findings

1.2.1. Profitability of perennial energy crops

- PECs have the potential to generate income for farmers and land-managers in Scotland.
- Comparison of gross margins shows income from PECs is likely to be lower than from other typical farm enterprises on suitable land, such as lowland cattle and sheep and 'mixed agriculture'. This is assessed on the basis of yearly average gross margins over the lifetime of the PEC in comparison to equivalent gross margins for other farm enterprises.

- Income (gross margin calculation) from PECs compared very favourably in the analysis compared to the farming type known as ‘general cropping: forage’. This is growing crops for animal consumption, usually on lower quality land, and it typically makes a significant loss.
- There is a need for greater confidence that PECs will deliver good economic returns in order for them to be viewed as an attractive, economically viable option by farmers and land managers in Scotland. High upfront establishment costs for perennial energy crops and low revenue potential are both likely to hinder uptake.
- Miscanthus showed the highest average gross margin of the three crops studied, at £382 per hectare per year. However, there are some potentially limiting factors:
    - There is uncertainty about achievable yields in the Scottish climate and on the grades of land above category 4.1 in the Land Capability for Agriculture in Scotland.
    - There is limited theoretical growing area in Scotland, which is much lower than for SRF or SRC.
- SRF and SRC showed lower profitability for farmers: £80 and £87 per hectare per year over their lifetime respectively for ‘SRF: broadleaved’ and SRC. However, there is more suitable land for growing these.
- SRF conifer would see a negative gross margin, given that the production costs outweigh the value of the crop sold.

1.2.2. Potential opportunities

- PECs could help diversify a business, creating additional income, without adding significant additional labour requirements or ongoing input costs because minimal management time and inputs are required once crops are established.

1.2.3. Potential barriers

- Cash flow could pose a barrier to uptake. The distribution of costs and income year-on-year for PECs is significantly different to typical farming activities which have an annual profit cycle. PECs need investment in site preparation and planting upfront, but income only arrives after first harvest several years later. This is 2-3 years for miscanthus with subsequent annual harvests, 6 years for SRC with periodical harvests thereafter, and 15 years for SRF first and only harvest.
- Farmers and land managers may view PECs as a risky proposition due to uncertainty about market demand and achievable crop sale prices, combined with the need for upfront investment to establish production.
- Other potential barriers to uptake include: farmer and land-manager unfamiliarity with PEC production, low appetite for risk, need for new skills, access to equipment and services, concerns about community perception of land-use change, and impacts on other agricultural production, e.g. available animal feed.

1.2.4. Enhancing economic potential and production

Potential approaches to improve the economic potential of PECs in Scotland include:

- Financial incentives, such as government specific subsidies under future agricultural support or other market-focused incentives.

- Risk reduction strategies, such as secure, attractively priced contracts with end markets, alongside expansion of the market.
- Innovations to allow processing at the farm and to improve transportability of crops could also help to increase the economically viable travel distance.
- Improving access to skills and knowledge to produce PECs could also remove a barrier to uptake, if economic prospects are improved.

1.2.5. Implications for wider Scottish economy

- Future demand for PECs to support the Scottish Government's climate ambition is likely to require increased production, and previous research suggests 38,000 hectares could be feasibly planted by 2032 and 90,000 by 2045.
- We modelled two demand scenarios to illustrate the potential range in results if land was transitioned to growing PECs:
    - **Scenario 1: conversion of approximately 38,000 hectares**. This would result in an economic gain in terms of increased gross margin of around £9.6 million. This would however result in a shortfall in non-PEC agricultural yield (crops, stock-feeding crops and grass) of between 537,600 and 700,000 tonnes.
    - **Scenario 2: conversion of approximately 90,000 hectares**. This would result in an economic loss of around £9.5 million per year, based on gross margin, and a shortfall in non-PEC agricultural yield (crops, stock-feeding crops and grass) of between 708,200 and 1.6 million tonnes. The financial loss is because under this scenario more economically advantageous land is transitioned to PECs and the PECs perform less well economically.

1.2.6. Economically viable production locations

- Economically viable production locations for PECs are influenced by multiple factors including proximity to markets and local access to services and facilities for crop management, such as harvesting contractors, to avoid incurring excessive costs.
- The research identified suitable growing regions (some SRC/miscanthus and most for SRF) within an economically viable transport distance to existing biomass plants and potential sites for Bioenergy with Carbon Capture and Storage (BECCS) near the proposed east coast carbon capture and storage feeder pipeline (assumed 50-100 km).
- Economic viability may be a barrier to SRF production increases even if suitable land is available, given that it is economically uncompetitive against other land use options.

1.3 Potential further steps

Key debates and areas for further research include:

- Considering more in-depth 'whole farm' economic analysis. This study focused on gross margin comparison, which is useful for comparing specific crops and farm enterprises, but has limitations in terms of how well it allows assessment of integration of energy crops into a whole farm business. This will vary farm to farm but could be explored through farm case studies. This could include considering a wider range of costs for farmers and that after initial set up the PECs would require less workload.

- Comparing the economic and environmental potential of using land for energy crops with utilising the same land for other renewable energy options, such as using the land for solar panels alongside grazing.
- Exploring the potential role for on-farm use of perennial energy crops.
- Considering future biomass markets, including how future Greenhouse Gas Removal (GGR) schemes, global demand and demand from biotechnology sector may impact it.
- Identifying how to make domestic biomass from energy crops a more attractive option than imports and a more profitable use of land, and on what basis this can be justified. For example, taking account of full LCA and rewarding greatest emission saving.
- Considering in more detail the role of PECs in the context of how the agriculture sector is changing and how it may have to change to reduce GHG emissions.
- Considering the value, including the financial value, of other benefits of energy crops, such as flood mitigation or animal shelter, relative to existing or potential alternative land-uses.
- Exploring how PECs support/interact with tier 2 or 3 objectives of the ARP.
- Considering the impact of subsidies.

The most economically and environmentally advantageous approach is likely to be site-specific and determined by local circumstances. Making judgements about the best use of land is complex for policy makers, farmers and land managers alike. Guidance on this decision-making is likely to be needed.

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2 Abbreviations table

BECCS	Bioenergy with Carbon Capture and Storage
CCC	UK Government Climate Change Committee
CCPu	Scotland's Climate Change Plan Update (2020)
CXC	ClimateXChange
LFA	Less Favoured Area (a designation in Scotland for disadvantaged agricultural areas – including crofting)
NETs	Negative Emissions Technologies
PEC	Perennial energy crops
SRC	Short Rotation Coppice
SRF	Short Rotation Forestry

3 Introduction

This evidence assessment focuses on examining the economic potential of perennial energy crops (PECs) for farmers and land-managers in Scotland, along with considering the wider economic implications for Scotland. The assessment builds upon recent ClimateXChange reports which demonstrated that there are significant opportunities for the expansion of perennial energy crop cultivation in Scotland (Martin et al, 2020) and that increased supply of biomass for energy generation from such crops will be needed to meet forecast future demand in the context of Scotland's climate mitigation plan goals (Meek et al, 2022). However, in scaling up domestic biomass production it is important to consider how the economics intersect with other relevant issues including biodiversity, land-use, water management and a 'just transition'. This report aims to consider these issues, alongside the economics and support the Scottish Government's development of policy in relation to perennial energy crop production.

3.1 The policy context for energy crops in Scotland

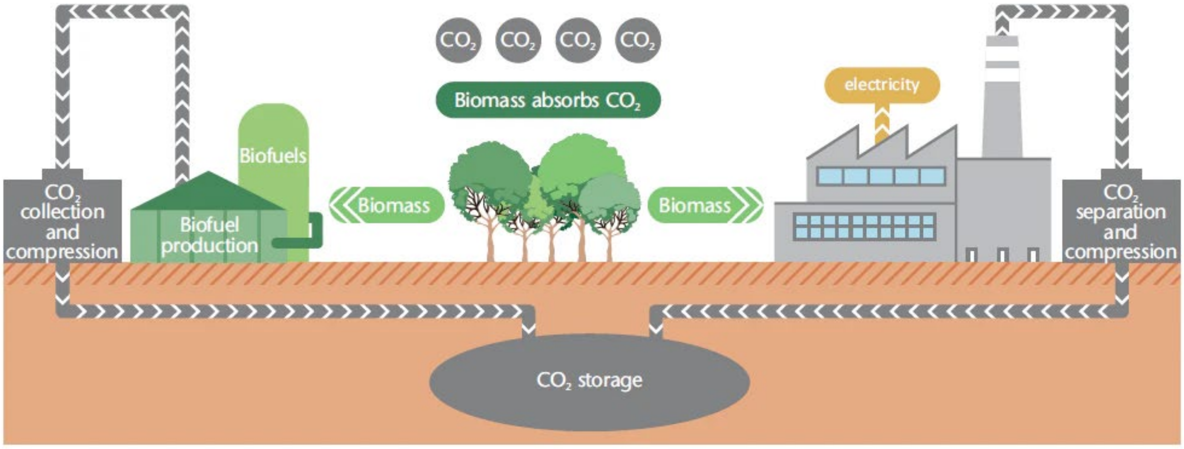
The Scottish Government's Update to the Climate Change Plan (CCPu) forecast a role for Negative Emissions Technologies (NETs) , including bioenergy with carbon capture and storage (BECCS), to remove carbon dioxide from the atmosphere to compensate for residual emissions.). The UK Climate Change Committee (CCC) acknowledges Scotland's opportunity to scale up domestic biomass production to meet this aim, recommending careful consideration of impacts on land-use and agriculture. In line with Scottish Government's Vision for Agriculture, and set out in the Scottish Agricultural Bill, future subsidy support which will replace Common Agricultural Policy, will be split across unconditional support and support targeted to sustainable food production and environmental outcomes, including low carbon farming and biodiversity. Scotland's draft 'Energy Strategy and Just Transition Plan' aims to use bioenergy where it can best support Scotland's Net Zero Journey, and aligns with and supports Scotland's goals for protecting and restoring nature. Considering the role for production of PECs in the evolving Scottish policy landscape will be critical.

Alongside this the UK Government has also published a new biomass strategy, which aims to support sector growth and strengthen biomass sustainability. The strategy acknowledges that bioenergy policy involves a mix of reserved and non-reserved powers, and so as the Scottish Government develops its Bioenergy Policy Statement, Scotland has an opportunity to build on UK policies and develop policies appropriate for Scotland. Further policy information is included in Appendix A.

3.2 Introduction to perennial energy crops for Scotland:

Previous research for CXC identified that perennial energy crops (PEC) present opportunities for scaling up biomass production in Scotland, with short-rotation coppice (SRC), short-rotation forestry (SRF) and energy grass Miscanthus, showing most potential (Martin et al, 2020). Details of each crop can be found in Appendix B. PECs support climate mitigation by providing a renewable energy source; displacing fossil fuel use; helping to reverse soil carbon loss, and acting as a carbon sink. When used for energy generation and combined with carbon capture and storage (CCS), such crops have the potential to generate negative emissions and contribute towards Scotland's net zero ambitions. PECs can also bring additional benefits, such as flood mitigation (see Section 4 below for further details).

Figure 3.2: Schematic diagram of bioenergy with carbon capture and storage 1



Currently, Scotland grows only a small area of PECs – about 250 ha (Martin et al, 2020). Previous geo-spatial mapping work for Scotland (Martin et al, 2020) has shown theoretical potential for approximately 900 kha of land, to be suitable for PECs (913kha SRF, 219 kha SRC and 52kha Miscanthus – with some overlap between suitable areas) mainly in the east and the lowlands. This analysis considered topography, soil type, climatic variables and suitable land capability classes[2] to identify these theoretically feasible growing areas. Future demand for PECs to support the Scottish Government's climate ambition is likely to require increased production of such crops.

3.2.1. Markets for PEC Biomass in Scotland

Research[3] has identified the following potential uses of biomass via 'Negative Emissions Technologies':

- BECCS Power - bioenergy with carbon capture and storage (BECCS) for electricity in a power station
- BECCS hydrogen - either via gasification of biomass or steam methane reforming of biomethane, with carbon capture and storage
- BECCS in industry (for heat and other industrial processes)
- BECCS Biomethane – processing of biomass via Anaerobic Digestion (AD), gasification or pyrolysis, with carbon capture and storage
- Biochar – pyrolysis of biomass, with carbon capture and storage

[1] IEA, 2017 IEA Technology Roadmap: Delivering Sustainable Bioenergy, Unlocking the potential of bioenergy with carbon capture and utilisation or storage (BECCUS) – Analysis - IEA, License: CC 4.0

[2] Land Capability for Agriculture in Scotland | Exploring Scotland | The James Hutton Institute – the study identified the capability classes for agriculture 4.1 to 6.1 and classes for forestry F1 to F5.

[3] Williams et al (for Ricardo), 2023, Report for the Scottish Government: Negative Emissions Technologies (NETS): Feasibility Study: Negative Emissions Technologies (NETS): Feasibility Study - gov.scot (www.gov.scot)

PEC biomass can also be used in combined heat and power plants and biomass boilers at a variety of scales. The market for the biomass produced from PECs is relatively immature in Scotland. There are several biomass energy plants ranging in size from large scale industrial units and power stations to small units supplying individual farms. These mostly utilise wood from local forests, waste wood from Scotland sawmills and other industries so the market for further PEC biomass is currently limited[4]. Scotland's largest wood-fuelled power station, is located in Markinch, with 55MW capacity utilising mostly recovered wood, some virgin wood chip. The next biggest is Steven's Croft, in Lockerbie which generates 44MW of electricity and 6MW of heat which initially planned to source fuel from local forests (60%), SRC willow (20%) grown within a 60-mile radius (and requiring around 4,000 hectares land) and recycled wood fibre (20%) (Warren et al., 2016), but the latest data suggests it mostly uses a mix of wood and waste wood[5]. BECCS plants are not expected to deploy in Scotland until 2030.

3.2.2. Evaluating economic potential of PEC in Scotland

To understand the real potential, it is critical to consider not just the overall economic viability of PECs, but also how the demand for land for PECs can be balanced against, or integrated with other uses such as food and fodder production and biodiversity, and the skills, knowledge and attitudes of the farmers or land managers.

4 The economic potential of energy crops

A Rapid Evidence Assessment (REA) seeking evidence of the economic potential of energy crops in Scotland was undertaken and identified peer-reviewed and grey literature. The methodology can be found in Appendix C. The review focused on Miscanthus, SRC and SRF to specifically identify:

- The positive and negative economic potential of energy crops.
- Other (non-economic) opportunities and barriers to deployment.
- Further economic potential (e.g., in relation to employment; technologies; wider decarbonisation, just transition).

Key insights are presented here, along with relevant insights from the stakeholder research. For full details of information found in the literature review and references to information sources (please see Appendix d), for details of stakeholder interviews conducted see Appendix G.

[4] Stakeholder interview

[6] Bioenergy Crops Better For Biodiversity Than Food-Based Agriculture | University of Southampton

4.1 Key findings of the rapid evidence assessment and stakeholder engagement

4.1.1. Evidence of positive economic potential

- There is evidence that PECs can be profitable, but there are limited studies directly applicable to Scotland and to the current economic climate (Appendix D: 15.1)
- Economic performance of biomass production is influenced by production costs, crop yields, crop price and end-use/market opportunities. (Appendix D: 15.1)
- Several studies comparing energy crops reported a high return per hectare for miscanthus primarily due to low maintenance cost along with the low requirement for field operations. (Appendix D: 15.1)
- The tree species chosen for SRF influences plantation establishment costs and therefore profitability as costs vary between species. Initial indications from trials underway in Scotland suggest hybrid apsen to have most potential, with common alder, silver birch and Sitka spruce having potential at some sites. (Appendix D: 15.1)

4.1.2. Evidence of negative economic impacts

- The most prominent evidence of negative economic impacts in the literature was the high upfront cost to establish PECs, lack of established markets, and the uncertainty over the stability of the long-term market. (Appendix D: 15.2)
- Profitability and economic considerations for farmers are dominated by high establishment costs, uncertainties about the market, a delayed period of revenue, and biomass yield. (Appendix D: 15.2)

4.1.3. Economic potential of PECs in comparison to other land uses

- The literature review did not provide clear evidence of how the three key PECs compare economically to other crops, annual crops and agricultural land-uses – some studies showed favourable comparison and others did not. Limited insights can be gained from the literature given the recent economic changes affecting agricultural costs and market prices (Appendix D: 15.3)

4.1.4. Influences on decisions to plant PECs

- One of the main factors affecting the uptake of PEC is economic profitability (Appendix D: 15.4)
- Appetite for and perception of financial risk, skills, attitudes and access to markets can influence farmer and land-manager decisions. (Appendix D: 15.4)
- Even where PECs, or energy crops in general, can deliver positive economic results for farmers and land managers, this on its own is not always sufficient to convince them to start growing PECs. (Appendix D: 15.4)

4.1.5. Other features of PEC production that influence economic potential

- Producing PECs has specific economic implications for growers which influence their economic potential and attractiveness. These include lack of flexibility of land-use, reduced market responsiveness, and opportunities for diversification alongside current farming enterprises. (Appendix D: 15.5)
- To view PECs as economically worthwhile, farmers need confidence that they can achieve an acceptable and secure market price into the future. As farms typically operate in a risk-averse manner, reduced risk is an important factor in farmer decision-making for PECs. (Appendix D: 15.5)
- The way PECs are deployed on farms influences their economic potential. Integration of PECs alongside other enterprises and on land which is not performing well could be advantageous. (Appendix D: 15.5)

4.1.6. Opportunities to improve economic potential

- Cultivation techniques, crop variety choice and other technological developments can influence economic potential of PECs in Scotland and have potential to improve profitability for farmers and land managers in future. (Appendix D: 15.6)
- There are factors which can negatively affect the economics of PEC production, which if addressed are potential opportunities to improve economic performance. (Appendix D: 15.6)
    - Gaps in the crop (i.e. patches where it didn't grow) was a key factor reducing profitability of miscanthus in the UK.
    - Ensuring access and enabling harvesting equipment is essential for economics of SRF to be viable
    - For SRF effective plantation establishment is important for the economics and general success of a SRF plantation
    - Single species monocultures can offer greatest economic return by providing higher yields per hectare
    - Highest yield are achieved on fertile soil or under intensive management systems, including weed control, fertilizer application and irrigation

4.1.7. Evidence of potential for wider economy

- There was limited research addressing the potential contribution to the wider Scottish economy and a just transition, but some opportunities and challenges can be inferred. These include sales for local energy generation and other industrial uses, employment opportunities in contract services, along with potential payments for environmental outcomes. (Appendix D: 15.7)

4.1.8. Evidence of non-economic opportunities

- Non-economic opportunities and benefits of PECs were identified including several relating to positive environmental outcomes such as reduced agro-chemical use, reduced soil and water pollution, carbon sequestration, and biodiversity benefits. (Appendix D: 15.8)

- The opportunities for environmental improvements resulting from PECs vary depending on planting, prior land-use and landscape context. (Appendix D: 15.8)

4.1.9. Challenges and deployment barriers

- Non-economic challenges facing the production of PECs in Scotland, relate to skills, land-use commitment, compatibility with current culture and habits, farm businesses, perceived land suitability and environmental concerns. (Appendix D: 15.9)
- Deployment barriers include the need for farmers to commit land for a long period of time, land quality, knowledge, profitability, time to financial return and social resistance relating to whether land should be used for energy or food production. In addition for SRC and SRF, converting land once planted is challenging, and additionally for SRF conversion be restricted by regulations as land will no longer be classed as agricultural. (Appendix D: 15.9)
- Lack of access to specialist skills and to specialist contractors and machinery was identified as a barrier to deployment. While there is interest amongst farmers in diversification, appetite for change is tempered by concern about moving into unfamiliar activities which require new skills.
- Culture and attitudes can be a barrier to PEC deployment. (Appendix D: 15.9)
- There are concerns about the impact on biodiversity from PECs. (Appendix D: 15.9)
- Energy generation from biomass is a potential source of direct and indirect emissions and limiting these emissions would need consideration. (Appendix D: 15.9)

4.1.10. Other relevant crops and planting regimes

- Hemp has the potential to provide high yields or returns with little or no pesticides and insecticides, significant potential in carbon sequestration, fits well into crop rotations with food and feed crops and helps improve soil structure and soil-borne pests. Constraints on producing hemp in Scotland includes the current lack of market as there are no large processing facilities in or near Scotland, strict regulations on growing hemp including the need to obtain a costly license, and some reports of low profitability according to Scottish growers. (Appendix D: 15.10)
- Specific studies focused on Scotland to show how PECs could be grown in agroforestry systems were not found, but provided the design of agroforestry systems can allow for economically efficient planting, management and harvesting it could provide an advantageous model. (Appendix D: 15.10)

4.2 Key evidence gaps

The research found some uncertainties – due to lack of Scottish specific data and in relation to climate impacts on PECs - which are described in the relevant sections above, and also some key gaps in the evidence which are summarised here.

4.2.1. Lack of Scottish data and research leading to economic uncertainty

Research related to the production and economic potential of energy crops in Scotland is limited. SRC is currently grown, but only at a small scale, and miscanthus still requires further trials and research before implementing at a commercial scale. SRF trials are currently underway in Scotland with findings slowly emerging as plantations reach maturity (Parratt, 2017). There is therefore uncertainty regarding the economic potential in Scotland.

The literature is inconclusive regarding the financial performance of PEC production. Conflicting results are found across studies, for example, a study in Ireland found miscanthus production to be an economically viable option (Zimmermann et al., 2014), yet in France, Miscanthus was found to be less profitable compared to conventional cropping systems (Glithero et al., 2013). Research by Warren (2014) reported that the soils and climate across Scotland offer significant biophysical potential, especially for SRC willow cultivation, which can also achieve good growth rates. However, with such limited data on Scotland and in light of the less favourable climate than found in locations of many studies there is uncertainty about the economic viability in Scotland.

4.2.2. Climate change

The effects of climate change on PECs are to some extent unknown. Research suggests that SRC willow yield may reduce as a result of rising temperatures, while miscanthus performs favourably (Alexander et al., 2014). However, as the temperature rises, this may change the habitat suitability, further research is required to establish the suitability and risks that a changing climate may have on seed development in miscanthus throughout the UK (Martin et al., 2020). We did not find research which commented on how extreme weather such as storms, flooding and drought would affect PECs. Some research suggests that water-logged soils hinder growth of PECs (Martin et al, 2020), but a recent technical webinar from Biomass Connect suggested that willow SRC is not negatively affected by water-logging, and can help improve water management when established.

4.3 Active debates within the sector

It is evident from the literature and stakeholder interviews that there are some topics with differing views including what types of land are most suitable for PEC growing considering the wider land-use debates, and likely impacts on biodiversity.

4.3.1. Land use and use of unproductive areas of land

In Scotland, there is competition for land to deliver food, materials, environmental services (such as carbon sequestration), leisure opportunities and more (Martin et al., 2020; Scottish Government, 2021). Scotland has the potential to produce 9.25TWh/yr and 1.75Modt/yr for SRC (Martin et al., 2020) such as SRC willow, however amongst the farming community there is social resistance relating to land being used for energy instead of food production (Anejionu and Woods 2019). The Scottish Government's Land-use Strategy (Scottish Government, 2021) highlights the complexity of balancing the need for land to support the move to net zero with other essential activities such as food production, and that whilst land-use decisions are often determined by the land suitability, much land is suited to multiple different uses. In these cases multiple factors need to be considered as to whether PECs are a suitable use for the land.

Literature identifies that using 'marginal' land, for energy crop production could be a solution to this land use debate. However, there are several challenges in understanding whether this 'solution' could usefully apply in Scotland. Ranacher et al., 2021 found there is a gap in the available literature regarding farmers' willingness to adopt short rotation plantations on marginal lands. There is also no agreed definition in the literature of what comprises 'marginal' land, so it is unclear how this would apply in the Scottish context. Much discussion in research focuses on cropland, yet in Scotland grasslands including rough grasslands, which may be viewed as 'marginal' from some perspectives, are a critical part of the Scottish rural economy and environment and so a more indepth analysis of the potential social, environmental and economic implications of PECs on grasslands is needed. Additionally, not all literature agrees on whether PECS will successfully grow on marginal land.

4.3.2. Biodiversity & ecosystem services

Converting land to energy production in Scotland will have direct impacts on biodiversity, wildlife, and landscape connectivity, yet the exact nature of these is unclear from the literature. Research shows that bioenergy crop choice and location influence biodiversity outcomes - choosing appropriate bioenergy crops in the right location is vital for the protection of biodiversity and ecosystems and to prevent damage to the surrounding ecosystem.[6] Contradictory evidence has been found throughout the REA on the effects of converting land for energy crop production in Scotland. Existing sustainability criteria for the use of biomass to produce heat or electricity require that PECs are not grown on land of high biodiversity value[7]. Beyond application of these criteria, the research could create uncertainty about how to select the right crops for the right locations in Scotland to ensure good outcomes for biodiversity and ecosystem services. Extrapolation of potential biodiversity effects from conversion of 'marginal' land has low confidence (Holland, et al., 2015) (Vanbeverena & Ceulemansa, 2019), and application of this research to the Scottish context with different land-use types is therefore very difficult.

The impact on biodiversity from SRC, SRF and Miscanthus differ depending on location, previous land use and crop type and management (e.g., cultivations, pesticide, and fertiliser use). The replacement of any semi-natural habitat by a dedicated bioenergy crop is likely to result in significant biodiversity losses due to creating a monoculture habitat (Martin et al., 2020). Significant areas of land classified as 'Less Favoured Areas' (LFA) in Scotland which were identified as potential PEC growing areas could be described as semi-natural – and seen as 'marginal' - but there is a risk of biodiversity loss if this is converted to PEC.

The REA identified a conflict in opinion as to whether PECs provide a biodiversity gain or loss. Firstly, factors such as reduced ground disturbance, increased diversity of nectar and

[6] Bioenergy Crops Better For Biodiversity Than Food-Based Agriculture | University of Southampton

[7] Defined as land which was primary forest, designated for nature protection, highly biodiverse grassland (except where harvesting is necessary to maintain grassland status), peatland, continuously forested, wetland in or after 2008.

pollen sources, and the potential to provide over wintering sites which are associated with energy crop production will benefit pollinating species. Conversely the monoculture nature of energy crops is likely to be detrimental to pollinator species as landscape homogenisation is widely accepted to be a driver for the current loss of pollinating species (Martin et al., 2020). Holland et al. (2015) identified ecosystem services such as hazard regulation, disease and pest control, water, and soil quality may benefit from the conversion of arable land to energy crop production, and that the transition of marginal land[8][9] to bioenergy crops will likely deliver benefits for some ecosystem services while remaining broadly neutral for others. On the other hand, conversion of forest to energy crops will likely have a negative impact due to the increased disturbance associated with the management cycle.

5 Estimating economic potential

This research looked at perennial energy crops (PECs), SRF, SRC and Miscanthus and included two core economic analyses:

1) Farm-scale economic analysis and comparison with typical land-use options:
   a. A farm scale economic analysis of the net economic benefit for a farmer or land-manager from producing and selling the Miscanthus, SRC and SRF.
   b. A comparison of this net economic benefit for a farmer or land-manager with typical existing land-uses.
2) Assessment of wider economic implications: drawing on geo-spatial data about existing farming and land-use types, the study analysed what the economics implications would be for the wider Scottish economy of a transition to growing more energy crops.

5.1 Farm Scale Economic Analysis

5.1.1. Methodology overview

- For the farm-scale economic analysis high, medium and low-cost scenarios were developed for the production costs for: Miscanthus; short rotation coppice: willow; short rotation forestry: conifer; and short rotation forestry: broadleaved. The higher scenario includes high output/high price minus low costs, the medium scenario scenario includes medium output/medium price minus medium costs and the low scenario includes low output/low price minus high costs.
- The following production costs were included; pre-planting/land preparation, planting, post-planting, harvesting and storage and reversion.
- Capital investment costs were not included: where specialist equipment would be needed, which a farmer would not typically have on a farm, such as cutting equipment for SRF, we have assumed services of a specialist contractor would be utilised and this cost has been included within the production costs.
- Estimates of likely income from PEC sales were combined with costs to create a ‘gross margin[10]’ (income minus costs) for each bioenergy crop. Because the PECs all have a

[8] Based on a meta-analysis of 45 studies on transition to energy crops from ‘marginal’ land.

[9] Definition of marginal land may not be applicable to Scotland.

[10] Gross margin in agricultural costings is typically defined as ‘Output from the enterprise less the Variable Costs, including the allocated variable costs of grass and other forage’

long lifespan, time series charts are used to show the income minus costs over the lifetime of the crop. The results of which can be found in section 5.1.3. Depending on the crop, the yield changes over the lifespan of the rotation, for example due to lower yields in early years after establishment and harvest only occurring in some years. Details on the yields during rotation can be found in Appendix D. For Miscanthus and SRF a low, medium and high price presented, whereas for SRC a single price is used due to limited data. Prices used in the analysis are in Appendix D.

- To compare to the economics of current land use, three farm types were used these were lowland cattle and sheep; mixed farming[11]; and general cropping - forage. These were selected because they are feasible on the land capability of grades; 4.1, 4.2, 5.1, 5.2, 5.3 and 6.1, - typically suitable for mixed agriculture, improved grassland and high-quality rough grazing, and also the land capability grades assumed suitable for PECs . To calculate the gross margins for the farm types used in the analysis the latest data from the 'Scottish farm business income: annual estimates 2020-2021' were used[12].
- Subsidies are not included in this analysis.
- Total average output in the farm business survey[13] includes the output categories; total crop output, total livestock output and miscellaneous output. For the 'general cropping - forage' category census data is used and output represents the estimated farm-gate worth (£s) of crops and animals without taking account of the costs incurred in production.

A more detailed description the methodology used, assumptions and data sources is included in Appendix E.

5.1.2. Limitations with the methodology

The calculations for the farm types used in the analysis are based on data from the Scotland Farm Business Income Survey, therefore the estimates are based on averages and so any other factors that might influence the costs and output for example climate, soil type will not be accounted for. This is the same for the costs and output estimates for the bioenergy crops. We have not allocated an economic value to any additional benefits a farmer may gain for the other farm enterprises, such as shelter for livestock on adjacent land.

It should also be noted that this study focused on gross margin comparison, which is useful for comparing specific crops and farm enterprises, but has limitations in terms of how well it allows assessment of integration of energy crops into a whole farm business. This will vary farm to farm and would require more in depth 'whole farm' economic analysis to be fully understood.

[11] Defined in the Scottish Farm business income survey as "Farms with no enterprise contributing more than two-thirds of their total standard output" – typically including livestock and crops, including animal fodder. An average income

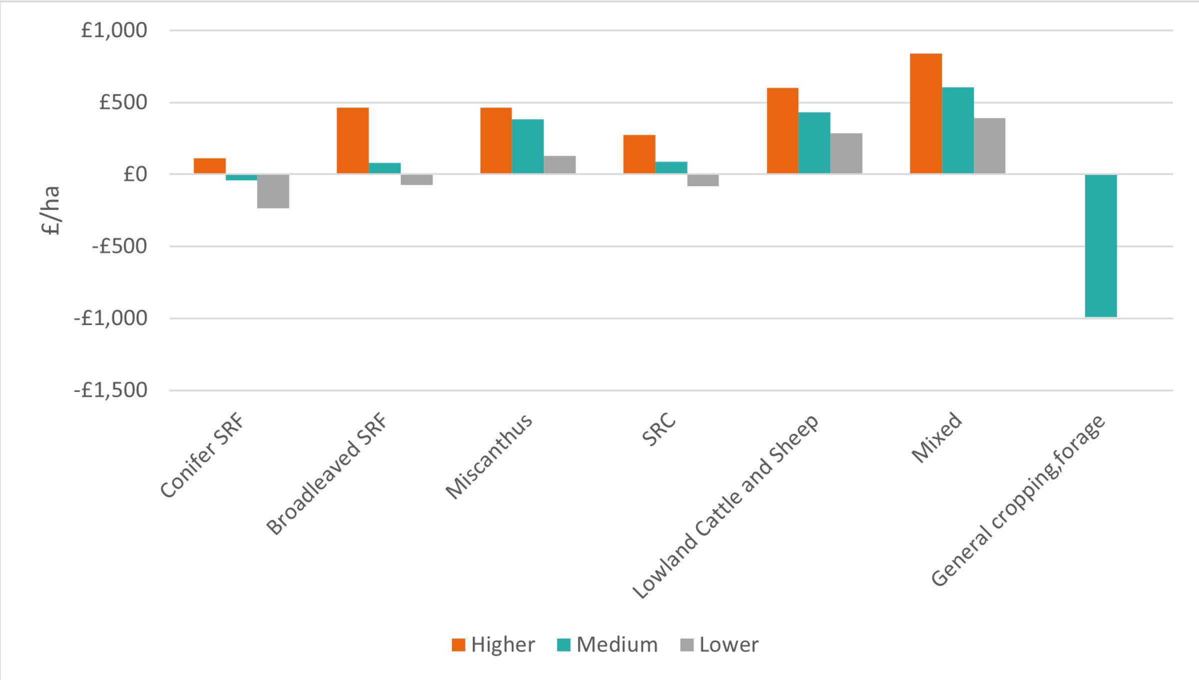
[12] Scottish farm business income: annual estimates 2020-2021 - gov.scot (www.gov.scot) – note that the mixed farming data is an average across farms that meet the definition above.

[13] Scottish Agricultural Census: results - gov.scot (www.gov.scot)

5.1.3. Results of Farm Scale Economic Analysis

Figure 5-1 shows what land managers could earn on average in a year if costs and yield were spread equally over the lifecycle of the bioenergy crop as well as for farm types (for full details on the method please see Appendix E). There are gross margins for a low, medium and high scenario for each of the bioenergy crops and for the farm types (except for general cropping, forage[14]). The low, medium and high scenario for lowland cattle and sheep and mixed farming includes the lower (25%), average and upper (25%) of data from the farm business income data respectively, average data from 6 years 2016-17 to 2021-22 uprate to reflect 2023 prices[15].

Figure 5-1 -Yearly average gross margins for each of the PECs over the lifetime of the PEC and for each farm type £/ha (2023 prices)



If costs and income were spread equally over the lifetime of the crop, the medium scenario suggests:

- Miscanthus produces a positive average annual gross margin of £382 per hectare, SRC £87 per hectare and SRF broadleaved £80 per hectare.
- SRF conifer would see a negative gross margin i.e., the production costs outweigh the value of the crop sold. The planting and the ground preparation costs are the main drivers behind this negative gross margin (see Appendix D for more detailed costs).
- Mixed farming and and lowland cattle and sheep farms both show a greater average annual gross margin than all of the PECs examined.
- The average gross margin per year for general cropping, forage is negative at around £990 per hectare, significantly lower than for all of the PECs. Based on these average

[14] The general cropping, forage category has only one scenario due to the data coming from the Scottish Government Census data which doesn't provide a low, medium and high scenario and the cost data coming form the Farm Management Handbook 2023/2024

[15] Scottish farm business income: annual estimates 2021-2022 - gov.scot (www.gov.scot)

annual gross margins, growing PECs in lowland cattle and sheep and mixed farming would reduce financial returns in the farm. Whereas, growing PECs in farms in the general cropping forage category could improve their financial returns.

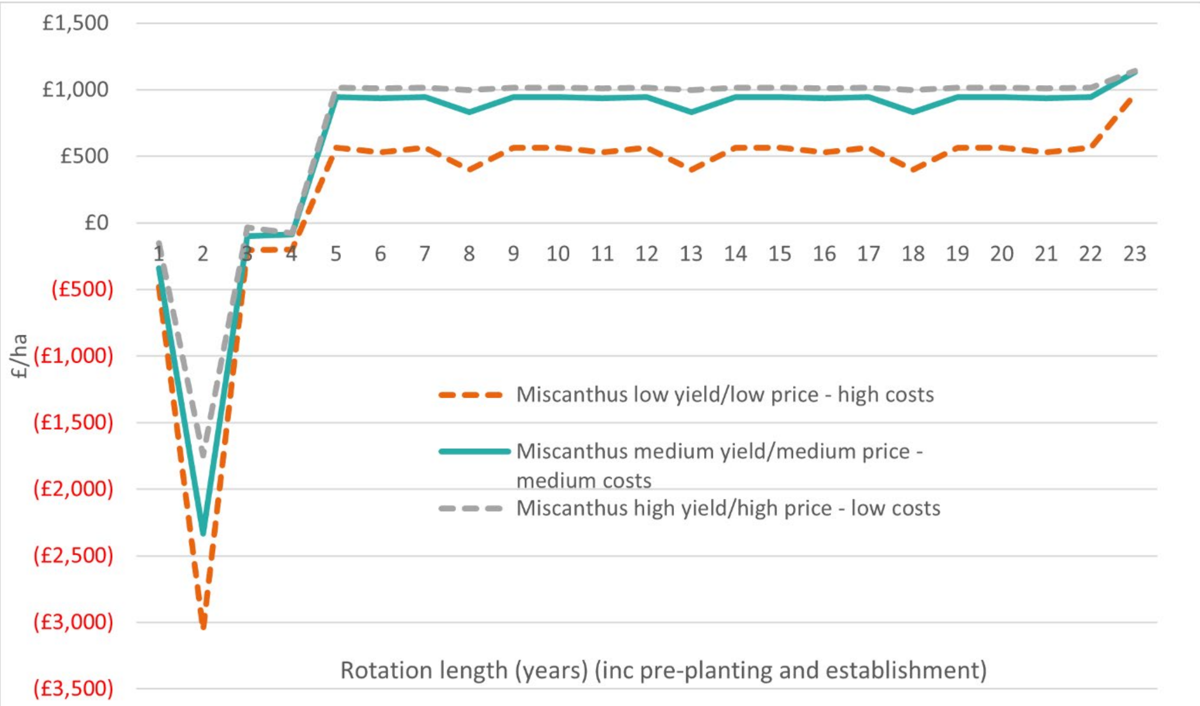
Figure 5-2, Figure 5-3, Figure 5-4, Figure 5-5 shows the low, medium and high scenario gross margins (output minus variable costs) over time of each of the PECs: Miscanthus, SRC, SRF broadleaved (silver birch) and SRF conifer (Sitka spruce). The higher scenario includes high output/high price minus low costs, the medium scenario includes the medium output/medium price minus medium costs and the lower scenario includes low output/low price minus high costs.

Costs included in the calculations included:

- Site preparation / land preparation (including from different prior land-uses where data is available)
- Establishment / planting
- Crop management costs e.g., during initial growth
- Harvesting
- Reversion (where relevant)

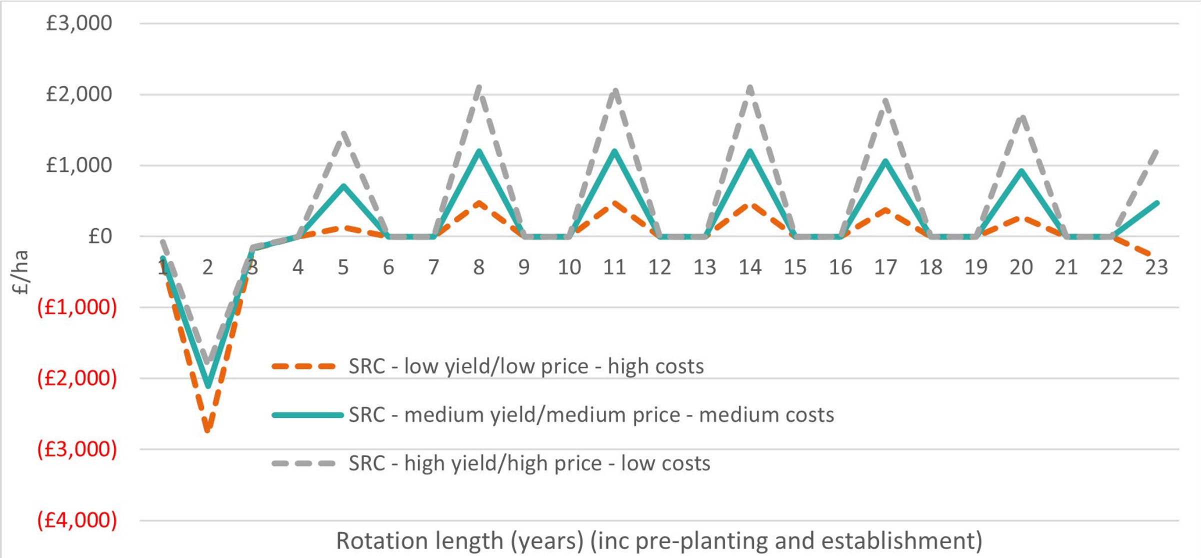
Detailed breakdowns of these costs for the PECs are included in Appendix E.

Figure 5-2 Gross margins for Miscanthus (£/ha) (2023 prices)



- Miscanthus shows an initial negative gross margin in the first two years during the site preparation and plant stages, but then picks up in the following years with harvesting driving the positive gross margins in the following years. The gross margin drops slightly in the year 21 when the costs of reversion take place.

Figure 5-3 Gross margins for short rotation coppice (£/ha) (2023 prices)



- Short rotation coppice shows a negative gross margin for the first 3 years, in part driven by the pre-planting/land preparation costs in years -1 and 0. Gross margin is then positive in the years 3, 6, 9, 12, 15 and 18 reflecting when harvesting takes place.

Figure 5-4 Gross margins for short rotation forestry – Sitka Spruce (£/ha) (2023 prices)

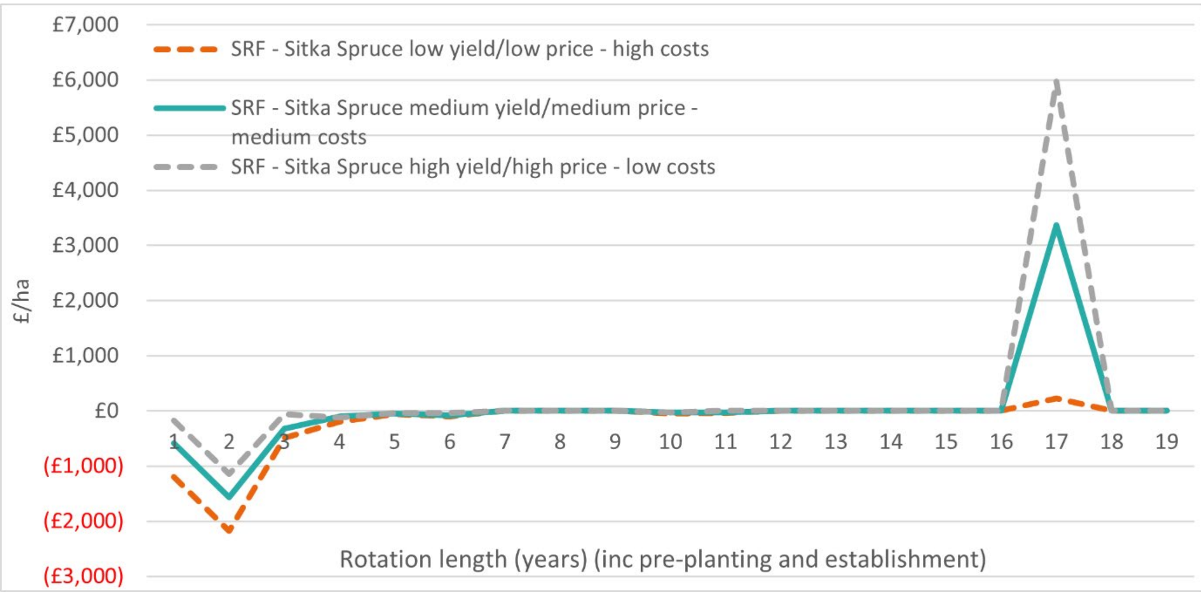


Figure 5-5 Gross margins for short rotation forestry – Silver Birch (£/ha) (2023 prices)

- Short rotation forestry for silver birch and Sitka spruce shows a negative gross margin except for the year 15 when harvesting takes place.

Linking back to Figure 5-1 with the lowland cattle and sheep category on average earning £433 per hectare per year, the mixed farming category £597 per hectare per year and the general forage making a loss of £990 per ha per year the results show;

- Miscanthus, initially has a lower gross margin than all the other farm types, however, after the first few years, land managers would be better off planting Miscanthus.
- SRC, produces a better gross margin than general cropping-forage after the first few years but is outperformed by all other categories when the yield is harvested in years five, eight, 11, 14, 17, 20 and 23.
- SRF, again outperforms general cropping- forage, but has a lower gross margin than the other farm types, except for when harvest takes place in year 18.

5.2 Assessment of implications for Scotland's rural economy

To consider the potential implications of growing more PECs, the results from the farm-scale economic analysis (Section 5.1) were extrapolated across Scottish regions, to consider a transition of approximately 40,000 to 90,000 hectares of suitable land to grow PECs – the area judged to be feasible by 2032 and 2045 respectively (see below for the source of these estimates).

5.2.1. Key findings:

This transition of land in mixed holdings and non-LFA cattle and sheep to PECs would create a shortfall of non-energy crops and and reduced income across the Scottish rural economy due. Because PECs would be more profitable than 'general cropping: forage' land-use, there would be an economic gain from transition, but loss of production of animal feed, which may have knock-on implications for livestock production costs (which have not been quantified here).

This research found that, if land to match the level of demand as set out in these scenarios, was utilised for perennial energy crops it would create:

- a gain in gross margin[16] of around £9.6 million (scenario 1) or a loss of around £9.5 million (scenario 2) per year across the regions.[17]
- a shortfall in agricultural yields (of farm outputs generated by existing land-use activity, which would not be available when the activity ceased to be replaced with PECs) across the regions between 537,600 tonnes (scenario 1) and 708,200 tonnes (scenario 2).

Our analysis which forms the basis of this assessment is set out below – with details of each scenario (approximately 40,000 and 90,000 hectares).

5.2.2. Limitations:

This assessment does not consider potential loss or additions to the economy due to changes in associated services. Some additional contracting employment for PECs servicing is likely based on the research, but this, and any potential shortfall in other employment from reducing other farm enterprises have not been assessed.

It should also be noted that the findings relate solely to gross margin comparison. Actual farm income – whole farm business income - is very different, comprising multiple farm enterprises (livestock, crops, diversifications) and may be supplemented with off-farm income. For the farm types considered here typical farm income levels are shown in Table 5-1 below (note General Cropping, Forage is not a type assessed in the Scottish Farm Business Income Survey so data is not available). Assessment of implications for PECs on the overall farm costs and income has not been fully assessed here and may reveal additional positive and negative economic implications of PECs.

Table 5-1: Annual Farm Business Income (£) (average of 6 years 2016-17 to 2021-2022)

	Farm total			Per hectare		
Farm Type	**Lower (25%)**	**Average**	**Upper (25%)**	**Lower (25%)**	**Average**	**Upper (25%)**
Mixed Farming	-9271	37,791	129,023	-58	225	551
Lowland Sheep & Cattle (non-LFA)	-20,688	25,756	105,926	-176	191	451

[16] Gross margin is farm income from a specific production enterprise, e,g, crop or livestock minus costs directly associated with production of that output, but excluding 'fixed costs' such as costs associated with farm buildings, general labour and finance costs. Further detail available in: Appendix E Methodology for economic analysis.

[17] The transition of a large land area – scenario 2 – to PECs creates a loss because of the assumptions within our study – we assumed that land which is more economically advantageous for PECs would be converted preferentially, so a larger portion of land transitioned in scenario 1 would make a profit from the transition to PECs, whereas in scenario 2 a large area of land which would make a loss from the transition was included, and so resulted in a total loss on balance.

5.2.3. Method and results

For each of non-LFA cattle & sheep, mixed holdings, general cropping; forage, areas that would be suitable to grow PECs have been identified (see Table 5-1). (See Appendix E for further details on how these areas were selected.) This was done by using the GIS mapping done in previous work for CxC (Martin et al,2020) which identified land suitable for PECs to identify the percentage of land in region which was suitable for PECs. This percentage was then applied to the land area estimated to be in each farm type in the region, to derive the land are potentially suitable for PECs by farm type. There is some overlap between the types of land suitable for each of the three types of PECs so the areas in the table cannot be summed to give a total area.

Table 5-1 Potential land suitable for each bioenergy crop on different farm types (hectares)

	General Cropping, Forage	Non-LFA Cattle & Sheep	Mixed Holdings	Total (all farm types)
Land potentially suitable for SRF	13,601	66,189	27,746	107,536
Land potentially suitable for SRC	7,967	50,520	20,156	78,643
Land potentially suitable for Miscanthus	1,352	12,633	4,770	18,755

A previous CXC study (Meek et al, 2022) indicated that, bearing in mind land suitability, an estimated total of approximately 27,000 ha PECs[18] could be planted by 2030, 38,000 by 2032 and 90,250 hectares by 2045. Using these estimates and the potential land that can grow bioenergy crops two illustrative scenarios have been created to estimate the potential economic gain/loss of growing bioenergy crops at the Scottish level.

Scenario 1:

From the results presented in section 5.1 it was financially beneficial to grow bioenergy crops on general cropping, forage land. Furthermore, of all the PECs, growing miscanthus was the most financially beneficial. Therefore, the first scenario assumes that two-thirds (66%) of the general cropping, forage land suitable for SRF and for SRC will be converted and 100% for Miscanthus. Only 66% of land for SRF and SRC are assumed to be converted to avoid double counting due to the likelihood that some areas identified are suitable for both PECs and thus appear in both estimates of suitable areas. Although the results in section 5.1 show that growing bioenergy crops on both non-LFA cattle and sheep and mixed holdings would not be financially beneficial, the loss was less on non-LFA cattle and sheep land. Therefore, to get to the 38,000 hectares, it was assumed that 15% of the land suitable for both SRF and SRC in non-LFA cattle and sheep holdings will be converted and 30% for

[18] This study focused mostly on Miscanthus and SRC, but has been used as a best estimate here to give some basis for understanding how potential demand for bioenergy crops could evolve in future to meet Scottish Government NETs ambition.

Miscanthus (see Table 5-2). Overall this means that about 20% of total land in Non-LFA Cattle and Sheep[19] and 1.1% of land in general cropping, forage are converted to PECs.

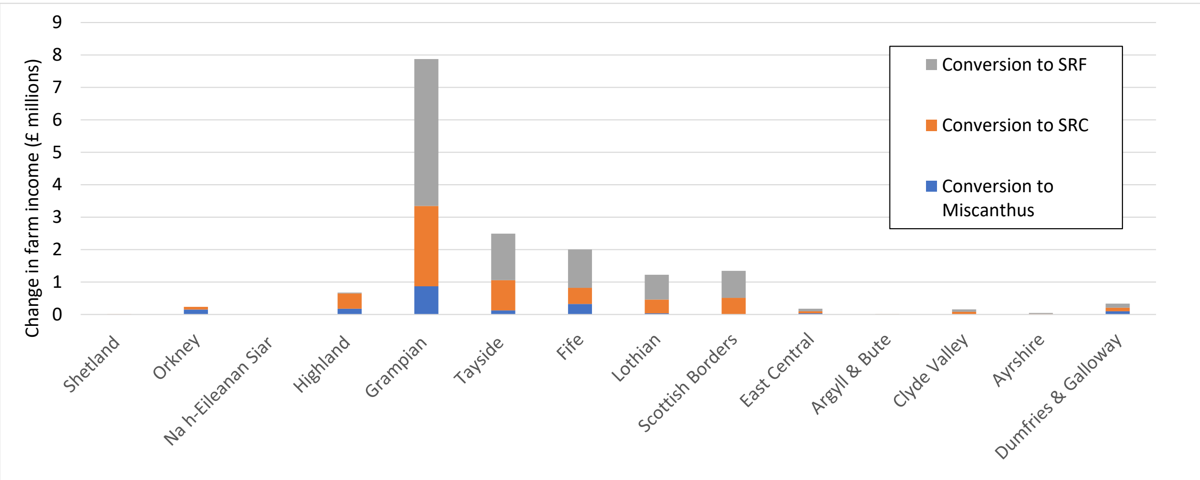
Table 5-2 Land that is converted for each bioenergy crop for each farm type in scenario 1 (hectares)

	General Cropping, Forage	Non-LFA Cattle & Sheep	Mixed Holdings	Total (all farm types)
SRF	8,977	9,928	-	18,905
SRC	5,258	7,578	-	12,836
Miscanthus	1,352	3,790	-	5,142
Total (all PECs)	15,587	21,296	-	36,883
Total land in farm type in Scotland	1,378,365	107,712	304,901	1,790,978
Percentage of total area converted	1.1%	20%	0%	2.1%

5.2.4. Results: scenario 1

Figure 5-6, shows that, for Scenario 1 there would be an economic gain for converting land used for general cropping and forage to PECs. This is because PECs have a positive, albeit small gross margin, compared to the large negative gross margin for general cropping and forage. The total gain in gross margins across the region is around £16.6 million, of which almost half occurs in Grampian.

Figure 5-6 Change in gross margin for converting General Cropping, Forage land to Miscanthus, SRC and SRF (Scenario 1)



[19] This refers to the percentage of all Non-LFA Cattle and Sheep land in Scotland – suitable and not suitable for PECs.

Figure 5-7, shows there would be potential economic loss for converting non-LFA cattle and sheep land to Miscanthus, SRC and SRF in table 5-2 (scenario 1) with Grampian showing a loss of a total of about £1.8 million. SRF showed the greatest loss in the majority of the regions, as it has the lowest gross margin of all the PECs but has more land suitable for it. Miscanthus showed the smallest loss across all regions. The total loss in gross margins across regions is just under £7 million. This loss is lower than the gain in gross margin from growing PECs on general cropping and forage farms, suggesting that achieving 38,000 ha of PECs could give a net increase in gross margins across the two farm categories of £9.6 million.

Figure 5-6 Change in gross margin from converting Non-LFA Cattle and Sheep land to Miscanthus, SRC and SRF (Scenario 1)

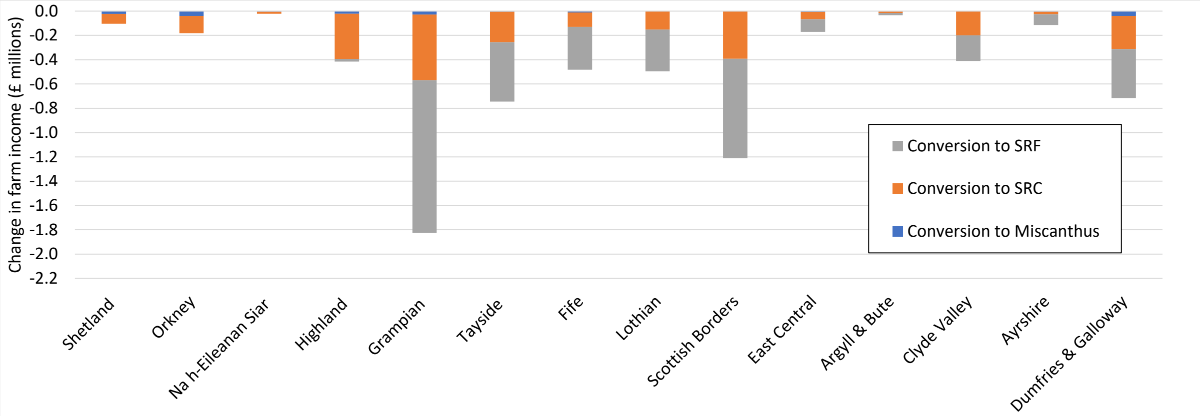
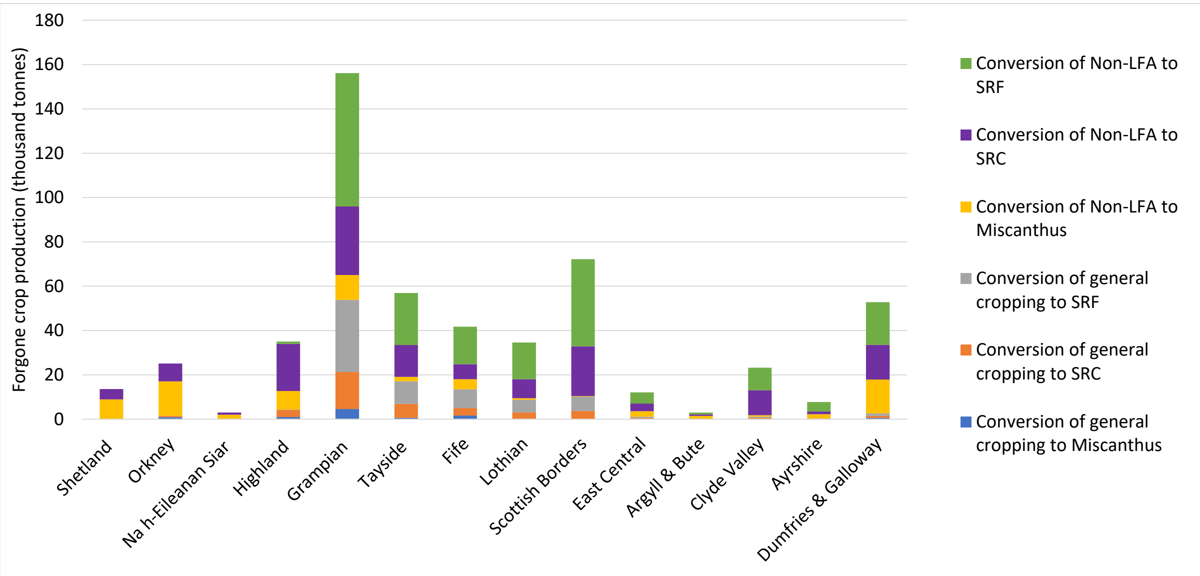


Figure 5-8 shows the reduction in production (crops, stock-feeding crops and grass from grazing land) that could occur when converting the land shown in Table 5-2 to PECs. From converting land to PECs, there is an estimated yield loss of 537,600 tonnes: 263,000 tonnes for crops replaced by with SRF, 85,300 tonnes for crops replaced by Miscanthus and 189,000 tonnes for crops replaced with SRC.

Figure 5-8 Reduction in production (barley, stock-feeding crops and grass) resulting from converting land to PECs (thousand tonnes) (Scenario 1)



Scenario 2:

For the second scenario to get to around 90,000 hectares of land, it was assumed that more of the suitable general cropping and forage land was converted to SRF and SRC (66%), and more of the non-LFA cattle and sheep land (30% of land suitable for SRF and SRC and 60% of land suitable for Miscanthus). It was assumed that a small percentage of the suitable land on mixed holdings was converted (50% of land suitable for SRF and SRC and 50% of land suitable for Miscanthus). Overall, this means that about 40% of the total land in non-LFA cattle and sheep farms, around 9% of total mixed holdings and 1.3% of total general cropping /forage land are converted to PECs.

Table 5-3 Land that is converted for each bioenergy crop for each farm type in scenario two (hectares) (Scenario 2)

	General Cropping, Forage	Non-LFA Cattle & Sheep	Mixed Holdings	Total (all farm types)
SRF	10,201	19,857	13,873	43,931
SRC	5,975	15,156	10,078	31,209
Miscanthus	1,352	7,580	4,770	13,701
Total (all PECs)	17,528	42,592	28,721	88,841
Total land in farm type in Scotland	1,378,365	107,712	304,901	1,790,978
Percentage of total area converted	1.3%	40%	9%	5%

5.2.5. Results: scenario 2

Figure 5-9, show the results of the conversion rates set out in table 5-3 (scenario 2). The only farm type which shows an increase in gross margin for conversion to PECs is general cropping and forage (due to its current large negative gross margin). Conversions on the other farm types (necessary to meet the target planting area of around 90,000 ha) give a loss in gross margins. Overall, the increase in income in general and cropping farms of £18.6 million is not enough to offset losses in the other two farm types, (£13.9 million in non-LFA cattle and sheep farms and £14. 2 million on mixed holdings) meaning there is a net loss in gross margin of £9.5 million.

Figure 5-9 Change in gross margins from converting Non-LFA Cattle and Sheep land to Miscanthus, SRC and SRF (Scenario 2)

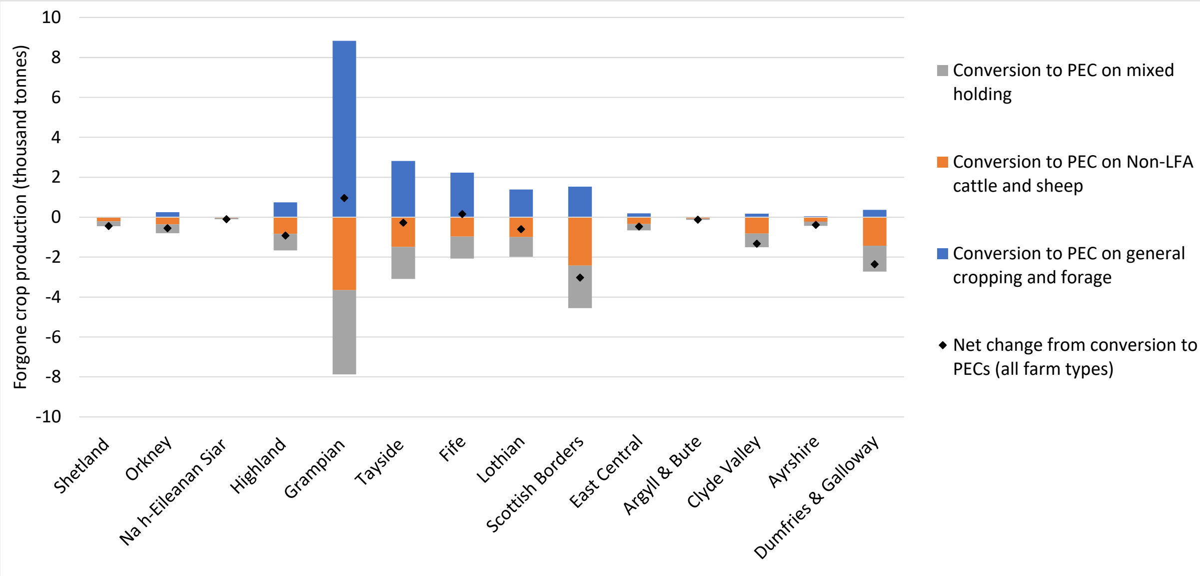
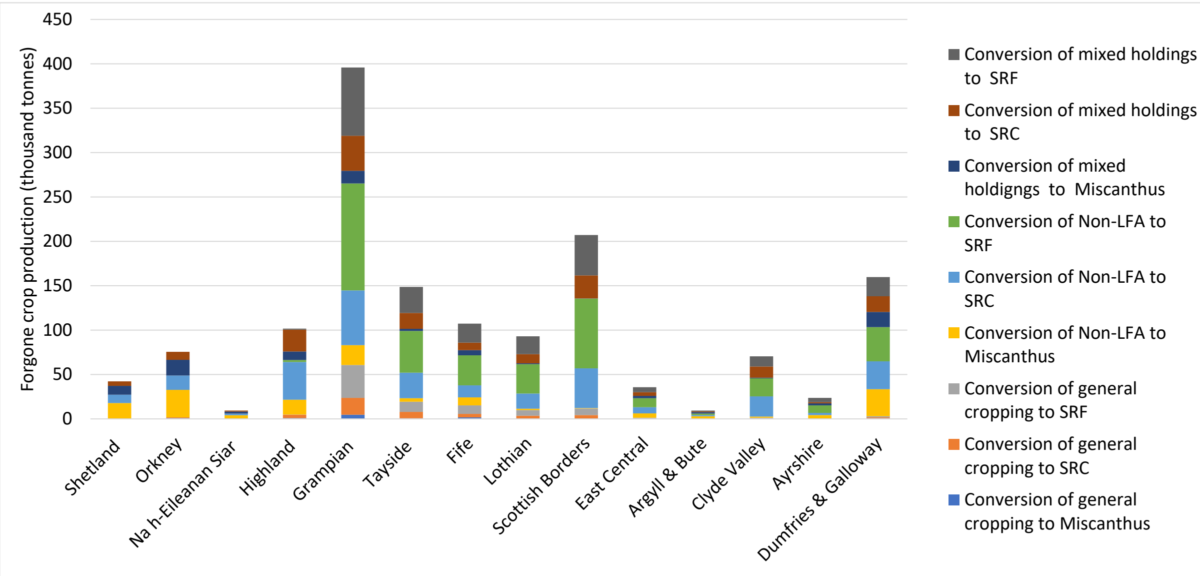


Figure 5-10 shows the crop production that could potentially be lost from converting the land shown in table 5-3 (scenario 2) to PECs. This based on loss of stock feeding crops (barley, maize and lupin) and grass silage and hay produced on each farm type. From converting land to PECs, there is estimated yield loss of 708,200 tonnes for replacing with SRF, 248,100 tonnes for replacing with Miscanthus and 523,900 tonnes for replacing with SRC.

Figure 5-10 Reduction in crop production (barley, stock-feeding crops and grass) resulting from converting land to PECs (thousand tonnes) (Scenario 2)



6 Preferred locations: considerations

Preferred locations for economically viable production of PECs are influenced by multiple factors including proximity to markets (current biomass energy plants and potential future BECCS plants) and local enough access to services and facilities for crop management (e.g. harvesting contractors) to avoid excessive costs. We assessed preferred locations for economically viable energy crops in Scotland considering the locations of end markets in relation to viable growing areas for PECs.[20]. Insights from our rapid evidence assessment and stakeholder consultation were also considered, for example comments on economically viable transport distance.

Our analysis showed economically viable areas for PEC production bearing in mind future anticipated demand resulting from Scotland's net zero ambitions, but only SRF could provide quantity needed, due to lack of availability of suitable land for SRC and miscanthus. As SRF is economically uncompetitive against current land-use, this suggests economic viability may be a barrier to PEC production increases even if suitable land within economically viable distance of end markets is available.

6.1.1. Proximity to users of biomass for energy

Biomass energy crops are bulky to transport and so haulage cost from the location where they are grown to where they are used is a factor which determines which growing locations are economically viable – a crop grown too far from its end destination will be prohibitively expensive to transport. It has been difficult to identify a specific economically viable distance in the available research. Stakeholder comments suggest that whilst 100km is a typical maximum distance to haul wood to a sawmill, a significantly lower distance is economic for biomass crops, as their value is lower than wood which will become sawn timber. In our economic analysis transport costs pre-farm gate e.g. for delivery of planting material are included, but haulage of the bioenergy crops to biomass plants has not been included in the costs as this will depend on the distance and whether the price paid to the farmer is at the farm gate or at delivery to the bioenergy plant. For the purposes of the analysis here, we assume a maximum viable distance of 100km, and consider a shorter 50km distance to reflect stakeholder feedback.

6.1.2. Proximity to existing biomass plants:

Biomass plants in Scotland were identified from DESNZ' Renewable Energy Planning database which lists both existing and planned plants[21]. Existing sites vary in scale and use – some are generating power for the grid, others are located on industrial sites such as distilleries, sawmills and papermills supplying heat and power for the industry, whilst others are small supplying e.g. a hotel. Eight sites were selected from the list as being most likely to consider using PECs as a fuel (See Appendix J). Plant which are located on sites where there is already

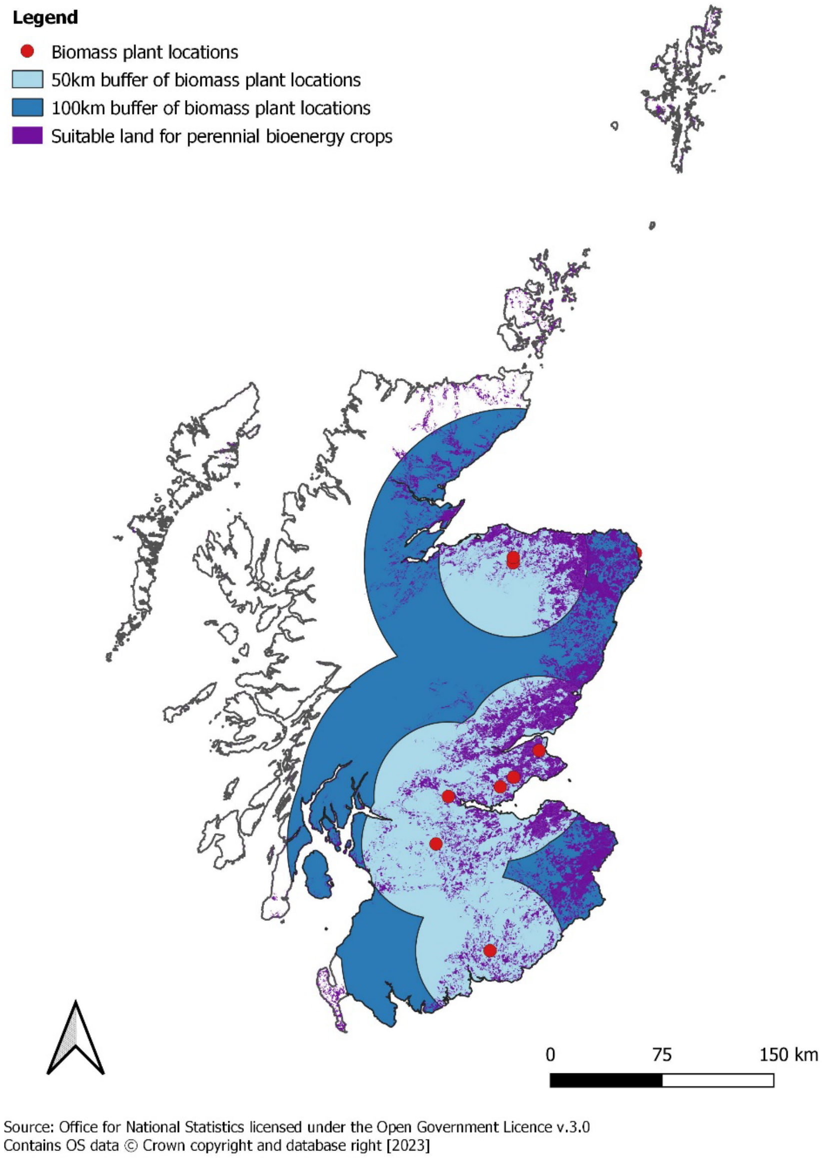
[20] Methodology and maps of potential production areas of the three crops produced within the previous project are in Appendix F.

[21] https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract. The database only includes plants generating electricity so large biomass boilers are not captured.

a ready supply of fuel (e.g. sawmills, paper and pulp) were excluded as were very small sites and sites which were not yet operational or under construction.

A buffer of 50km and 100km from these biomass plants has been applied in Figure 6-1, to show the potential geographical areas which could supply biomass markets in Scotland.

Figure 6-1: Biomass plant locations



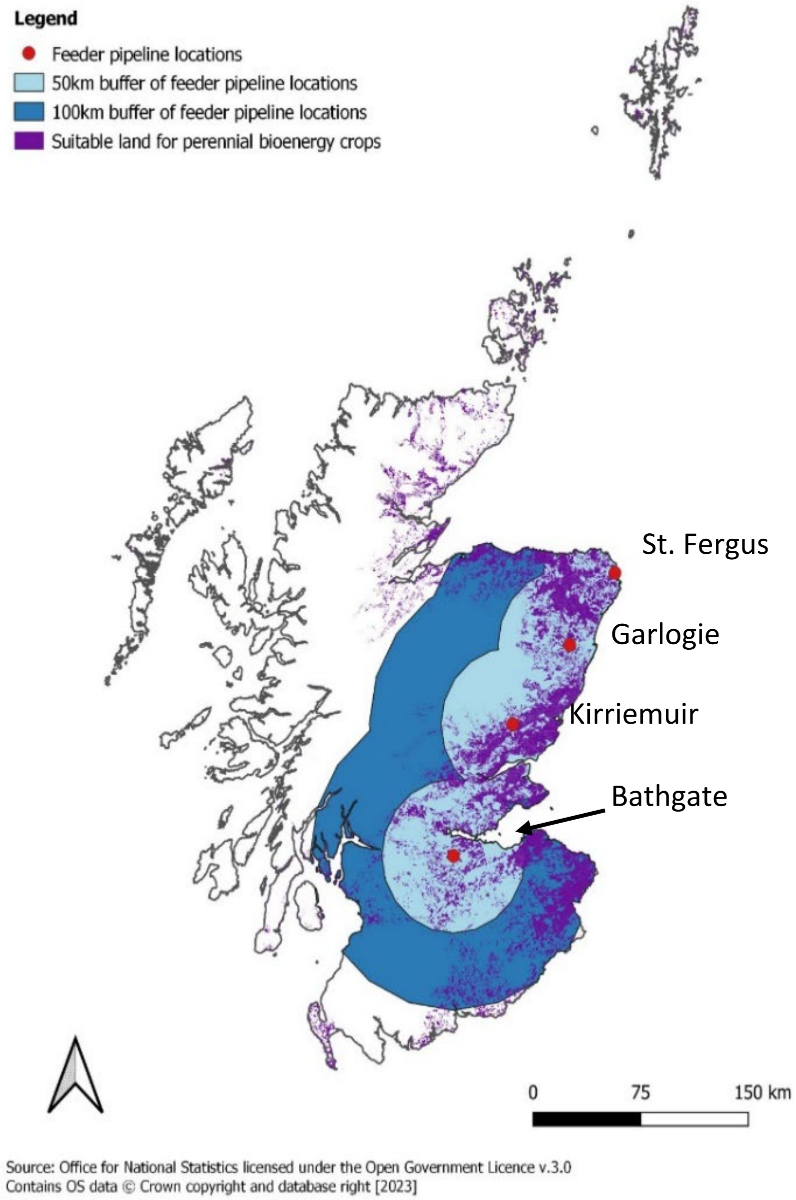
6.1.3. Proximity to future BECCS facilities:

CCC[22] highlights that Scotland has very good potential for deploying Bioenergy with Carbon Capture and Storage (BECCS) due to its access to a potential CO_2 storage site in the North Sea, along with its ability to produce domestic BECCS feedstocks. A pilot facility, the Acorn Transport and Storage Facility in Aberdeenshire looks set for further investment after the UK

22 Scottish Emissions Targets - first five-yearly review (theccc.org.uk)

government announced in March 2023 that it considers this site to be one of the two best placed to deliver its objective of capturing 20-30 megatonnes of CO_2 across the UK economy by 2030[23]. The proposed access points to this facility are via a feeder pipeline along Scotland's east coast which starts at Bathgate and ends at St Fergus, with two injection points at Kirriemuir and Garlogie. Large scale BECCS plants for electricity, biomass gasification for hydrogen, or biofuel production[24] may be located in proximity to these access points to benefit from easy access to the pipeline. This study assesses how much land suitable for growing bioenergy crops is within 50km and 100km of these access points. This mapping is presented in Figure 6-2.

Figure 6-2 Feeder pipeline locations and nearby land suitable for PECs



[23] Green growth for Scotland with multi billion pound investment - GOV.UK (www.gov.uk)
[24] These three types of BECCS (Bioenergy with Carbon Capture and Storage) were identified in CCPu, along with BECCS in industry, as potential options for Scotland.

Table 6-1 shows the total potential PEC growing areas with these distances.

A previous CXC study (Meek et al, 2022) indicated that, bearing in mind land suitability, an estimated total of approximately 27,000 ha PECs[25] could be planted by 2030 and 38,000 by 2032; With this area of land, depending on the yields obtained for PECs and the efficiency of the power plant, PECs could provide feedstock for a BECCs power plant producing between 60 and 80 MWe. The data in Table 6-1 suggests that this land is available, within 50km of all proposed access points along the east coast feeder pipeline for SRC and Miscanthus, but this would require a large portion of the suitable land to be used. A larger land area which is suitable for growing SRF is available.

Table 6-1: Total potential PEC growing areas within 50km and 100km of potential BECCS sites, and existing biomass plant locations.

	Feeder pipeline locations		**Biomass plant locations**	
	Within 50km	Within 100km	Within 50km	Within 100km
SRC	82,471 ha	161,016 ha	117,222 ha	225,013 ha
Miscanthus	8,224 ha	18,057 ha	18,280 ha	28,873 ha
SRF	551,303 ha	826,528 ha	555,193 ha	858,669 ha

6.1.4. Access to service and facilities for crop management, harvesting and processing.

Access to services and facilities for crop management harvesting and processing, such as local contractors with suitable equipment has been identified in the research and by stakeholders as a factor which would influence the suitability of growing areas for PACs. The evidence review did not provide information on the availability and access to these services in Scotland, or the speed with which services could develop if a growth in production were planned. Easy access should not be assumed, particularly given the shortage of forestry skills in Scotland and constraint on travel distance which influence the economic viability - access issues would need to be addressed before an area could be suitable for economically viable PEC growing.

6.1.5. Other location considerations

As is evident from the REA, biodiversity and other ecosystem services can impacted by PEC cultivation. Choice of crop, cultivation regime and location need to be carefully considered to optimise environmental benefits and avoid negative impacts. The impact is highly situation specific and could not be assessed in detail within scope of this research but should be considered carefully when selecting locations.

[25] This study focused mostly on Miscanthus and SRC, but has been used as a best estimate here to give some basis for understanding how potential demand for bioenergy crops could evolve in future to meet Scottish Government NETs ambition.

7 SWOT & PESTLE Analysis

This section provides analysis of the strengths and weaknesses of these crops, and the factors supporting or hindering uptake, drawing together the research findings. A PESTLE analysis was also carried to understand the potential enabling and preventative factors which could influence the economic viability of energy crops in Scotland. Further detailed SWOT and PESTLE analyses are available in Appendix I.

7.1 SWOT Analysis of energy crop economic potential

Table 7-1 presents SWOT analysis common to PECs assessed in this research. Further discussion of variations between Miscanthus, SRC and SRF is included in Section 9.

Table 7-1: Summary of strengths, weaknesses, opportunities and threats for PEC in Scotland.

Strengths	Weaknesses
• Feasible growing areas including proximity to potential BECCS sites (varies by crop) • Low input & maintenance costs • Alternative markets beyond energy (e.g. Miscanthus for animal bedding; SRF grow on for other wood products) • Stable annual income if sequentially planted • Shading benefits for adjacent land	• Cash flow- upfront cost to establish crops, and several years before first harvest income • Lack of specific subsidies / financial support for energy crops. • Need for specialist knowledge and equipment – access constraints • Lack of processing facilities • Biomass cost currently compares unfavourable to fossil fuels • Biomass for energy is a lower value crop than sawmill wood / biomass for other industries (such as bio-based plastics)[26] • Limits farmer land-use rotation choices • Costs of transport for bulky crop – constrains distance from end market • Shading disadvantage for adjacent crop.
Opportunities	**Threats**
• Income diversification: potential additional revenue stream with limited workload after establishment. • To design PEC planting to deliver additional environmental benefits such as water management, biodiversity, soil health. • To improve farm energy security/costs by use of biomass on farms • To harness innovation pipeline and developing knowledge base to increase yields / cut costs (see Appendix H) • Contractor services employment e.g., establishment / harvest.	• Uncertain/under-developed end market • Uncertain future market price • Competition from cheaper imported biomass • Potential competition between different Scottish users (e.g., on farm vs BECCS) • Public / NGO negative perceptions • Farmer/land-manager preferences for current land-use and perception of PECs as financially risky. • Limited geographical spread of contractors.

[26] Based on stakeholder comments.

7.2 PESTLE Analysis

The PESTLE analysis considersthe political, economic, social technical, legal and environmental factors which currently enable or prevent energy crops becoming an economically viable prospect for farmers in Scotland. The summary PESTLE is set out in Table 7-2 below, discussion of the results follows in Section 9.

Table 7.2: Summary of PESTLE analysis for growing PECs in Scotland.

	Enabling factors	Preventative factors
Political	• Political support by Scottish / UK government –identified as critical to climate goals.	• Uncertainty of specific policies/ government financial support. • Limited grant funding opportunities for farmers and land-managers.
Economic	• Low input costs / labour costs once established. • Income diversification opportunity / additional income stream if planted on previous unproductive land. • Machinery innovation could cut costs of production.	• Large initial investment and lack of cash flow in years before first harvest. • High production costs, compared to imported biomass. • Uncertain markets and market prices • Low profitability over whole crop lifetime.
Social	• Potential for employment in contracting services (e.g. planting / harvesting).	• Perception of PEC as financially risky. • Attitudes / preferences of farmers and land-manager – preferences for familiar farm enterprises. • Concerns about competition for land / resources e.g. livestock farmers concern about loss of local feed crops. • Moral concerns about PEC replacing other land-uses e.g. food crops. • Negative publicity about energy crops. • Age of farmers: older farmers may not be in business long-enough to see profits.
Technical	• Potential to use existing harvesters for Miscanthus. • Production and harvesting technology improvements in the pipeline.	• BECCS is an emerging technology – no current plants in Scotland. • Need for specialist machinery, especially for SRC/SRF, which is limited in Scotland. • Interdependence between producers and bioenergy plant: concurrent development of market and supply is challenging.
Legal	• Long-term contracts between end users and farmers can give confidence for investments.	• SRF results in legal land-use category change – reversion to farming may be prevented in future. • Some crops are subject to cultivation licences (e.g. Hemp, Eucalyptus). • Long-term land-use decisions difficult for tenant farmers.

Environmental	• Desire for ecosystem services which some PECs could deliver e.g. flood control. • Agrochemical restrictions driving interest in low-input PECs • Potential to increase soil carbon • Biodiversity / habitat benefits in some circumstances, but some uncertainty	• Concerns about biodiversity impacts of 'monoculture'. • Environmental benefits depend on sustainable production methods. • Right crop – right land is critical: carbon stored in soils could be released by planting on peaty soils / uplands areas. • Limited suitable areas e.g. some reports state SRC cannot tolerate water-logged soils. • Winter hardiness of Miscanthus a constraint for Scotland. • Future climate change favour Miscanthus.

8 Discussion

The research and analysis show multiple positive and negative features of the PECs. The implications of these for economic viability of PECs in Scotland is discussed here.

8.1 Economic potential to farmers and land managers

8.1.1. Economic potential of PECs in Scotland for farmer and land managers

Overall, the economic analysis showed Miscanthus could be most profitable over the life cycle, but though SRC and SRF broadleaves appear to achieve lower profitability, there are larger areas suited to these crops and less uncertainty about their suitability to the Scottish climate.

Achievable biomass yields, which significantly influences economic viability, is still subject to some uncertainty as commercial growing and trials in Scotland are limited, particularly for SRF and Miscanthus. The analysis shows a significant difference between high, medium and low costs and income from the three PECs considered. It could be reasonably assumed that this level of uncertainty may lead to farmers and land-managers having low confidence to plant the crops. Forthcoming results of Scottish research trials and developments may improve confidence, for example Miscanthus varieties more suitable to Scotland's climate are in development (see Appendix H) which could extend the range or improve yields in Scotland.

Equipment needs, and therefore costs and economic potential, vary for the different PECs:

Miscanthus can be harvested by typical harvesting equipment which an arable or mixed farmer would either own, or have easy access to via local contractors; whereas for SRC and SRF the equipment needs are more specialist, so requires significant investment or access to local contractors, which is currently constrained in Scotland.

The PESTLE analysis shows that, of the factors which are likely to prevent farmers and land-managers from currently viewing PECs as an attractive proposition and hinder the uptake across Scotland. The most important, are:

- the low or negative income from the crops,
- upfront investment requirement, and
- uncertain market for the crops.

Stakeholder feedback suggested some approaches which may addressing these issues:

- Financial support for farmers, land-managers and other necessary parts of the sector including to enable adoption of forthcoming innovations aimed at improving yields and cutting costs, such as new harvesting techniques and mobile machinery for processing materials on farms.
- Fixed price and long-term contracts for future crops, at prices higher than production costs. However, given imported biomass and fossil fuels appear to be available at lower cost it is unlikely that end-users will find it feasible to offer attractively priced contracts.
- Greater clarity over the likely environmental impacts in Scottish context – both local impacts such as on biodiversity and wider impacts for example indirect land-use change from competition for food / animal feed crops – and how to design of PEC planting in Scotland to maximise positive environmental benefits.

8.1.2. Locational and temporal issues

In terms of suitable and preferred locations for energy crop production in Scotland, as described in Section 6, the proximity to biomass markets (such as power plants) is a key determining factor. The research has shown that there are suitable growing regions, primarily for SRC and SRF within 50km to 100km of existing biomass plants, or potential sites for BECCS plants close to the proposed east coast feeder pipeline, which are likely to be the dominant market demand in a future, more mature biomass market aligned to the Scottish Governments climate ambition. There is some uncertainty about the economically viable distance to transport energy crops, with stakeholders suggesting it would be significantly less than the typical 100km for sawmill quality wood. The number of viable production areas with 50km of potential sites is lower, but they are most advantageous due to lower transport costs (and GHG emissions).

The study did not explore in detail the potential for on-farm use of biomass, but stakeholder consultation suggested this may be an economically viable alternative, particularly for farms not located close to a suitable biomass plant, and given the context of high energy costs. On farm use of PECs is not a negative emissions technology, as it is not feasible to apply carbon capture to small scale plants, but it would contribute to decarbonising agriculture if it replaced fossil fuel use for power and heating in farm buildings.

Looking ahead, if demand for biomass grows in Scotand, UK and elsewhere as countries expand BECCS capacity the market prices for PECs may change. Input costs can also vary significantly. It is beyond scope of this research to deliver a full analysis of future scenarios for the market, or local market dynamics related to specific BECCS sites, but it is clear from the range of profitability demonstrated in Section 5.1, that a range of scenarios should be planned for.

Interactions between PECs and adjacent land-use and wider landscapes and ecology was shown to be an important location factor to consider. Impacts could be beneficial, such as shading / shelter for livestock and to reduce wind exposure for adjacent crops, or could be negative depending on local landscape features, for example reduced yields in adjacent crops due to shading. Positive potential biodiversity impacts have been suggested by some stakeholders, such as habitat for birds, mammals and beneficial insects if edges between PEC and other land-use is maximised, but there was also concern about negative consequences of land-use change and monoculture PECs on biodiversity. Water management benefits also vary across the crops, and the lifecycle of the crops. The implication of the research is that the effective integration of PECs into natural landscapes and farming systems in Scotland to deliver maximum additional environmental benefits will require careful design in relation to the specific local environmental context.

A key issue for economic viability of PECs is the distribution of costs and income over time. Poor cashflow for farmers and land-managers is typical for PECs, because initial costs of establishment are not recouped until harvest after several years. The time from establishment to first harvest varies so the time where a farmer/ land-manager would likely experience cash flow challenges would also vary. The shortest time to first harvest was for Miscanthus, at around 2-3 years for full harvest with potentially a small harvest in the first year, SRC is typically 3 years for first harvest, and 6 years to first full harvest, and for SRF there is typically around 15 years till first harvest. Sequential planting can help create a more regular income because a portion of the crop would be ready for harvest each year. For SRC/ SRF this can be feasible if the harvesting equipment is already available on the farm, or the yearly harvest would be enough to warrant a visit from a contractor. For Miscanthus, there is an annual harvest once established so sequential planting of a portion of land intended for Miscanthus each year would allow for some of initial income to be used for subsequent planting reducing the size of initial outlay whilst increasing the area allocated to the crop over time.

8.1.3. Income diversification

Stakeholder comments suggest that the current levels of interest from farmers in diversification, including into crops with lower input costs and stable income, could be a significant enabler to the uptake of PECs. However, the economic analysis suggests that this would only be the case, if the core barriers around profitability, cashflow and financial risk were addressed.

8.1.4. Other factors influencing PEC uptake

The research found that farmer and land manager attitudes, habits, skills and perceptions, as well as those of the wider community are likely to be influential, alongside the economics, in determining the degree to which energy crops are adopted in Scotland. Low appetite for financial risk is a key preventative factor, with most farmers looking to reduce their exposure to risk and so only likely to be interested in energy crops if they are perceived as a low risk strategy in their own right, or a beneficial diversification of income as part of a wider business risk reduction strategy. The research suggests that, without clearer evidence of favourable market, price and productivity the current perception of these crops as relatively risky is unlikely to change. Concerns about competition with other crops, sustainability credentials, and public perception of the 'morality' of energy crops is also likely to influence farmers and land-manager attitudes. Alongside these factors, it was highlighted during the research that farmers often have a strong preference for their current farming enterprises and so may be reluctant to adopt new crops even if they appear financially advantageous and that a significantly higher financial return may be needed to persuade a shift to energy crops in these circumstances.

8.2 State of the evidence base and identification of any key gaps

The key gaps and debates in the literature were described in Section 4, and limitations in economic analysis in Section 5. The research shows a need for more robust evidence on potential yields, production costs and environmental impacts specifically for Scotland.

Quantification of potential wider farm benefits, such as shelter for livestock, and estimation of economic value of these benefits to farmers was not identified through this research, but could help create a fuller picture of the economic potential of energy crops for Scotland.

We found limited research on the risks for crop failure / poor productivity from pest, diseases, extreme weather which hampers full assessment of the financial risk exposure of farmers and land-managers associated with planting PECs.

This study has not included a detailed comparison of PECs for NETs with annual bioenergy crops and other bioenergy technologies, such as anaerobic digestion or smaller scale use of PECs on farms for direct energy generation. The REA and stakeholder feedback indicated potential for farmers to benefit from energy security and reduce energy costs if they were to utilise energy crops for their own energy generation. This study has not modelled the current economics of investment in relevant plant and ongoing cost: benefit of this scenario. This research would be potentially beneficial to understand how local small-scale use compares to larger scale use in NETs, and therefore fully understand the relative economic potential of PECs in Scotland.

The research found debates and discussions about how land should be used to fulfil societies various material needs (food, fuel, fibre etc.) and provide space for biodiversity and deliver other ecosystem services. To inform this debate various additional factors, beyond the scope of this research are relevant including the relative benefits of using land for PECs vs other types of renewable energy such as wind and solar energy. Stakeholders highlighted that solar, for example compares, well and there is growing interest in agrivoltaics – solar voltaic panels within agricultural land that may still retain some of its agricultural use such as livestock grazing.

9 Conclusions

Perennial energy crops have the potential to generate income for farmers and land-managers in Scotland.

- However, income is likely to be lower than they could earn from other farm enterprises, such as lowland cattle and sheep and 'mixed agriculture', that are typical on the types of land which may be suitable.
- The exception is where PEC profitability is compared to 'general cropping: forage' farming type (growing crops for animal consumption, usually on lower quality land) this activity typically makes a significant loss, so PECs compared very favourably in the analysis.
- for PECs to be viewed as an attractive, economically viable option by farmers and land managers there is a need for greater confidence that it will deliver good economic returns. The high upfront establishment costs for perennial energy crops and low revenue potential are both likely to hinder uptake.

9.1 Profitability of perennial energy crops based on gross margin calculations

If costs and income were spread equally over the lifetime of the crop and compared, PECs are less profitable than current farming enterprises, except for 'general cropping: forage' which is not typically making a profit.

- Of the three crops studied, Miscanthus showed the highest average gross margin at £382 per hectare per year but there are some potentially limiting factors:
  - uncertainty about achievable yields in the Scottish climate and on the grades of land above category 4.1 in the Land Capability for Agriculture in Scotland. If yields were lower, then profit may be lower.
  - Limited theoretical growing area in Scotland – much lower than for SRF or SRC based on analysis of land quality and characteristics and Scotland's climate.
- SRF and SRC showed lower profitability for farmers: £80 and £87 per hectare per year over their lifetime respectively for SRF: broadleaved and SRC, making them less attractive but there is more suitable land for growing these. SRF conifer would see a negative gross margin i.e., the production costs outweigh the value of the crop sold.

9.1.1. Potential opportunities

- The research also identified some potential positive attributes of PECs which might encourage uptake - PECs could help diversify a business, creating additional income, without adding significant additional labour requirements or ongoing input costs – minimal management time and inputs are required once crops are established.

9.1.2. Potential barriers

- Cash flow could pose a problem - the distribution of costs and income year-on-year for PECs is significantly different to typical farming activities which have an annual profit cycle. PECs need investment in site preparation and planting upfront, but income only arrives after first harvest several years later (2-3 years Miscanthus, 6 for SRC, 15 for SRF) and then only periodically after that.

- Coupled with uncertainty about market demand and achievable crop sale prices, the need for upfront investment to establish PEC production, means farmers and land managers may view them as a risky proposition and be reluctant to grow them.
- We identified other potential barriers to uptake, including farmer and land-manager unfamiliarity with PEC production, low appetite for risk, need for new skills, access to equipment and services, and concerns about community perception of land-use change and impacts on other agricultural production, e.g. available animal feed.

9.2 Enhancing economic potential and production of PECs

Potential approaches to improve economic potential in Scotland include:

- financial incentives, such as government specific subsidies under future agricultural support,
- risk reduction strategies such as secure, attractively-priced contracts with end markets, alongside expansion of the market.
- Innovations to allow processing at the farm and to improve transportability of crops could also help to increase the economically viable travel distance.

9.2.1. Implications for wider Scottish economy:

- Previous research suggests 38000 could be feasibly planted by 2032 (scenario one) and 90,000 by 2045 (scenario two).
- We found that, if land to match this level of demand, was utilised for perennial energy crops (using the scenarios as defined in section 5.2), it would create a gain in gross margin of around £9.6 million (scenario 1) or a loss of around £9.5 million (scenario two) across the regions.

9.2.2. Economically viable production locations:

Economically viable production locations for PECs are influenced by multiple factors including proximity to markets (current biomass energy plants and potential future BECCS plants) and local enough access to services and facilities for crop management (e.g. harvesting contractors) to avoid excessive costs.

- We identified suitable growing regions (some SRC/Miscanthus and most for SRF) within an economically viable transport distance to existing biomass plants and potential sites for BECCS near the proposed east coast carbon capture and storage feeder pipeline (assumed 50-100 km).
- As SRF is economically uncompetitive against current land-use, this suggests economic viability may be a barrier to PEC production increases even if suitable land is available.

9.3 Potential further steps

Key debates and areas for further research include:

- Considering more in-depth 'whole farm' economic analysis. This study focused on gross margin comparison, which is useful for comparing specific crops and farm enterprises, but has limitations in terms of how well it allows assessment of integration of energy crops into a whole farm business. This will vary farm to farm but could be explored through farm case studies. This could include considering a wider range of costs for farmers and that after initial set up the PECs would require less workload.
- Comparing, the economic and environmental potential of using land for energy crops with utilising the same land for other renewable energy options (for example using the land for solar panels alongside grazing) and
- Potential role for on-farm use of perennial energy crops.
- Considering future biomass markets, including how future Greenhouse Gas Removal (GGR) schemes, global demand and demand from biotechnology sector may impact it.
- Identifying how to make domestic biomass from energy crops a more attractive option than imports and a more profitable use of land, and on what basis this can be justified. For example, taking account of full LCA and rewarding greatest emission saving.
- Considering in more detail the role of PECs in the context of how the agriculture sector is changing and how it may have to change to reduce GHG emissions.
- Considering the value, including the financial value, of other benefits of energy crops, such as flood mitigation or animal shelter, relative to existing or potential alternative land-uses.
- Exploring how PECs support/interact with tier 2 or 3 objectives of the ARP.
- Considering the impact of subsidies.

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11 Appendix A: Policy Context for Energy Crops in Scotland

11.1 Climate Change Policy

The Update to the Climate Change Plan (CCPu)[27], published by the Scottish Government in December 2020, whilst focused on reducing emissions, identifies the need to also remove carbon dioxide from the atmosphere to compensate for residual emissions. It foresees a role for technologies to achieve a net reduction in emissions – often referred to as Negative Emissions technologies (NETs). It identifies several NETs pathways with potential in Scotland, including bioenergy with carbon capture and storage (BECCS). Climate Committee's (CCC) 6th Carbon Budget sets out that achieving the required scale of BECCS will necessitate a significant increase in the domestic production of biomass feedstocks[28].

The CCC's 2022 review of Scotland's progress[29] highlighted that Scotland's planned deployment of NETs was ambitious, comprising two thirds of UK government overall ambition for 2030, but also notes the advantage of Scotland's large land area and potential to draw on substantial biomass stocks. It recommends consideration of the impacts and interactions that increased domestic biomass production could have on land use and agriculture. The Scottish Government has acknowledged that these targets can't be met – the NETs feasibility study gives more realistic targets[30]. Failure to meet NETs targets for Scotland implies deeper emissions reductions in harder-to-decarbonise sectors, such as aviation and agriculture, and so it is critical to consider how farmers and land-managers can deliver the necessary biomass feedstocks. The CCPu includes a proposal to develop rural support policy to enable, encourage planting of biomass crops within broader measures on sustainable, low carbon farming[31]. The CCC recommends maintenance and enhancement of support for agroforestry[32], and a target of 5% trees on farmland by 2035.

11.2 Agricultural policy

Scottish Government's Vision for Agriculture recognises the essential role agriculture has in delivering sustainable food production, climate adaptation and mitigation, biodiversity recovery and nature restoration and proposes that future subsidy support for agriculture will be split across unconditional support and support targeted to environmental outcomes, including low carbon farming and biodiversity The new Scottish Agriculture Bill as introduced to parliament on 28th September 2023 provides a replacement for the Common Agricultural Policy (CAP) and has been drafted to provide the required powers and framework to deliver the Vision for Agriculture. The bill would require Scottish Ministers to prepare a five-year Rural Support Plan for farming, forestry, and rural development. The

[27] Securing a green recovery on a path to net zero: climate change plan 2018–2032 - update - gov.scot (www.gov.scot)
[28] The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf (theccc.org.uk)
[29] https://www.theccc.org.uk/publication/scottish-emission-targets-progress-in-reducing-emissions-in-scotland-2022-report-to-parliament/
[30] Supporting documents - Negative Emissions Technologies (NETS): Feasibility Study - gov.scot (www.gov.scot)
[31] Update to the Climate Change Plan 2018 - 2032: Securing a Green Recovery on a Path to Net Zero (www.gov.scot) p. 193
[32] Agroforestry is the practice of planting trees, usually to produce a crop of food or wood products, on farmland in combination with arable or livestock farming, often in small patches or strips with fields.

Agricultural Reform Route Map (ruralpayments.org) sets out the milestones and timescales for change. The Agriculture Bill and Rural Support Plan will have implications for how economically viable it may be in future for farmers and land-managers to grow energy crops. Whilst the details are yet to be confirmed, it is clear that any expansion of perennial energy crops will need to take these policy developments into account.

11.3 Other key policies:

Principles of 'just transition' are defined in legislation[33] and Scotland's draft 'Energy Strategy and Just Transition Plan'[34] was published in January 2023. It describes Scotland's aim to use bioenergy where it can best support Scotland's Net Zero Journey, and aligns with and supports Scotland's goals for protecting and restoring nature. It contains a commitment to review the potential to scale up domestic biomass supply chains. Bioenergy crops, if economically viable, could offer the agricultural sector a new income stream and support the rural economy, which would be consistent with the draft plan. The draft plan also includes a proposal to develop a strategic framework for the most appropriate use of finite bio-resources (published in a Bioenergy Action Plan), acknowledging the potential for competing demands on land and natural resources. CCPu also acknowledges the need for open a discussion on optimum land uses beyond just farming and food production to multi-faceted land use including forestry, peatland restoration and management and biomass production.

11.4 UK biomass policy context

The UK Government's Department for Energy Security and Net Zero (DESNZ) published a Biomass Strategy in August 2023 which set out the Government's view that well-regulated BECCS can deliver negative emissions and ensure positive outcomes for people, the environment, and the climate. It commits the UK Government to strengthen sustainability criteria and verification processes for biomass, acknowledging challenges with international supply chains, and creating a cross-sector sustainability framework for biomass (subject to consultation). The focus will be on addressing greenhouse gas emissions, indirect land-use change, and potentially soil carbon changes. The strategy anticipates a key role for both domestic and imported biomass use across the economy, on a limited timescale. It also sets out how the government is actively developing demand side policies to support emerging technologies such as BECCS and Greenhouse Gas Reduction (GGR) business models, for example the potential for a 'Contracts for Difference' (CfD)[35] approach. The strategy acknowledges that bioenergy policy involves a mix of reserved and non-reserved powers, and

[33] The just transition principles are defined in the Scottish legislation as:
'the importance of taking action to reduce net Scottish emissions of greenhouse gases in a way which:
a) supports environmentally and socially sustainable jobs,
b) supports low-carbon investment and infrastructure,
c) develops and maintains social consensus through engagement with workers, trade unions, communities, non-governmental organisations, representatives of the interests of business and industry and such other persons as the Scottish Ministers consider appropriate,
d) creates decent, fair and high-value work in a way which does not negatively affect the current workforce and overall economy,
e) contributes to resource efficient and sustainable economic approaches which help to address inequality and poverty.'

[34] Draft Energy Strategy and Just Transition Plan (www.gov.scot)

[35] A Contract for Difference (CfD) is a private law contract between a low carbon electricity generator and the Low Carbon Contracts Company (LCCC), a government-owned company. Contracts for Difference - GOV.UK (www.gov.uk)

so as the Scottish Government develops its draft Bioenergy Policy Statement, Scotland has an opportunity to build on UK policies and develop policies appropriate for Scotland.

13 Appendix B: Introduction to Perennial Energy Crops

13.1.1. Introduction to Miscanthus

Miscanthus is a tall perennial grass with woody canes like bamboo, of East Asian Origin. The most common variety of Miscanthus grown is the sterile hybrid *Miscanthus x giganteus* (*M. giganteus).* Miscanthus is a renewable source of fibre which has a wide potential range of uses as biomass or fibre. Whilst Miscanthus can be grown in parts of Scotland, it is not currently grown at commercial scale and further trials are required to verify its potential future contribution (Meek et al., 2022). Nonetheless, Martin, et al 2020 found 51,800ha of land is theoretically suitable in Scotland to grow Miscanthus which could produce 2.59TWh/yr and 0.52Modt/yr.

To grow, the crop must be established by planting pieces of rhizome (underground plant stem capable of producing the shoot and root systems) which have been collected from fields where Miscanthus is already established[36]. Prior to planting, site preparation may typically involve breaking up compacted soil, removing weeds (using herbicides), ploughing to 30cm depth, then further levelling and soil cultivation to create a fine level soil to around 15cm[37]. Equipment which is typically available on an arable farm can be used for this site preparation and planting. Planting using specialist equipment achieves best results, but a potato planter could alternatively be used[38]. Biodegradable plastic film to prevent frost damage and retain moisture and fencing to prevent rabbits damage can improve success of crop establishment. Once planted, some gap filling might be needed (done manually) and chemical weed control in the first year or so. Fertilisers are not usually needed. After the first year the material is cut back and left in the field. In year 2, depending on the growth rate, there will be a small harvest, or another cut back. Once established a Miscanthus crop is harvested annually, usually in early spring when moisture content is lower, and can be productive for around 15 years. The material is baled, or sometime chipped, to enable easier transport and storage. Sometimes drying is required in storage (natural or mechanical ventilation). At the end of the crop lifetime, to revert the land to other uses, a herbicide is often used to kill Miscanthus shoots and rhizome, followed by ploughing.

13.1.2. Introduction to short rotation coppice[39]

Short Rotation Coppice (SRC) commonly consists of high-yielding varieties of either poplar or willow, densely planted on a piece of land. The solid, woody biomass provides a source of biofuel that is either used alone or combined with other fuels to power district heating systems and electric power generation stations[40],[41]. It was noted previously by Martin et al. (2020), that the production of energy crops in Scotland has in the past been limited, with only SRC currently grown at small commercial scale (250ha). There is greater potential for further SRC cultivation in Scotland provided that suitable land area is available.

Most types of land, except for heavy clay soils and water-logged land, are suitable for SRC. The initial steps to establishment include removing weeds using herbicide, ploughing to 30cm

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[36] Teagasc- Miscanthus Energy Crop Miscanthus Energy Crop - Teagasc | Agriculture and Food Development Authority

[37] Sustainable Bioenergy Feedstocks Feasibility Study report for the Department for Business, Energy and Industrial Strategy (BEIS) published in 2021

[38] Miscanthus Growers' Handbook (forestresearch.gov.uk)

[39] Sustainable Bioenergy Feedstocks Feasibility Study report for the Department for Business, Energy and Industrial Strategy (BEIS) published in 2021

[40] Short rotation coppice (SRC) – Crops4energy

[41] Short rotation coppice establishment – Forest research

and further cultivation to 15cm. Rods or cuttings are planted with a specialist planter. Gap filling and protection using rabbit or deer fencing may also be needed. During the first year weed control using herbicides and control of plant diseases using pesticides may be needed. Once established, SRC plantations are typically harvested at 3-year intervals using a forage harvester with a specific cutting system, then chipped and stored outside on a concrete base or in the field. Plantations typically remain productive for 15-25 years[42]. After this, a new planting can be established, or the field reverted through a process that involves stump grinding and the application of herbicides to prevent regrowth.

13.1.3. Introduction to short rotation forestry

Short rotation forestry (SRF) involves planting relatively fast-growing tree species and harvesting them for biomass after around 15-20 years, which is much quicker than conventional forestry. Species can be coniferous (e.g., Sitka spruce, Douglas fir) or broadleaved (e.g., aspen, poplar, silver birch, downy birch, sycamore). SRF is not currently operated commercially in Scotland although there are some trial plots. Nonetheless 912,600 ha of suitable land is theoretically currently suitable for planting of SRF in Scotland (Martin et al., 2020). Limited, recent literature material and evidence was found in the REA relating to the economic potential of SRF in and around the UK.

Process steps are like conventional forestry: the plantation is grown from seedlings or cuttings, or sometimes direct seeding, into land prepared through steps such as drainage, ploughing, and fencing. Some weed control or replacement planting may be needed initially, but after this limited maintenance is required. All the trees in a growing area are harvested at the same time using specialist cutting equipment, then either cut into lengths and stacked to air dry ready for collection or chipped on site. With SRC the shorter rotation, and the higher planting density, reduces the potential for co-production of logs for sawmill timber[43]. After harvest the site can be cleared, using machinery and herbicides as per SRC and then replanted or reverted to other land-use. Alternatively new stems can be allowed to regrow for coppicing, or a single good stem selected to continue growing for harvest after 15-20 years. Broadleaved varieties tend to produce higher wood density which is advantageous for use as bioenergy.

[42] As above
[43] Feedstocks innovation study task 1 report

14 Appendix C: Methodology to Rapid Evidence Review

The Rapid Evidence Assessment (REA) methodology used for this project aligns with NERC methodology[44] and comprised of the following steps.

1. **Define the search strategy protocol, identify key search words or terms, define inclusion/exclusion criteria.** A list of key words, terms and search strings was created and reviewed by Ricardo's bioenergy and agriculture technical experts and the project steering group to direct the REA review to the most relevant sources. This list was and divided into six relevant categories 'Energy Crops'; 'Economic potential'; 'Farm business and agronomic considerations'; 'Preferred/feasible locations'; 'Agricultural & land-use options'; 'Other considerations e.g., just transition, decarbonisation' to ensure that all appropriate aspects of the economic potential of energy crops were identified which supported the focus the review. Any literature that is considered out of scope based on our list of assumptions was excluded from the search. We also excluded literature that is older than 10 years, unless it was from a credible source and was the only piece of evidence available (particularly for data).
2. **Searching for evidence and recording findings.** Literature was searched using Google Scholar and Science Direct, utilising our accounts with Science Direct and Research Gate to access restricted pdfs where required. Grey literature, such as farming press and industry reports were used to provide examples and case studies of the economic potential of energy crops. In addition to the search engines, two existing evidence reviews, prepared by Ricardo were used to sources relevant literature: 'Evidence review: Perennial energy crops and their potential in Scotland' and 'Evidence review: Increasing Sustainable Bioenergy Feedstocks Feasibility Study'. Academic paper 'Greenhouse Gas Removal Technologies –approaches and implementation pathways in Scotland' (Haszeldine et al, 2019) was also provided to us to supplement our evidence base. For each individual search a unique search reference was assigned, the date, search string used, total number of results found, and the total number of relevant papers found were recorded. Our search strings can be found in the table below.

TableA-1: Search strings used for REA

"Perennial energy crops" "Scotland"
economic potential bioenergy crops Scotland
"Perennial energy crops" "farm level" "Scotland"
"Short rotation coppice" "economic potential" "Scotland"
Miscanthus energy crop Scotland
"Miscanthus" "economic potential" "UK"
economic potential "short rotation forestry" Scotland
economic impact short rotation coppice Scotland
profitability short rotation coppice UK
profitability short rotation forestry UK
farmers weekly economic potential of perennial energy crops
"short rotation forestry" "UK" "profit"

[44] https://nora.nerc.ac.uk/id/eprint/512448/1/N512448CR.pdf

revenue + perennial energy crops Scotland
Short Rotation Forestry Trials in Scotland Forest Research
short rotation forestry for energy "willow" "poplar" "economics"
perennial energy crops "operating costs" "UK"
hemp energy crop economics Scotland

All results were recorded in an excel spreadsheet with information extracted on the following:

a. Country
b. Type of energy crop (SRC, SFC or Miscanthus)
c. Additional information on crop type
d. Scale of deployment
e. Positive economic potential
f. Negative economic potential
g. Issues/barriers of deployment (non-economic uptake considerations)
h. Temporal considerations (e.g., agronomic/climatic conditions)
i. Further economic potential (e.g., decarbonisation of agricultural practices and creation of new jobs)

A RAG (red, amber, green) rating was assigned to each source, based on the g criteria:

Description	Rating
Quality	
Peer reviewed journal, sound data sources and methodology	Green
Government funded research reports, sound data sources and methodology	Green
Research funded by NGOs (e.g., AHDB), sound data sources and methodology	Amber
Work is unreliable because of unreliable data sources, or limited sources, or because the method is not robust	Red
Information from websites, blogs etc., of unknown quality	Red
Relevance	
Timeframe: within last 10 years	Green
Timeframe: within last 20 years	Amber
Timeframe: older than 20 years	Red

3. **Screening.** Sources of evidence was then screened initially by title and then accepted papers were then screened again using the summary or abstract. Literature was screened for information on the following inclusion criteria:
   a. SRC, SRF, Miscanthus (and hemp / alternatives if strong evidence to show economic viability)
   b. Economic potential (positive and negative) of energy crops – qualitative and quantitative information
   c. How farmers / land-managers are making decisions about which enterprises and land-uses to adopt and research which provides evidence of likely preferences and decision-making influences.
   d. Agronomic or other considerations which would influence viability / adoption by farmers / land-managers.

4. **Extract and appraise the evidence.** The screening provided an organised list of papers which enabled evidence to be extracted directly from the literature into the report. Literature extracted also guided the internal workshop and supported information included in the SWOT and PESTLE tables.

15 Appendix D Evidence of positive economic potential

We found some evidence in literature that PECs can be profitable for farmers and land managers, but limited studies directly applicable to Scotland and to the current economic climate. The price of fuels and other agricultural inputs have been subject to significant rises and fluctuations since most studies were undertaken and studies were mostly in locations with different growing conditions to Scotland. Economic performance of biomass production is influenced by production costs, crop yields, crop price and end-use/market opportunities (Olba-Zięty et al., 2021).

Several studies comparing energy crops reported a high return per hectare for miscanthus, (Martin et al., 2020, Zhang et al, 2020). One reason for this is that miscanthus can produce high outputs from low inputs which is economically significant for farmers (Donnison and Fraser 2016), particularly in the current context of high agricultural input costs. Miscanthus is attractive as it requires few farm operations, has low labour needs, crop management is straightforward and existing farming machinery and skills can be utilised in its production (Shepherd et al., 2020a and Glithero et al 2013) thus improving its economic potential in comparison to annual crops (such as cereals) used for energy. Growers invest in miscanthus due to this low maintenance cost along with the low requirement for field operations (Shepherd et al., 2020). However, Mola-Yudego et al., (2014) in a Swedish study found SRC willow had the lowest production costs overall, compared with other energy crops (miscanthus, reed canary grass and triticale). The production costs, and therefore profit, will vary depending on equipment available on farm (Ostwald et al,2013a).

The tree species chosen for SRF influences plantation establishment costs and therefore enterprise profitability - costs vary between species: Hybrid Aspen requires a costly micro-propagation technique, and so is more costly to establish than Poplar (Tullus et al., 2013). The literature did not provide detailed information on how well-suited different species are to the Scottish climate and the expected yields of biomass in Scotland. Initial indications from trials currently underway in Scotland (Parratt, M, 2017) suggest Hybrid Apsen appears to have most potential, with common alder, silver birch and Sitka spruce having potential at some sites, but full assessment of biomass is not complete and economics are not assessed.

A farming press example of a grower for Terravesta, the major purchaser of Miscanthus in England (Davies, in Farmers Weekly, 2020), reported that for Miscanthus, an average net profit of £530.85/ha over a 15-year period based on a mature yield of 14/t/ha was achievable. Stakeholders interviewed for this study indicated that Miscanthus is still economically viable under this growing model in England, despite current economic conditions, but questioned whether this yield, which would be a key determinant of profit, is feasible in Scottish growing conditions.

15.1 Evidence for negative economic impacts

The most prominent evidence of negative economic impacts in the literature was the high upfront cost to establish PECs, lack of established markets, and the uncertainty over the stability of the long-term market (Martin et al., 2020 and Witzel and Finger 2016).

Profitability and economic considerations for farmers are dominated by these costs, market dynamics and biomass yield (Zimmermann et al., 2014).

High establishment costs and uncertainties about the market, mean that farmers may perceive PECs as financially risky and are discouraged from growing them (Witzel and Finger 2016, Zimmermann et al., 2014, Hastings et al., 2017). Previous farm-scale modelling was conducted to improve the understanding of the potential economic PEC supply across the UK. The results concluded that without increases in market prices, SRC willow would likely only provide a small proportion of the UK's PEC target (Alexander et al., 2014). Similar studies were not found for SRF and Miscanthus, and the economics will have changed since this study making it difficult to understand from the literature if this is still the case but it is clear market access and price is a key issue.

In relation to Scotland specifically, the research found that high initial capital investment and a delayed period of revenue are major factors that negatively influence economic potential of PECs. Farmers receive no income from crop sales in the first years after establishment of PECs leading to poor cash flow, which can be an obstacle preventing farmer uptake (Bocquého, 2017). This period before first crop sales varies: typically 2-3 years for miscanthus production (Martin et al. (2020), around 4 years for SRC (Warren, 2016), and 10-20 years for SRF (Martin et al., 2020, Tullus et al., 2013), meaning a farmer may be waiting several years before the crop breaks even, for example miscanthus typically breaks even after between 4 and 11 years (Martin et al 2020).

15.2 Economic potential of PECs, in comparison to other crops

The literature review did not provide clear evidence of how the three key PECs being studied here compare economically to other crops, annual crops and agricultural land-uses – some studies showed favourable comparison and others did not. Key studies are highlighted below, but limited insights can be gained on this question from the literature given the recent economic changes affecting agricultural costs and market prices. See Section 5 for a comparative analysis reflecting current economic situation. Petrenko and Searle (2016) found the profitability of miscanthus and SRC to be competitive, with oats in the south of England, and with oats and rye in Southern Germany and, but could not compete with wheat in Europe generally or typical arable rotations in France (Glithero et al., 2013). Lower input costs may mean that PECs are more competitive now, than arable crops which typically require high levels of expensive inputs (such as fuel, pesticides and fertiliser), but literature does not confirm this. Glithero et al (2013) showed miscanthus to have lower biomass production costs (calculated as cost per gigajoule of energy) in comparison to straw-based crops in England. Busch (2017), in Germany, found SRC to be financially superior when compared to three different crop rotation systems consisting of oilseed rape, wheat, barley, and maize crops, concluding that SRC can compete against annual crops provided proper site selection and a suitable market (in this case, wood chip production). Mola-Yudego et al., (2014) highlight research in Northern Ireland which showed similar gross margin to grain production, assuming average yields in both cases.

We did not find research which compared energy crop economics with livestock farming systems economics.

15.3 Influences on farmer and land-manager decisions on planting PECs

One of the main factors affecting the uptake of PEC is economic profitability (Olba-Zięty,2021). Appetite for and perception of financial risk, skills, attitudes and access to markets can also influence farmer and land-manager decisions about planting PECs. Evidence from the literature, and our research interviews with stakeholders suggests that even where PECs, or energy crops in general, can deliver positive economic results for farmers and land managers, this on its own is not always sufficient to convince them to start growing PECs. A choice-experiment study in Sweden, found that lower production costs can enable farmers to achieve higher profit from energy crops, in comparison the traditional crops, but that further compensation of up to 215 Euro per hectare would be needed to persuade a farmer to switch to SRC (Ostwald et al,2013a).

A study by Warren (2014) on farmers' attitudes to PECs in south-west Scotland found that farmers perceived growing SRC to be 'financially risky'. SRC production was associated with uncertain returns on harvested wood as prices can be volatile. A lack of access to local markets was also highlighted as a potential barrier to current market adoption by producers (Alexander et al., 2014).

15.4 Other economic features of PEC production which influence economic potential for farmers and land-managers in Scotland

Producing PECs has specific economic implications for growers which influence their economic potential and attractiveness. These include challenges: lack of flexibility of land-use, reduced market responsiveness; and opportunities for diversification alongside current farming enterprises.

Unlike with annual arable crops, miscanthus producers can't maximise profitability by changing crop each year to react to market prices (Hastings et al. (2017). The implication of this, which was highlighted during stakeholder interviews, is that to view PECs as economically worthwhile, farmers need confidence that they can achieve an acceptable and secure market price into the future. Long term production contracts between private biomass processors/plants and farmers are an important consideration in managing financial risk for producers (Bocquého, 2017). Stakeholders highlighted that joined up contracts including harvesting and haulage services, currently being used for some crops, can also help reduce risk and simplify the economics for producers.

The literature review suggested that the way PECs are deployed on farms influences their economic potential. Integration of PECs alongside other enterprises and on land which is not performing well could be advantageous. Glithero et al., (2013) reported that when integrated as a diversification enterprise on-farm miscanthus can be highly competitive. Less productive land, for example poor agricultural land with insufficient returns for food crop, is suitable for miscanthus (Shepherd et al., 2020a), which implies it could provide an economic benefit if deployed on this type of land within a farm.

Brown et al., (2016) report that introducing SRC into traditional cropping systems allows producers to diversify their farming operation, which in turn enhances income, improves income security and reduces risk. Alexander and Moran., 2013, similarly found a portfolio of crops including conventional crops, alongside Miscanthus has been found to achieve a more stable income for farmers, and furthermore conclude that, as farms typically operate in a risk-averse manner, reduced risk is an important factor in farmer decision-making for PECs.

The economic potential of SRC is largely dependent on the establishment of strong markets and demand driven by power companies (Brown, 2016). In the UK, it is generally found that further development of energy cropping only occurs once a plant has been built and several farmers adopt SRC practices to supply crops for that plant (Alexander et al., 2015).

15.5 Opportunities to improve economic potential of PECs in Scotland

Cultivation techniques, crop variety choice and other technological developments can influence economic potential of PECs in Scotland and have potential to improve profitability for farmers and land managers in future. For example, the use of plastic mulch film to reduce establishment time can improve crop economics (Hastings et al. 2017). Introduction of new and seed propagated hybrids of Miscanthus alongside agronomic developments have been projected to significantly reduce the cost of Miscanthus production. Mobile briquetting of Miscanthus can also increase the economic potential of Miscanthus (Perrin et al., 2017). Through the Biomass Innovation Fund, £32 million of research funding was awarded to innovation projects across the UK to deliver 'commercially viable innovations in biomass production. Several innovations have potential to improve yields and reduce production costs for Miscanthus in Scotland, including efficient and mobile harvesting equipment and development of new cultivars more suited to colder climates (see Appendix F).

The literature review and stakeholder interviews both highlighted some factors which can negatively affect the economics of PEC production, which if addressed are potential opportunities to improve economic performance. Gaps in the crop (patchiness) was a key factor reducing profitability of miscanthus in the UK, resulting in longer payback periods. Tackling this by addressing issues such as planting technique, bad rhizome quality, poor overwintering, or variations in the soil quality helps maximise crop yield and improve farmer income (Zimmermann et al., 2014). Ensuring access for harvesting equipment is essential for economics of SRF to be viable – ensuring areas planted are on slopes not more than around 20 degrees is important to ensure the economic benefits of mechanised harvesting can be accessed (Martin et al 2020). For SRF effective plantation establishment is important for the economics and general success of a SRF plantation, yet our research did not find clear consensus on how to achieve this: Tullus et al., 2013 found low planting density was preferred amongst producers to minimize establishment costs, although impact on yield is uncertain in the literature. Research also found that single species monocultures can offer greatest economic return by providing higher yields per hectare (Liu et al., 2018), highest yield are achieved on fertile soil (Tullus et al., 2013) or under intensive management systems, including weed control, fertilizer application and irrigation (Walle et al., 2007).

15.6 Evidence of potential for Scotland's wider economy

There was limited research addressing the potential contribution to the wider Scottish economy and a just transition, but some opportunities and challenges can be inferred. These include sales for local energy generation and other industrial uses, employment opportunities in contract services, along with potential payments for environmental outcomes. The requirement for contractors and local services during annual Miscanthus harvesting presents employment opportunities (Martin et al., 2020), as does SRF planting and harvesting (Liu et al., 2018). Depending on the existing farm enterprises, and choice of PEC, the workload for PECs may fall at a different time of year to other peaks in labour demand, helping to spread labour requirement through the year and reduce overall labour requirement. This could make farming more economically viable on farms which rely on family labour or very small workforces and reduce seasonal labour demands.

In addition to being used as BECCS feedstock, PECs have other potential uses and markets. Miscanthus can be sold for animal bedding, thatching, paper production, horticulture, construction materials[45], and biodegradable plastics (Anejionu and Woods 2019). There has been research on using Miscanthus as a feedstock for fermentation to transport fuels or through anaerobic digestion (AD) to biogas (Witzel and Finger, 2016). Miscanthus for AD has been found to be uneconomical according to Whittaker et al.(2016). Our stakeholder interviews confirmed that farmers would benefit more from growing feedstocks tailored to AD if this is their desired market, yet Winkler et al. (2020) reported significant potential for additional income from biogas production.

SRF and SRC, (when processed into woodchips) can provide a fuel source for biomass boilers and CHP units on-farm and for local domestic or other use[46] (Spackman, 2012, Ranacher et al., 2021). This can be an alternative market to diversify income sources and also potentially save farmers money on their own energy bills. The literature did not provide details on the economic implications of this but the stakeholder interviews flagged that farmers are currently interested in exploring opportunities to cut energy bills. Miscanthus was also identified to be used in small scale CHP plants on-farms for heating buildings and for domestic uses such as wood burners[47].

Beyond selling the biomass from PECs as a product, the literature reviewed suggested the potential of PECs to deliver environmental and ecological benefits which could potentially be monetised. SRC and SRF are currently not eligible for carbon credits, and it is unlikely that PECs can provide evidenced carbon storage in biomass or soils in order to qualify under other certification schemes. There may be opportunities to gain economic benefit from

[45] Teagasc Miscanthus best practice guidelines Miscanthus_Best_Practice_Guidelines.pdf (teagasc.ie)
[46] Energy crops need support to fulfil potential – Farmers Weekly
[47] DEFRA Area of crops grown for bioenergy in England and the UK Area of crops grown for bioenergy in England and the UK: 2008-2014 - GOV.UK (www.gov.uk)

flood protection and biodiversity benefits that some PECs can deliver – the research has not identified significant information on this.

15.7 Evidence of non-economic opportunities

Non-economic opportunities and benefits of PECs were identified during the research, including several relating to positive environmental outcomes such as reduced agro-chemical use and biodiversity. All three PECs investigated require less chemical inputs, and reduce soil and water pollution (McCalmont et al., 2017). They also sequester carbon, for example miscanthus has a carbon mitigation potential of 4.0–5.3 Mg C ha-1 yr-1 (Zimmermann et al., 2014). Conversion of agricultural land to SRC leads to a reduction in management intensity of the land, resulting in potential soil benefits (Schiberna et al., 2021). The impacts of SRF may be positive or negative depending on what the land was previously used for. Soil compaction and disturbance caused by the harvest of SRF can lead to erosion and a loss in soil organic matter (Martin et al., 2020). Impacts may be neutral or possibly negative if conversion of land is from pasture or native forest to SRF (Griffiths et al., 2019). However, if displacing arable production, SRF has been reported to improve soil stability (Martin et al., 2020) with the potential to have positive effects on carbon soil organic carbon, water retention and erosion rates (Griffiths et al., 2019). SRF can also help flood alleviation as a SRF plantation would slow the rate of water flow (Martin et al., 2020).

The opportunities for biodiversity improvements resulting from PECs vary depending on planting, prior land-use and landscape context. Miscanthus has been reported to have positive effects on biodiversity (Bourke et al 2014 and Berkley et al 2018) in comparison to arable cropping systems. Shepherd et al., 2020 found an abundance of wildlife in UK miscanthus fields which, apart from at harvest time is left undisturbed. However, the effects on biodiversity of large-scale plantations are unknown (Bourke et al 2014). The introduction of SRC sites within arable cropping systems has in some cases been found to enhance the presence of some pollinators (hoverflies, bumblebees and butterflies), which can benefit crop production. However, it should be noted that these benefits are highly context dependent (Berkley et al., 2018). Opportunities to increase bird populations and diversity is thought to increase if native species of SRF are introduced (Martin et al., 2020).

15.8 Challenges and deployment barriers

The research identified several non-economic challenges facing the production of PECs in Scotland, relating to skills, land-use commitment, compatibility with current culture and habits, farm businesses, perceived land suitability and environmental concerns. Deployment barriers for Miscanthus include the need for farmers to commit land for a long period of time, land quality, knowledge (Glithero et al 2013), profitability, time to financial return and social resistance relating to whether land should be used for energy or food production (Anejionu and Woods 2019). These barriers also apply largely to SRC and SRF: land committed towards SRC and SRF will be in production for several years and conversion back to arable and the removal of tree roots is challenging (Warren 2016). Additionally for SRF land conversion may be deemed irreversible as reversion to farming use may be prohibited by government regulations once SRF is planted, and the land will no longer be classed as agricultural.

Lack of access to specialist skills (including a shortage of trained foresters[48]) and to specialist contractors and machinery (e.g., for SRF mechanised planting machines was also identified as a barrier to deployment. The most likely cause of this is limited demand and a 'lack of off the shelf machinery'[49]. Whilst this could be seen as an opportunity for development of new infrastructure and employment opportunities, it could currently also be seen as a practical constraint for many producers. The establishment of SRC requires new skills and different machinery compared to conventional cropping, this unfamiliarity and technical lack of knowledge prohibits adoption by producers (Warren, 2014). Stakeholders who we interviewed suggested that there is increased interest amongst farmers in diversification, but that appetite for change was tempered by concern about moving into unfamiliar activities which require new skills.

Culture and attitudes can be a barrier to PEC deployment. Warren et al. (2016) found Scottish farmers opposed SRC (willow) production because they considered it was not suitable for their current farming business or the land. Whilst fertile land is best for SRF production, a study conducted by Walle et al., 2007 found that farmers willing to introduce SRF, are not willing to do so on their 'best agricultural soils'. Ranacher et al., 2021 found there is a gap in the available literature regarding farmers' willingness to adopt short rotation plantations on less productive land. Another potential barrier which may prejudice farmers against SRC cultivation is the cultural separation of forestry and farming in Scotland - SRC has historically been viewed as a threat towards the socio-cultural identity of Scottish agriculture (Warren, 2014). In addition, an Environmental Impact Assessment – something which farmers may not be familiar with and is likely to incur costs - may be required[50] if converting agricultural land to forestry for SRF or SRC (Martin et al., 2020).

Concerns about biodiversity identified included, concern about SRF reducing the habitat for ground feeding birds and other 'open land' wildlife (Martin et al., 2020).The winterhardiness of miscanthus is considered a constraint for this crop in Scotland (Martin et al., 2020), and according to stakeholder may reduce achievable yields.

From a biofuel perspective, as with all PECs, it has been noted in the literature that energy generation from biomass is a potential source of direct and indirect emissions, despite carbon being captured during crop growth. Production, transport and processing are potential sources of direct emissions (Alexander et al., 2015). Considerations to limit such emissions, for example distance from farm to biomass plant, must therefore be taken into account. Indirect emissions related to land use change are more varied in the literature.It has been noted that the establishment of SRC on peat/high organic soils, found in the upland areas of Scotland, can potentially harm soil organic carbon (SOC) levels (Martin, 2020) . Existing sustainability criteria for the use of biomass to produce heat or electricity

[48] Forestry sector workforce 'chronically under-resourced' | The Scottish Farmer
[49] Forest Research -Short Rotation Forestry Establishment Microsoft Word - TD Project Report FCS SRF DI SRMast v AJH.doc (forestry.gov.scot)
[50] Dependent on size of planting area and location in relation to National Scenic Areas and other sensitive areas – latest guidance available from Forestry Scotland. Scottish Forestry - Environmental Impact Assessments

require that PECs are not grown on land that was peatland in January 2008, or of high biodiversity value, and that any change in SOC from cultivation of PECs is taken into account when checking that the electricity or heat produced meets the relevant GHG saving criteria (see e.g. Ofgem, 2018 and Ofgem, 2021, Low Carbon Contracts Company, 2022).

15.9 Other relevant crops and planting regimes

Aside from Miscanthus, SRC and SRF there are other potential energy crops – both perennial and annual crops – which can be used for bioenergy and which are potentially suitable for Scotland. The literature reviewed above mostly considered planting of PECs as replacement for arable crops . There is also literature to suggest integrating PECs alongside existing land-use may be feasible and potentially relevant for Scotland. These alternative crops and planting regimes are considered here. Note that relatively limited research was carried outon these as the PECs above were the core focus of this study.

15.9.1. Hemp

Hemp was once widely grown in Scotland and suits both the climate and growing conditions in the main agronomic areas especially parts of the Borders, East Lothian, Fife, Angus, Moray and the Black Isle. Hemp has a significant potential in carbon sequestration and there is evidence to demonstrate its suitability as a feedstock for bioenergy production therefore, bringing a new 'cash-crop' to Scotland which would also offer new job opportunities[51]. Dogbe and Revoredo-Giha., (2022) found through a farmer's survey, that farmers identify diversification benefits i.e. planting hemp 'as a safety net' as a reason for producing hemp in Scotland. Biomass Connect technical article (2023), considering the UK as a whole, found hemp to have greater versatility and profitability than other biomass crops like Miscanthus, willow and poplar and high biomass yield (12-15t/ha of air-dried biomass). They also reported it to be an above-average energy crop for some biochemical-based biofuel production (in comparison to other similar yielding bioenergy crops)[52]. Hemp can also be used in bio-based building materials such as Hempcrete and textiles [53].

Hemp has the potential to provide high yields or returns with little or no pesticides and insecticides (Dogbe and Revoredo-Giha., 2022). It fits well into crop rotations with food and feed crops and helps improve soil structure and soil-borne pests. Constraints on producing hemp in Scotland includes the current lack of market as there are no large processing facilities in or near Scotland, strict regulations on growing hemp including, the need to obtain a costly license, and some reports of low profitability according to Scottish growers[54].

15.9.2. PECs in agroforestry systems,

Agroforestry is the planting of trees on farmland, alongside cropland or pastureland, usually in strips, clusters or scattered individual trees, that can be grazed or cultivated in between. The REA did not find specific studies focused on Scotland to show how PECs could be grown in agroforestry systems, but provided the design of agroforestry systems can allow for

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[51] Hemp Project | The Rowett Institute | The University of Aberdeen (abdn.ac.uk)
[52] Hemp-as-Biomass-Crop-1.pdf (biomassconnect.org)
[53] HEMP-30 catalysing a step change in the production - phase 1 report (publishing.service.gov.uk)
[54] Carbon-busting hemp could help transform Scottish agriculture to zero emissions (theconversation.com)

economically efficient planting, management and harvesting (i.e. still allow for machinery access), it could provide an advantageous model. Kralik et al., 2022[55] conducted a study to address the economic efficiency of agroforestry systems using SRC in comparison to conventional 4-year arable rotation, in Czechia. The results of this paper showed that the agroforestry system generate similar income and profits as the conventional annual crops when cultivating on appropriate sites and practicing good farming principles.

In terms of the scale of production which could be delivered through agroforestry, for the UK in general, Morris and Day (2023) estimated that 20% of UK farmland could transition to agroforestry by 2060. Utilising the aforementioned land area and yield data, the study observed three UK scenarios for SRC Willow. One scenario found where 30% of the yield arising from SRC Willow was used for bioenergy purpose and this would equate to 1.2 million tonnes of domestic wood fuel and therefore contribute significantly towards bioenergy needs and net zero.

[55] Agroforestry systems as new strategy for bioenergy — Case example of Czech Republic - ScienceDirect

16 Appendix E Methodology for economic analysis

16.1 Farm scale economic analysis

16.1.1. Calculating the gross margins for bioenergy crops

Step 1: Calculating the costs for the activities for the different types of bioenergy crops

Miscanthus, willow short rotation coppice (SRC), and short rotation forestry are the energy crops for which there is information that lets us build a baseline model that takes into consideration the different costs involved in the production process of these crops. We conducted an extensive literature review of the growing cycle for different crops, identifying the different steps for growing each of the crops and identifying the costs to undertake those actions. The costs used in our analysis are based on the costs that were used in the Sustainable Bioenergy Feedstocks Feasibility Study report for the Department for Business, Energy and Industrial Strategy (BEIS) published in 2021. This report carried out an extensive review of the available information for different types of bioenergy crops. Information was obtained through a literature review, which was supplemented by interviews with a range of key stakeholders, and expert insight from the project team. In addition, insights were gained through a review of development of SRC in Sweden, which has the largest planted area of SRC in the EU. A list of organisations consulted during the stakeholder analysis is given in appendix 2 of the Feedstocks Innovation Study report.

The three scenarios identified in the Feedstocks Innovation Study (low, medium and high-cost scenarios) were used in the analysis. This allows for some variation in factors that affect costs in agriculture and establish hypothetical scenarios that capture different combinations of costs. In the following sections, an overview of the actions and the costs are included for each of the three bioenergy crops;

- Site preparation / land preparation (including from different prior land-uses where data is available)
- Establishment / planting
- Crop management costs e.g., during initial growth
- Harvesting
- Reversion (where relevant)

For information on the assumptions on the costs please see the Feedstock Innovation Study.

Miscanthus

For Miscanthus, the cost of production is made up from a number of elements that will be grouped in four phases. The phases for growing Miscanthus are:

- Site preparation
- Planting
- Harvesting
- Reversion

Figure B-1 shows an example timeline of the Miscanthus growth cycle.

Figure B-2 Growing cycle for Miscanthus

	Year -1	Year 0	Year 1	Year 2	Every 3 years
Jan	Existing crop	Site preparation	Dormancy/Cut back	Dormancy	Harvest
Feb					
Mar					
Apr		Planting	Growth	Growth	Growth
May					
Jun		Gap filling			
Jul		Growth			
Aug	Site preparation				
Sep					
Oct					
Nov		Senescence	Senescence	Senescence/ Harvest	Senescence
Dec					

Table B-1 shows all the input costs for Miscanthus used in this study taken from the Feedstocks Innovation Study adjusted to 2023 prices using the latest GDP deflators[56]. As well as adjusting for inflation, fertiliser costs have been increased using the latest data from AHDB on fertiliser prices[57]. Using this data, costs for fertilisers were adjusted by comparing the average annual increase in fertilisers from 2019 to 2023.

Table B-1 Input costs for Miscanthus (2023 prices)

Broad action category	Cost element	**Unit**	**Lower**	**Medium**	**Higher**
Site preparation	Professional costs 1 (Advice on Environmental Impact Assessment)	£/ha	0	120	120
	Professional costs 2 (Advice on agronomy)	£/ha	0	0	28
	Soil sampling	£/ha	7	7	7
	Land rent equivalent	£/ha	0	0	0
	Clearance & ploughing	£/ha	89	97	106
	Total herbicide / insecticide + application 1	£/ha	57	57	69

56 GDP deflators at market prices, and money GDP March 2023 (Quarterly National Accounts) - GOV.UK (www.gov.uk)

57 GB fertiliser prices | AHDB

	Miscellaneous / risk to allow for unforeseen issues in land preparation	£/ha	0	61	180
Planting	Power harrow	£/ha	57	68	68
	Pest control incl. rabbit fencing	£/ha	0	0	341
	Rhizomes, planting, rolling	£/ha	1533	1987	2271
	Fertiliser + application 1	£/ha	18	61	67
	Total herbicide + application 2	£/ha	57	66	69
	Weed/spray	£/ha	84	93	102
	Miscellaneous / risk to allow for unforeseen issues during planting	£/ha	0	57	142
Harvesting	Mowing / cutting	£/ha	79	85	97
	Baling (at £12/wet tonne)	£/t	12	14	17
	Loading, stacking, storage (at £2/wet tonne)	£/t	2	2	5
	Fertiliser + application 2	£/ha	25	157	229
	Miscellaneous / risk 2 to allow for unforeseen issues during havesting	£/ha	0	0	102
Reversion	Reversion costs (herbicide + plough)	£/ha	145	153	174
	Overall Total		**2143**	**3025**	**4105**

The broad action category: site preparation category includes costs of establishment. The establishment phase involves preparing the soil for the new crops, acquiring all the plant material, weed control, and planting the crops. In the production phase, the crops are matured and harvested throughout the years. This is the longest phase as it repeats for every harvest and includes all processes related to harvesting and regrowing the crop. The third phase will be reversion, when the plant material is removed, and the field is made available for a new crop (see Figure 13-1).

There are variabilities and uncertainties related to estimating the production costs for each crop. These may arise for a variety of reasons such as:

- Differences in soil type and/or condition
- Differences in climate
- Differences in farming practices across different companies/farms
- Differences in end-product requirements/specifications.

In the establishment phase, the first lifecycle stage of Miscanthus, the field is taken care of and prepared for plantation. In our model, we have done this in year -1, with year 0 being the reference year for the plantation of the crops. In year -1, the land is prepared for the plantation of the crops in year 0. Several factors affect the cost of planting such as the site, soil type, and drainage. We have incorporated this variance into our model by modelling for different cost scenarios to reflect different possible cost combinations.

In the high-end cost scenario, we have included a possible pest-control component, such as rabbit-fencing to protect the crops. If needed, the pest control section could possibly be a major cost factor.

A couple of years after planting the Miscanthus crops, the first harvest happens. This first harvest marks the beginning of the production phase, which happens every year for the next 18 years. In the production phase, all steps related to harvesting the Miscanthus yield take place. These include mowing/cutting the plant, baling the harvest, and loading it to be further processed or sold. A margin for miscellaneous costs has also been included in the high-cost scenario. At the end of the crop's life cycle, the reversion process happens to make the land suitable for other crops.

SRC: In this study, we have considered short-rotation coppice such as poplar and willow, two species which can be used for energy generation. Similar to Miscanthus, we have considered different costing phases that are involved in the process of growing SRC. However, given the differences there are between growing these crops and Miscanthus, the processes will be different, meaning that costs will also differ from Miscanthus. We have considered the following phases in the SRC production process:

- Pre-planting/land preparation
- Planting
- Post-planting
- Harvesting
- Reversion

The same as Miscanthus, the costs have been taken from the Feedstocks Innovation Study adjusted for inflation and the fertiliser costs adjusted as explained in the Miscanthus method section (see Figure B-2).

Figure B-2 Growing cycle for SRC

	Year -1	Year 0	Year 1	Year 2	Every 3 years
Jan	Existing crop	Site preparation	Dormancy/Cut back	Dormancy	Harvest
Feb					
Mar					
Apr		Planting	Growth	Growth	Growth
May					
Jun		Gap filling			
Jul		Growth			
Aug	Site preparation				
Sep					
Oct					

Nov Dec		Senescence	Senescence	Senescence/ Harvest	Senescence

Table B-2 Range of production costs for SRC (2023 prices)

Broad action category	Cost element	Unit	Lower	Medium	Higher
Pre-planting/land preparation	Professional costs 1 for EIA advice	£/ha	0	127	127
	Professional costs 2 for agronomy advice	£/ha	0	28	28
	Soil sampling and testing 1	£/ha	7	7	7
	Soil sampling and testing 2	£/ha	7	7	7
	Land rent equivalent	£/ha	0	0	0
	Total herbicide plus application 1	£/ha	57	57	60
	Land prep (ploughing)	£/ha	89	97	106
	Land prep (power harrow)	£/ha	61	69	75
	Land prep (miscellaneous / risks)	£/ha	34	68	103
	Pest protection (rabbit fencing)	£/ha	0	341	341
	Fertiliser + application 1	£/ha	18	112	164
Planting	Plant material	£/ha	1107	1249	1419
	Planting	£/ha	454	454	511
	Fertiliser + application 2	£/ha	18	112	164
	Total herbicide plus application 2	£/ha	57	57	60
Post-planting	Herbicide / weed / spray 1	£/ha	84	93	93
	Gapping up	£/ha	15	17	19
	Cutback / mowing	£/ha	51	57	62
Harvesting and storage	Harvesting, handling and storage	£/ha	710	823	852
	Fertiliser + application 3	£/ha	18	112	164
	Herbicide / weed / spray 2	£/ha	84	102	102
Other annual costs	Miscellaneous / risks	£/ha	11	23	34
	Reversion costs	£/ha	341	341	511
	Overall Total	£/ha	3,242	4,301	4,911

In the pre-planting stage, the land is prepared for growing the SRC crop. Similar to Miscanthus, in the land preparation stage different steps to prepare the land such as soil sampling and testing, ploughing, and power harrow take place. We have modelled these to happen in year -1, with year 0 being the year in which planting takes place. Heavier or more compacted soils will require additional ploughing and sub-soiling compared to lighter costs.

Multiple herbicide applications may be needed depending on the specific circumstances. A rabbit fence or other forms of pest control might be needed.

In the planting phase, costs for the plant material and other costs involved in the planting process (such as labour costs and fuel costs) are taken into consideration as well as the costs for soil fertilisation and herbicide application. Fertiliser will be applied either by the farmer or a contractor after planting in and around the plants. Fertiliser could be a purchased product or sewage sludge (if permitted) which comes at zero cost.

In the post-planting phase, the farmer maintains the plants to ensure the plants are healthy and the soil usage is being optimised. At the end of third year when the leaves have fallen, the farmer will apply herbicide and cut back the crop to encourage the plant to grow more stems and fill any gaps in the crop with new, larger size rods which can compete with the already established plants which have just been cut back. In this phase, the farmer also cuts the emerging shoots to encourage more shoots per plant.

Once the plants are ready for harvest, the harvesting process begins. We have combined all the different costs (machinery, labour, fuel, handling, storage, etc) into a single category as there would be too much granularity if we considered them separately. After each harvest, the application of fertiliser and weed/spraying takes place. We have also allowed for possible miscellaneous costs which could affect the final cost of this process.

Short Rotation Forestry (SRF)

Two scenarios have been defined for SRF:

- SRF conifer scenario
- SRF broadleaved scenario

As with Miscanthus and SRC the costs for SRF have been taken from the Sustainable Bioenergy Feedstocks Feasibility Study report for the Department for Business, Energy and Industrial Strategy (BEIS) published in 2021. The costs have been adjusted for inflation to 2023 prices using the latest GDP deflators[58].

A low, medium and high scenario for both SRF broadleaved and SRF conifer are included.

For the SRF broadleaved scenario, the costs are based on fast growing native broadleaves on medium quality land in lowlands, grown without thinning on a 15- to 20-year rotation and harvested conventionally as pole length or shortwood. The lower cost outcome uses fast growing poplar on farmland, whereas the medium and higher cost outcomes use birch in forest conditions. For more information on the costs please see the Feasibility Study. Details on the costs can be found in Table 13-4. For the SRF conifer scenario, the costs are on the basis on a fast-growing conifer species (e.g., Sitka Spruce) on medium quality land, grown without thinning on a 15 to 20-year rotation and harvested conventionally as pole length or shortwood. The lower cost outcome assumes new planting, whereas the medium and higher cost outcome assume restocking in forest conditions. For all costs, please see Table B-5.

[58] GDP deflators at market prices, and money GDP March 2023 (Quarterly National Accounts) - GOV.UK (www.gov.uk)

Table B-2 Range of production costs for broadleaved short rotation (2023 prices)

Broad action category	Cost element	Unit	Lower	Medium	Higher
Ground preparation	Deer fencing	£/ha	0	727	965
	Rabbit control	£/ha	0	79	119
	Spirals	£/ha	710	0	0
	Draining	£/ha	0	45	85
	Cultivation	£/ha	51	170	369
Planting	Plant supply	£/ha	1079	937	1516
	Planting, restock	£/ha	0	250	443
	Planting, New	£/ha	97	0	0
	Beat up, Labour & plants	£/ha	125	392	766
Establishment and maintenance	Top up Spray (Hylobius)	£/ha	0	0	0
	Weeding	£/ha	199	352	505
	Cleaning/respacing	£/ha	0	0	51
	General maintenance	£/ha	182	250	312
	Forest-scale operations	£/ha	51	62	91
	Management overhead	£/ha	0	0	0
	Land rent equivalent	£/ha	0	149	206
Harvesting	Thinning	£/ha	0	0	0
	Clearfell	£/odt	5	7	8
	Residue removal	£/ha	0	0	0
	Comminution (chipping)	£/odt	3	6	9
Reversion	Reversion	£/ha	1136	1419	1817
	Overall Total	**£/ha**	**3628**	**4833**	**7246**

Table B3 Range of production costs for conifer short rotation (2023 prices)

Broad action category	Cost element	Unit	Lower	Medium	Higher
	Deer fencing	£/ha	0	290	647
	Rabbit control	£/ha	0	0	0
	Spirals	£/ha	0	0	0
	Draining	£/ha	0	45	85
	Cultivation	£/ha	170	250	466
Planting	Plant supply	£/ha	676	738	1022
	Planting, restock	£/ha	0	227	312
	Planting, New	£/ha	153	0	0
	Beat up, Labour & plants	£/ha	193	386	562

Establishment and maintenance	Top up Spray (Hylobius)	£/ha	0	102	261
	Weeding	£/ha	165	324	432
	Cleaning/respacing	£/ha	0	79	119
	General maintenance	£/ha	182	250	312
	Forest-scale operations	£/ha	51	62	91
	Management overhead	£/ha	0	0	0
Harvesting	Thinning	£/ha	0	0	0
	Clearfell	£/odt	5	7	8
	Residue removal	£/ha	0	0	0
	Comminution (chipping)	£/odt	3	6	9
Reversion	Reversion	£/ha	1136	1419	1817
	Overall Total	**£/ha**	**2700**	**4180**	**6135**

Step 2: Calculating the output (yield and price)

Miscanthus

Data for yields in Scotland were obtained from the Scottish farm management handbook. Similar to what has been done in the costing section, different scenarios have been considered in order to account for possible variance in yields. 12 ODT, 14 ODT and 15 ODT were used for the low, medium and high scenario, respectively. ODT/ha stands for Oven dry tonne per hectare and corresponds to the total amount of above-ground living organic matter produced in a single hectare. Harvesting takes place in year 3 and is harvested on annual basis. Pricing data for Miscanthus was obtained from the John Nix pocketbook, £95, £97, £98 £/odt for the lower, medium and higher scenario, respectively (adjusted from 2021 to 2023 prices using the latest GDP deflators). This value is taken from the value that is offered to farmers from Terravesta. There are penalties if the crop is out of specification and bonuses available of £2/tonne if bales have been stored in a barn.

SRC

SRC is harvested with 2–3-year intervals and similar to Miscanthus, yields can vary for a wide range of reasons such as site conditions, type of planting method, years since planting, crop type, orography, and weather conditions. The yields used in the analysis come from the official statistics published by Defra which looks at Plant biomass: Miscanthus, short rotation coppice and straw[59]. These are 24, 35, 45 odt/ha, respectively. In the analysis, fluctuations in the yield of SRC have been included (Table -6).

Table B4 SRC rotation used in analysis if assuming fluctuations take place

Year	Units	Lower	Medium	Higher

[59] Section 2: Plant biomass: Miscanthus, short rotation coppice and straw - GOV.UK (www.gov.uk)

Year 1	odt/ha			
Year 2	odt/ha			
Year 3	odt/ha	20	29	38
Year 4	odt/ha			
Year 5	odt/ha			
Year 6	odt/ha	26	38	49
Year 7	odt/ha			
Year 8	odt/ha			
Year 9	odt/ha	26	38	49
Year 10	odt/ha			
Year 11	odt/ha			
Year 12	odt/ha	26	38	49
Year 13	odt/ha			
Year 14	odt/ha			
Year 15	odt/ha	25	35	46
Year 16	odt/ha			
Year 17	odt/ha			
Year 18	odt/ha	23	33	43
Year 19	odt/ha			
Year 20	odt/ha			
Year 21	odt/ha	21	31	40

For the price of SRC, the value used in the latest John Nixs Pocketbook (2022) has been used. Adjusted to 2023 prices this is £59 per odt. This figure is based on what a grower in Cumbria could get.

SRF

SRF is harvested at 15-year intervals for both conifer (sikca spruce) and broadleaved (silver birch). The yield estimates were taken from the Feedstock Innovation Study. The price for both types of SRF were taken from a stakeholder from Scottish Forestry, which estimated that the payment for SRF that had been stacked and cut would be between £50 to £64.

Step 3: Calculating the gross margin

To calculate the gross margins for the bioenergy crops, firstly the costs were placed over the lifetime of the crop. For example, clearance and ploughing costs for Miscanthus were included in the first year (-1). The accompanying spreadsheet shows how all the costs are spread over the lifecycle of the crop. The costs were then taken away from the output estimates to calculate the gross margins over the lifecycle of the crop.

To calculate the gross margins for all the farm types used in the analysis the latest data from the Scotland farm business survey[60] was used using data from the years 2016 to 2022. An average over these years was used to take account of variability in agricultural costs and outputs. To get to the £ per hectare value, using the time series data from 2016, total average output for each of the farm types was divided by the average size of the farm. For variable

[60] Scottish farm business income: annual estimates 2021-2022 - gov.scot (www.gov.scot)

costs, total average inputs – other fixed costs were taken away from the total average inputs to get to the variable costs. This was then converted to per hectare values. For the general cropping, forage category data was taken from the latest census[61] for the output data and the costs were taken from the farm management handbook[62].

Table C: Breakdown of costs and outputs used for gross margin calculations (average data from 6 years from 2016-17 to 2021-22 from Scottish Farm Business Income Survey)

Type of farm	**Lowland Sheep & Cattle**			**Mixed**		
Performance band	Lower 25%	Average	Upper 25%	Lower 25%	Average	Upper 25%
Total crop output	10,516	22,962	48,895	73,507	102,314	180,117
Total livestock output	74,755	126,232	304,160	72,675	104,739	165,523
Miscellaneous output	7,184	8,973	11,508	13,028	20,741	50,036
Total average output	**92,455**	**158,167**	**364,563**	**159,210**	**227,793**	**395,676**
Crop expenses	15,097	20,175	38,586	37,388	45,197	67,023
Livestock expenses	42,485	62,298	142,947	41,068	52,412	73,146
Other fixed costs	92,125	91,391	151,465	133,423	146,043	208,434
Total average inputs	149,707	173,864	332,999	211,879	243,652	348,603
Total average inputs - other fixed costs	**57,582**	**82,473**	**181,534**	**78,457**	**97,609**	**140,169**

Table D: General cropping – forage gross margin calculation data

	Arable silage	forage maize	Whole winter wheat fermented	Whole winter wheat cracked	**Average**	**Total**
Total cost per annum (£/ha)[63]	1,193	1,113	1,441	1,625	**1,343**	
General cropping – forage output (£/ha)[64]						**58**
Gross margin (£/ha)						**1285**

Gross margin calculation: *Average total cost per annum – forage output = gross margin*

Figure A: Excerpt from Scottish Farm Mangement Handbook showing data used in the calculations in Table D above.

[61] Scottish Agricultural Census: results - gov.scot (www.gov.scot)
[62] fas.scot/downloads/farm-management-handbook-2022-23/
[63] Source: Scottish Farm Management Handbook 2022-23
[64] Source: Final Results of the June 2021 Agricultural Census: Table 12

	Arable silage pea/ cereal mix ensiled	Forage maize under plastic ensiled	Wholecrop ferm'd winter wheat ensiled	crack'd winter wheat ensiled
Yield (t FW/ha)	30	40	25	15
Yield (t DM/ha)	8	15	10	12
ME (MJ/kgDM)	10	10.5	10.5	10.5
CP (%)	16	9	9.5	9.5
		£/ha		
Variable costs	722	512	913	1,097
Establishment costs				
Plough	71	71	71	71
Sow	65	151	65	65
Roll and de-stone	20	20	20	20
Fuel	84	84	84	84
	240	326	240	240
Production costs				
Spray	14	14	41	41
Fertilise/Slurry/FYM	12	17	35	35
Lift, cart and clamp crop	170	172	170	170
Other crop expenses	3	3	3	3
Fuel	32	71	39	39
	231	276	288	288
Total cost per annum (£/ha)	**1,193**	**1,113**	**1,441**	**1,625**
Cost per t FW (£/t)	**40**	**28**	**58**	**108**
Cost per t DM (£/t)	**149**	**74**	**144**	**135**

16.1.2. Comparing bioenergy crops to existing land-use economics: three scenarios

Bioenergy energy crop scenarios

For the low scenario, high costs were compared with lower output. For the medium scenario, medium costs were compared with medium output. For the high scenario, low costs were compared with high output.

Farm scenarios

For the different farm income scenarios, the farm business income definitions were used from the Scotland farm business survey. For low this uses the lower 25% percentile for that farm category, for medium the average percentile was used and for the higher, the upper 25% percentile was used.

16.1.3. Yearly average gross margins for each of the bioenergy crops and farm types

To calculate the yearly average gross margins for each of the bioenergy crop and the farm type scenarios a discount rate was applied to future years. The discount rate applied is the standard discount rate recommended by the green book[65]. The Green Book recommends that costs and benefits occurring in the first 30 years of a programme, project or policy be discounted at an annual rate of 3.5%, and recommends a schedule of declining discount rates thereafter. A discount rate is applied as it is assumed that people prefer to receive financial outputs now rather then in the future.

[65] Green Book supplementary guidance: discounting - GOV.UK (www.gov.uk)

16.2 Assessment of implications for Scotland's rural economy

Using the geo-spatial mapping data from the previous project, which identified land that was theoretically suitable for PEC production considering land capability, slope, and climate (Martin et al, 2020), percentages of the land that could be converted to bioenergy crops were derived for each of the regions. This percentage was then applied to the land area estimated to be in each farm type in the region, to derive the land are potentially suitable for PECs by farm type. The land area in each farm type in each region was estimated by combining data on crop areas in each region with estimates of the percentge of crop area at the Scottish level which occurs in each each farm type.

A previous CXC study (Meek et al, 2022) indicated that, bearing in mind land suitability, an estimated total of approximately 27,000 ha PECs could be planted by 2030, 38,000 by 2032 and 90,250 hectares by 2045. Two scenarios were then constructed to see what land transitions could meet these areas of PECS. Using information on the gross margins for the three farm types of interest and the gross margins for the PECs, the economic impact of each land use change can be ranked.

Table E Change in gross margin (£/ha) in transitioning to PECs

	SRF	SRC	Miscanthus
Non-LFA Cattle & Sheep	-£414	-£347	-£52
Mixed holdings	-£577	-£511	-£215
General cropping	£1,009	£1,076	£1,371

These rankings were used to guide how much of the potential land suitable for PECs in each farm type was assumed to be converted, with more land converted for more economically beneficial transitions. Care was also taken, particularly in Scenario 2, where high levels of trnaition are needed to meet the higher PEC target area, that levels of overall change were not too high. This resulted in the assumed changes shown in the Tables below

Table F Assumed changes in land use Scenario 1

	Percentage of suitable land assumed converted to PECs			Ha converted to PECs			
	Non-LFA Cattle & Sheep	Mixed Holdings	General Croppin g, Forage	Non-LFA Cattle & Sheep	Mixed Holdings	General Croppin g, Forage	Total area
PEC				ha	ha	ha	ha
SRF	15%		66%	9,928	-	8,977	18,905
SRC	15%		66%	7,578	-	5,258	12,836
Miscanthus	30%		100%	3,790	-	1,352	5,142
Total land are converted				21,296	-	15,587	36,883
Percentage of total land in farm type converted				20%	0%	1.1%	2.1%

Table G Assumed changes in land use Scenario 2

	Percentage of suitable land assumed converted to PECs			Ha converted to PECs			
PEC	Non-LFA Cattle & Sheep	Mixed Holdings	General Cropping, Forage	Non-LFA Cattle & Sheep	Mixed Holdings	General Cropping, Forage	Total area
				ha	ha	ha	ha
SRF	30%	50%	75%	19,857	13,873	10,201	43,931
SRC	30%	50%	75%	15,156	10,078	5,975	31,209
Miscanthus	60%	100%	100%	7,580	4,770	1,352	13,701
Total land are converted				21,296	-	15,587	42,592
Percentage of total land in farm type converted				40%	9%	1.3%	5.0%

The Potential change in farm income due to change in gross margin was calculated by multiplying the change in gross margin from each transition in Tables E, with the areas in transition in Tables F and G. This was done on a regional basis.

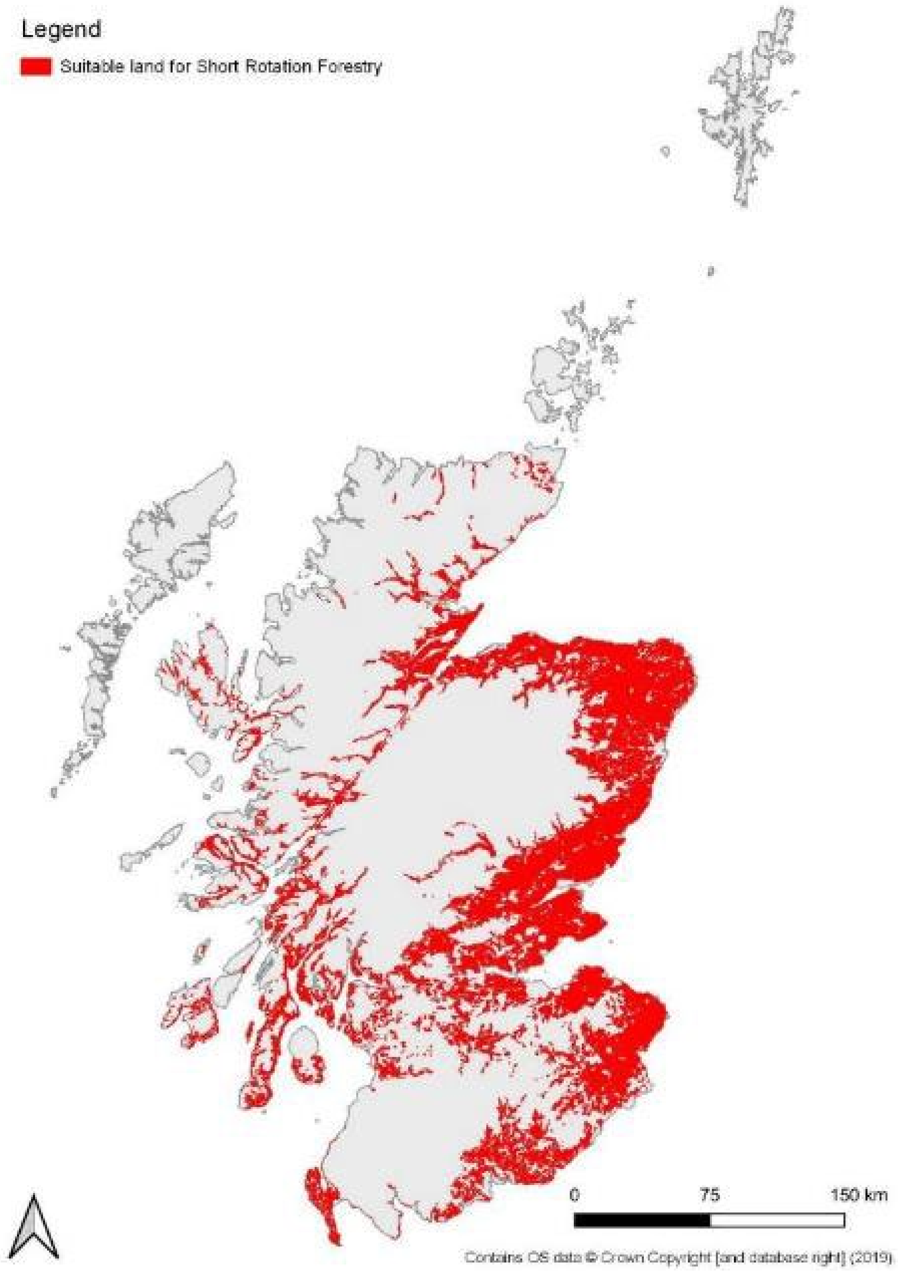
The estimated shortfall in crop production from a shift to PECs, was calculated by using data on the areas of crop land in each farm type and the areas converted to PECs to calculate lost areas of crop production. These were then multiplied by typical crop yields[66]. This was all done at a regional level. Estimate the change in livestock production that might come from the shift to PECs would require a more detailed analysis than was possible in this study.

66 June Agricultural Census (ruralpayments.org)

17 Appendix F: Mapping outputs from 2020 project

A previous CXC Project (Martin et al, 2020) used geo-spatial mapping to identify suitable areas of land in Scotland for growing PECs. The project focused on land capability of grades; 4.1, 4.2, 5.1, 5.2, 5.3 and 6.1, which are typically suitable for mixed agriculture, improved grassland and high-quality rough grazing [67], and assessed what area of these grades where suitable for SRC and Miscanthus growth which limited the potential production area. For SRF the assessment also included land capability for agriculture grades F1, F2, F3, F4 and F5.

Figure C-1: Distribution of suitable land available for Short Rotation Forestry



[67] The James Hutton Institute, N.D., *Land Capability for Agriculture in Scotland*. https://www.hutton.ac.uk/sites/default/files/files/soils/lca_leaflet_hutton.pdf

Figure C-2: Distribution of suitable land available for Short Rotation Coppice

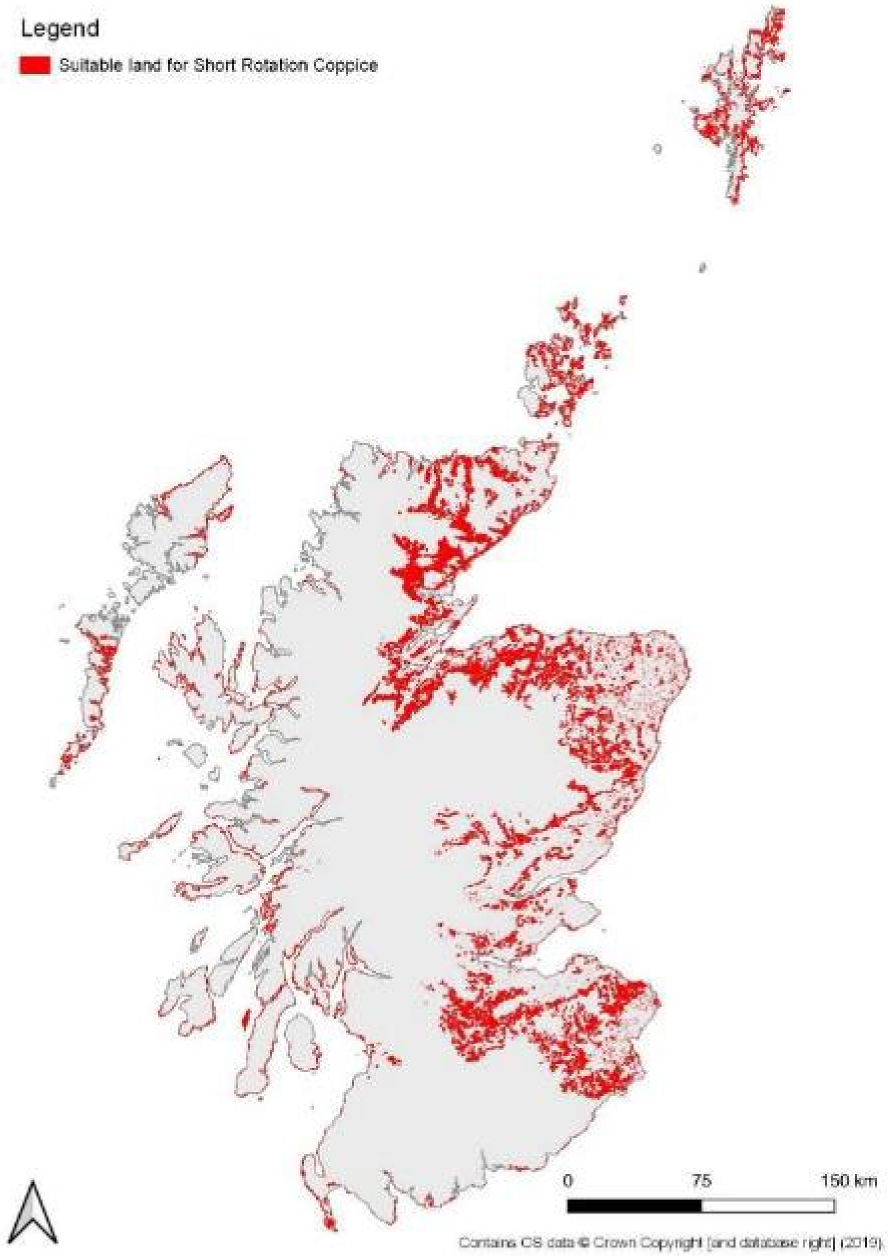
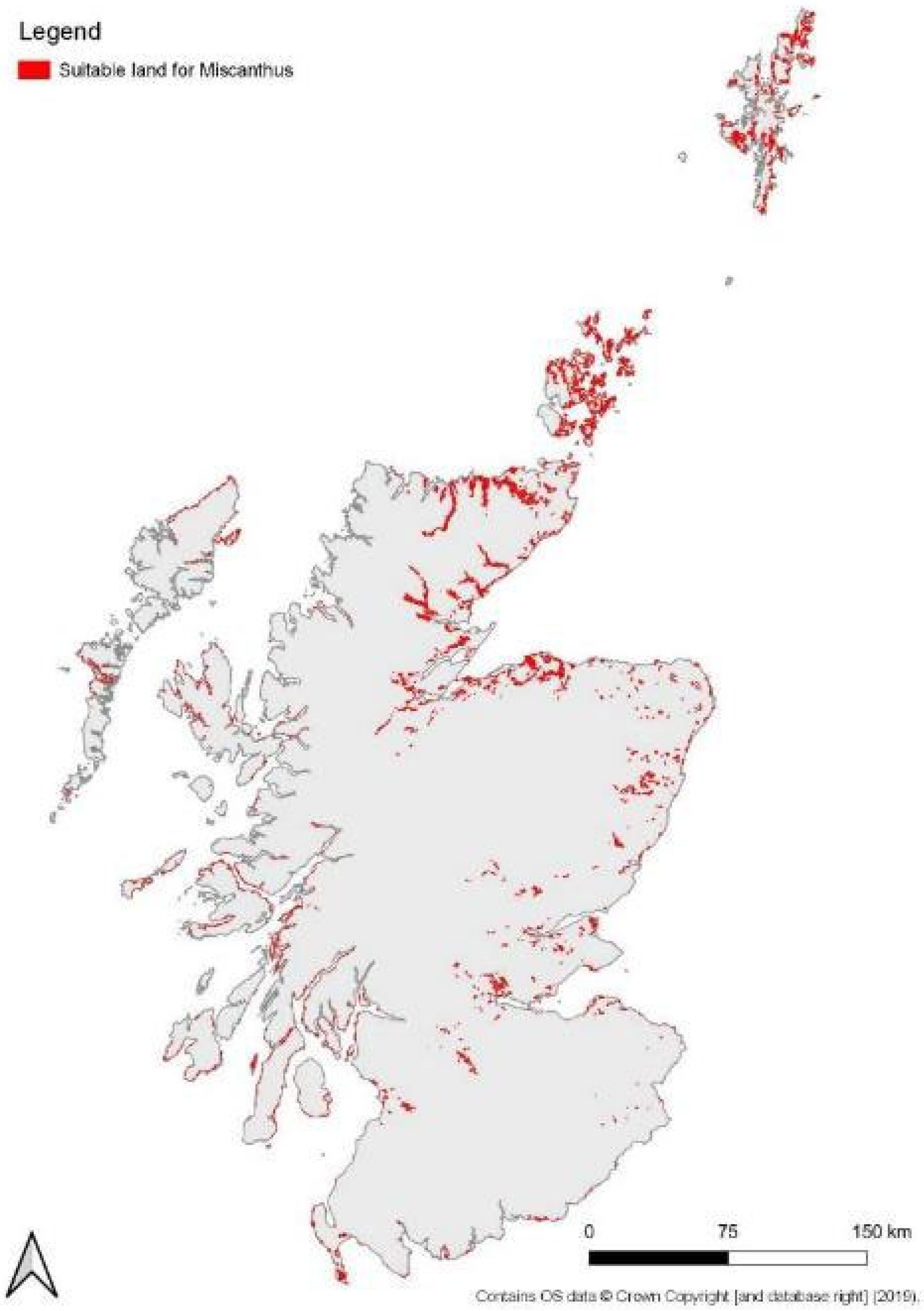


Figure C-3: Distribution of suitable land available for Miscanthus



Data attributions

The data used in the bioenergy crop growth analysis was downloaded from multiple sources. In order to comply with their licences, as well as to acknowledge the use of the data, attributions for each data source is provided in Table C-1. In all cases these attributions are those directly required by the data licence or metadata.

Table C-1: Data attributions

Dataset name and data source	Data attribution
James Hutton Institute: Land Capability for Agriculture, 1:250,000	James Hutton Institute: Land Capability for Agriculture, 1:250,000 copyright and database right The James Hutton Institute 1980. Used with permission of The James Hutton Institute. All rights reserved. Any public sector information contained in these data is licensed under the Open Government Licence v.2.0
James Hutton Institute: Land Capability for Forestry, 1:250,000	James Hutton Institute: Land Capability for Forestry, 1:250,000 copyright and database right The James Hutton Institute 1980. Used with permission of The James Hutton Institute. All rights reserved. Any public sector information contained in these data is licensed under the Open Government Licence v.2.0
Ordnance Survey: Terrain 50 50m resolution digital elevation model	Contains OS data © Crown Copyright [and database right] (2019).
Ecological Site Classification	Forestry Commission, (2019).
Centre for Ecology and Hydrology: Gridded Estimates of Areal Rainfall (GEAR)	Tanguy, M.; Dixon, H.; Prosdocimi, I.; Morris, D.G.; Keller, V.D.J. (2019). Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2017) [CEH-GEAR]. NERC Environmental Information Data Centre. https://doi.org/10.5285/ee9ab43d-a4fe-4e73-afd5-cd4fc4c82556
Centre for Ecology and Hydrology: Climate Hydrology and Ecology Research Support System (CHESS)	Martinez-de la Torre, A.; Blyth, E.M.; Robinson, E.L. (2018). Water, carbon and energy fluxes simulation for Great Britain using the JULES Land Surface Model and the Climate Hydrology and Ecology research Support System meteorology dataset (1961-2015) [CHESS-land]. NERC Environmental Information Data Centre. https://doi.org/10.5285/c76096d6-45d4-4a69-a310-4c67f8dcf096
James Hutton Institute: National Soils of Scotland, 1:250,000	James Hutton Institute: National Soils of Scotland, 1:250,000 copyright and database right The James Hutton Institute 2019. Used with permission of The James Hutton Institute. All rights reserved. Any public sector information contained in these data is licensed under the Open Government Licence v.2.0
Scottish Natural Heritage: Carbon and Peatland Map 2016.	Contains public sector information licensed under the Open Government Licence v3.0.
Forestry Commission: National Forestry Inventory Woodland Scotland 2017	Contains Forestry Commission information licensed under the Open Government License v3.0.
European Space Agency: CORINE 2018	© European Union, Copernicus Land Monitoring Service 2019, European Environment Agency (EEA)
Ordnance Survey: Open Zoomstack	Contains OS data © Crown Copyright [and database right] (2019).
Scottish Natural Heritage: National Parks, National Scenic Areas, Country Parks etc.	Contains public sector information licensed under the Open Government Licence v3.0.
Scottish Natural Heritage: World Heritage Sites, Battlefields, Conservation Areas etc.	Contains public sector information licensed under the Open Government Licence v3.0.
Scottish Natural Heritage: Ramsar, SAC, SPA, SSSI etc.	Contains public sector information licensed under the Open Government Licence v3.0.

18 AppendixG: Methology for geospatial analysis of agricultural land use change

Geospatial analysis

To calculate the current land area available for change to bioenergy cropping, based on the locations from the previous CXC project, geospatial analysis was completed. The percentage of the total land area suitable for bioenergy growth in each agricultural region was calculated and applied to the total hectarage of the the agricultural land used within the land capability categories. This was then divided into three main farm types: Non-LFA cattle and sheep, Mixed holdings, General cropping – forage. This presented a total hectarage by agricultural region and farm type that could be converted to SRC, Miscanthus and SRF. This data was used in economic calculations to present the change in economic potential for the three farm types under a land use change to bioenergy crops. Details of sources used are presented in Table D-1.

Table D-1 Data sources and usage

Data type	Source	Reference	Usage	Assumption
Table 14 Land Use by Region Dataset	Scottish Agricultural Census June 2021	agricultural-census-june-2021-tables.xlsx	Hectarage of barley (spring and winter), stockfeeding crops (maize and lupin) and grass (under 5 years old, and 5 years old and over) used to calculate the current land usage within the Scottish agricultural regions.	N/A
Table 17 Livestock by Region (Number of heads) Dataset	Scottish Agricultural Census June 2021	agricultural-census-june-2021-tables.xlsx	Data used to calculate the percentage split of the number of animals using grass (hay and silage) within Scotland.	Assumption that beef and dairy cattle will consume similar feed amounts each day, supported by review or recommended dry matter intake by online sources.
Table 1 Crops and grass area,	Agricultural Statistics: Results of	agricultural-statistics-december-2020.xlsx	Data used to calculate the percentage split of grass cut for hay and silage.	Assumption that all grass yield would

hay and silage production, 2010 to 2020	December 2020 Agricultural Survey			match yields of hay and silage crops.
Table 1b. Agricultural area in hectares, 2011 to 2021	Scottish Agricultural Census June 2021	agricultural-census-june-2021-tables.xlsx	Data used to calculate the percentage split of stockfeeding crops between maize and lupin.	Only Maize and Lupin stockfeeding crops have been included as these have been named in the Table 14 footnote.
Barley usage in Scotland	NFU Scotland: What we produce	https://www.nfus.org.uk/farming-facts/what-we-produce.aspx	Data used to calculate the percentage of barley produced in Scotland used for animal feed.	Assumed that all barley produced for animal feed is produced in land capability categories 3.3-5.3, in line with the areas selected for potential growth of SRC and Miscanthus.
Land capability - agriculture	James Hutton Institute: Land Capability for Agriculture, 1:250,000	https://www.hutton.ac.uk/learning/exploringscotland/land-capability-agriculture-scotland	Dataset used to compare the land capability categories against the potential growth area of SRC and Miscanthus to calculate the percentage of land area for bioenergy growth applied in calculations.	
Land capability - forestry	James Hutton Institute: Land Capability for	https://www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-forestry	Dataset used to compare the land capability categories against the potential growth area of SRF to calculate the percentage of	

	Forestry, 1:250,000		land area for bioenergy growth applied in calculations.	
Percentage of crops by farm type	Technical knowledge	-	Division of crops between farm types used to split the total hectarage of crops into three main farm type categories: Non-LFA cattle and sheep, Mixed holdings, General cropping – forage for economic farm level analysis.	Assumptions have been made on the percentage split of the crops focused within the mixed agriculture and improved grassland land capability categories, based on the removal of total crops used for other farm types (e.g. specialist dairy and non-animal feed cropping categories – general cropping and specialist cereals).

19 Appendix H: Stakeholder engagement methodology and key findings

In addition to the rapid evidence assessment and economic analysis, we conducted stakeholder engagement with a robust representative sample of stakeholders from across the Scottish agricultural network to provide input into the project. The engagement was conducted in two stages:

1. **Topic expert research interviews:** eight semi-structured interviews of approx. one hr were carried out as part of the evidence gathering process. Interviewees were sent a briefing of key areas of enquiry prior to their interview to aid their preparation. Ricardo recorded each discussion as meeting recording, transcript and attendee notes.

2. **Stakeholder workshop:** Stakeholder input was sought to scrutinise findings and ensure the SWOT and PESTLE are as complete and robust as possible. This engagement was delivered through a one hour structured on-line meeting held on the 16th October 2023 with a combination of stakeholders who had already contributed to individual interviews and representatives of wider organisation and businesses. Initial finding were presented by the project team and comment on accuracy, completeness and additional considerations sought throughout. Following the meeting, the presentation and list of questions (below) was sent to all attendees with an invitation for follow up comment.

Insights were gained into:

- What influences farmer and land-manager decisions on energy cropping.
- Wider concerns or questions about potential implications.
- Benefits and disadvantages of energy crops.
- Opportunities to drive greater uptake.
- Insights in economic aspects and state of knowledge on this for Scotland in particular.

Feedback reflected some of the points of discussion and debate that were identified in the REA such as questions over what land is suitable and how best to use land given Scotland's climate targets and other priorities, and debate over yields, prices and how to ensure wider environmental benefits from energy crops, and to what extent this is possible in Scotland.

The insights from this stakeholder engagement have been integrated into Section 4 Evidence Base and Section 7 SWOT & PESTLE analysis.

Summary of questions posed to stakeholders during the engagement element of the project:
General:

- Do you think there are opportunities for farmers and land managers in Scotland to benefit from producing perennial energy crops?
- If so, which crops, locations and circumstances do you think could be most economically viable, and why?
- How could we improve our costings and economic assumptions to make them more reflective of the reality of the Scottish context?
- What economic and other considerations would most influence farmers' and land-managers' decision to start producing energy crops?
- What are the most significant potential benefits and challenges at a wider economy scale?

Economic analysis at farm scale

- How could we improve our costings and economic assumptions to make them more reflective of the reality of the Scottish context?
- Would you suggest any adjustments to our costs?
- Would you suggest any adjustment to our yield or prices?
- Are the rotation lengths appropriate?

Preferred locations

- How is best to select preferred biomass locations? E.g. based on areas in proximity to market usage? Or based on land with best production potential?
- Are there any existing or proposed large-scale biomass plants in Scotland?
- What is a maximum travel distance from farm to plant?
- Are there any key biomass planting / harvesting contractors in Scotland? If so, where?

Output of Stakeholder Engagement

The output of the stakeholder interviews included suggestions for data and information sources to support the economic analysis. Stakeholders also provided commentary on the opportunities and challenges of perennial energy crop production in Scotland; this is summarized below:

Key strengths common to all perennial energy crops:

- Low input & maintenance costs
- Stable income on low/variably productive land
- Water & biodiversity management benefits (depending on location / planting design)

Miscanthus	Short Rotation Coppice	Short Rotation Forestry
Low input & maintenance costs Use existing harvester (maize harvester) Alternative markets (eg bedding) Earlier harvest income than SRC/SRF & annual harvest Knowledge base/innovation pipeline Harvest contractor employment Soil health	Sequential planting to allow harvest every year (albeit small volumes) Opportunity to improve efficiency with modern machinery Potential for biodiversity net gain / natural capital payments Soil health / shelter benefits for other enterprises on farm.	No costs whilst growing Alternative markets (for same diameter wood/ maybe to grow on) Suits wider range of conditions Potential community involvement Shelter for livestock / crops Poor cashflow

Key weaknesses common to all perennial energy crops:

- Period of years before first harvest / income (shortest for Miscanthus, longest for SRF)
- Uncertain market / income prospects (market price / grants / incentives)
- Total biomass production costs currently higher than fossil fuels; and less than existing land-uses.
- Storage & transport costs due to bulk
- Need specialist planting / harvesting equipment / processing facilities
- Public scepticism / green-washing concerns
- Lack of familiarity

Miscanthus	Short Rotation Coppice	Short Rotation Forestry
Upfront cost: 2-3yrs to harvest Winter hardiness challenge (although new cultivars being developed) Land-use change carbon stock Challenge sourcing planting stock	Need access to drying / chipping Farmers consider financially risky Limits rotation flexibility Risk of sharing neighbour crop Pests: willow rust Yield uncertain over lifetime	Need access to drying / chipping Change of land-use/payment lost Limits rotation flexibility Risk of sharing neighbour crop Longest period before harvest Less research in Scotland Competition for wood output

Individual stakeholder interviews:

Crops4Energy	Kevin Lindegaard	Director of Crops for Energy
Eadha Enterprises	Peter Livingstone	CEO
NatureScot	Cécile Smith	Climate Change & Land Use Adviser
NatureScot	Kirsty Hutchison	Agricultural Officer | Natural Resource Management
NFUS	David Michie	Crop Policy Lead
NFUS	Kate Hopper	Policy Manage Climate Change
Scottish Forestry	Jason Hubert	Head of Forest Sector Development
Willow Energy	Jamie Rickerby	Director

19.1.1. Stakeholder online workshop attendees:

Scottish Land and Estates
Terravesta
Crown Estate Scotland
SRUC/BiomassConnect
CONFOR
SEPA
NFUS
AHDB
Willow Energy
CAAV
SOAS
Crops4Energy
Scottish Forestry
Director of International Land Use Study Centre - James Hutton Institute
NatureScot
AHDB
Scottish Land and Estates

20 Appendix I: Biomass Feedstock Innovation Funding in the UK

There is currently significant investment in innovation to increase the production of sustainable domestic biomass, including the Biomass Feedstocks Innovation Programme[68], which is funding innovative ideas that address barriers to biomass feedstock production across the UK. It is supporting projects those seeking to improve productivity through breeding, planting, cultivating and harvesting. Summaries of the 12 funded projects, taken from the GOV.UK programme page, are given below[69].

1) **Biomass Connect: Biomass Innovation and Information**

Led by UK Centre for Ecology & Hydrology. The Biomass Connect Phase 2 project will create a demonstration and knowledge sharing platform to showcase best practice and innovations in land-based biomass feedstock production.

2) **Project BIOFORCE (BIOmass FORestry CrEation): Creating geospatial data systems to upscale national forestry-based biomass production.**

Led by Verna Earth Solutions Ltd (formerly Forest Creation Partners Limited). Project BIOFORCE will create and demonstrate new, upgraded versions of Forest Research's industry-standard Ecological Site Classification (ESC) tool, and Verna's successful ForestFounder system.

3) **Transforming UK offshore marine algae biomass production**

Led by SeaGrown Limited. Scarborough-based SeaGrown operates a 25-hectare offshore seaweed farm in the North Sea off the Yorkshire Coast. This project seeks to apply SeaGrown's experience in pioneering this new sector to create an innovative, automated end-to-end seaweed farming system.

4) **EnviroCrops - Perennial Energy Crops Decision Support System (PEC-DSS)**

Led by Agri Food and Biosciences Institute (AFBI).The EnviroCrops web app is envisaged as a central source of impartial information in an easy to access, free or low-cost, user-friendly format, that will enable farmers, land managers and consultants to make an informed decision about planting biomass crops.

5) **Miscanspeed - accelerating Miscanthus breeding using genomic selection.**

Led by Aberystwyth University. The aim of this project is to demonstrate the application of genomic selection (GS) in accelerating the breeding of high yielding, resilient Miscanthus varieties for the UK.

6) **Technologies to enhance the multiplication and propagation of energy crops (TEMPEC)**

Led by New Energy Farms EU Limited. The project objectives are to increase the number of energy grass varieties that are available, increase yield and develop agronomic improvements to multiplying and planting energy crops.

7) **Optimising Miscanthus Establishment through improved mechanisation and data capture to meet Net Zero targets (OMENZ)**

[68] https://www.gov.uk/government/publications/biomass-feedstocks-innovation-programme-successful-projects

[69] https://www.gov.uk/government/publications/biomass-feedstocks-innovation-programme-successful-projects/biomass-feedstocks-innovation-programme-phase-2-successful-projects

Led by Terravesta Farms Ltd. The project will utilise the Terravesta Harvest Hub platform to integrate data collected from all stages of our establishment pipeline alongside their existing harvest and growth data. Through data integration with the current supply chain, the OMENZ team will gain insights into long term crop performance and improve the entire Miscanthus biomass supply chain, benefiting both growers and end-users.

8) Demonstration of on-farm pelletisation technology.

Led by White Horse Energy Ltd in developing and constructing a robust mobile pelletiser enabling farms to process a range of feedstocks, enabling domestic biomass pellets to displace imported pellets in the UK energy supply mix.

9) Teesdale Moorland Biomass Project

Led by Teesdale Environmental Consulting Ltd (TEC Ltd). The Teesdale Moorland Biomass Project aims to utilise existing managed heather moort and harvest commercially viable biomass products from naturally generated moorland crops that are currently burned in situ as part of annual land management practices.

10) Taeda Tech Project – Soilless cultivation for rapid biomass feedstock production

Led by University of Surrey. The project uses novel aeroponic technology to rapidly cultivate Short Rotation Coppice (SRC) willow cuttings which can be planted into the field for bioenergy.

11) Net Zero Willow

Led by Rickerby Estates Ltd. The team is developing innovations aimed at revolutionising the industry and maximising marginal gains through more efficient machinery.

12) Accelerating Willow Breeding and Deployment

Led by Rothamsted Research. The Accelerating Willow Breeding and Deployment (AWBD) project will accelerate the breeding of SRC willow and generate information to guide the intelligent deployment of current varieties.

21 Appendix J: SWOT and PESTLE Analysis: Detailed Results

The SWOT analysis assessed the current economic potential for perennial energy crops for farmers and land-managers in Scotland, looking at strengths, weaknesses, opportunities, and threats (SWOT) to provide a simplified picture and more clarity of what would be needed in order for these crops to be an attractive proposition economically, whilst also considering the other factors which farmers and land-managers would be likely to consider alongside the economics. The SWOT tables below are grouped according to the following categorisations:

- **Perennial energy grasses** (primarily Miscanthus);
- **Short rotation coppice** (primarily Willow);
- **Short rotation forestry** (including broadleaved; conifer)

Table G1. SWOT table covering Perennial energy grasses, focused on Miscanthus.

Strengths	**Weaknesses**
• Can harvest with maize harvester - farmer / contractor will have this (but not many people grow maize in Scotland). • Alternative markets e.g. bedding provides more security for farmers to encourage adoption. • Early harvest, better cashflow for farmers - 3yrs to first harvest (but some small harvest in first year) • Knowledge gaps - not flagged in research. • Limited input needs - lower costs	• Upfront investment; delay in income (2-3yrs) • Winter hardiness (Scotland); • Gap in support e.g. grants (energy crop scheme for establishment grants in early 2000s) - nothing right now. • Limited market right now, uncertainty for future market. • Higher yield than SRC • Doesn't respond to N fertilizer – limited opportunity to boost yield • Not frost tolerant - less suited to Scotland. But there are more frost hardy cultivars being developed.
Opportunities	**Threats**
• To incentivise with grants, as there are none right now; • Employment opportunity in harvesting contracting. • Biodegradable film mulch - can boost economic performance; other innovations under biomass feedstock - opportunity to take these up (e.g. hybrid varieties which are more • Grassland that is becoming unprofitable - could be used.	• Loss of carbon stock through land-use change (eg. if convert grassland) • Challenges in sourcing high-quality planting stock (esp. if there is uptake in planting)

Table G2. SWOT table covering Short Rotation Coppice

Strengths	Weaknesses
• Sequential planting; allows harvest every year. But limits economics with small amounts.	• Farmers consider financially risky; low selling price; high cost of harvest. • Low selling price / high harvest costs. • Single market for energy • Focused on a small number of species – more data needed on e.g. aspen • Concern re. removal of flexibility of land use in a rotation • Challenges around growth area (willow won't grow well everywhere)
Opportunities	**Threats**
• Modern machinery can improve efficiency. • Breeding to achieve higher yields happening. • Opportunities for biodiversity net gain and natural capital • Additional benefits of woodland habitat linkage • Benefits as a neighbour crop for shelter • Soil health benefits of willow? • Purification of contaminated soils? (willow)	• Variable yield / uncertainty over lifecycle. • Risks as a neighbour crop for shading • Risks of pest (rust) for SRC willow •

Table G3. SWOT table covering Short Rotation Forestry

Strengths	Weaknesses
• No costs whilst growing - to harvest point. • Alternative markets potentially for same small diameter wood. • Wider range of growing conditions	• Longer growing period before harvest. • Need to replant after harvest. • Loss of 'agriculture' classification as land and resulting loss of farm subsidy payment. • Less research: only the Forest Research plots - a few years ago, but not yet got full result. • Storage / transport: particularly for SRF in research (check) • Concern re. removal of flexibility of land use in a rotation
Opportunities	**Threats**
• Variable yield / uncertainty over lifecycle. • Community-scale growth plans and ownership: potential economic driver for socio-economic regeneration • Biodiversity/conservation/amenity value • Grazing options on planted land and animal welfare benefits • Benefits as a neighbour crop for shelter • Options for diversification/flexibility through growing on to larger trees for other uses (e.g. timber)	• Competition for output for other (possible more profitable) wood uses, such as timber • Risks as a neighbour crop for shading

PESTLE Analysis of economic potential of energy crops in Scotland

Energy crops are subject to a range of enabling and preventative factors which would influence the benefits and potential uptake of the crops in Scotland. A political, economic, social, technical, legal, and environmental (PESTLE) analysis was therefore undertaken to assess the potential to…increase economic viability and uptake of energy crops in Scotland This assessment was produced following the SWOT analysis to incorporate the strengths and opportunities of each energy crops (and more generally) identified in the SWOT.

Table G4. Summary PESTLE Analysis: enabling and preventative factors for economically viable energy crops in Scotland

The combination of high production costs, particularly the upfront investments uncertain policies and uncertain market prices for future harvests discourage farmers from growing SRC plants. (Zięty et al, 2022)

	ENABLER	BARRIER
Political		• Uncertain policies /lack of political support for key energy crops over multiple governments (Zięty et al, 2022, Davies et al, 2020) For example, the Energy Crops Scheme which provided establishment grants was withdrawn in 2013, and despite strong lobbying, Defra had resisted allowing Miscanthus to be counted as an ecological focus area (EFA) under greening. • Lack of specific grant funding available to help pay for establishment Miscanthus (Davies 2020). • The combination of high production costs and uncertain policies as well as the prices of the products discourage farmers from growing SRC plants. (Zięty et al, 2022)
Economic	• Miscanthus- 'high return per hectare' (Martin et al., 2020 D1) • Yield and sale price are biggest contributing factors to achieving good economics (Martin et al., 2020 D1) • Farmers currently growing a bioenergy crop also had a higher average income compared to their nongrowing counterparts. (Brown et al 2016 D2) • Establishment grants and cash advance systems are widespread and efficient ways of limiting liquidity constraints (Bocquého, G., 2017 D3) • profitability was the main reason for growing these crops (Glithero et al., 2013)	• Large initial investment and no income for 2-3 years (Miscanthus), 4-5 years (SRC), (10-20 years) SRF (Martin et al., 2020 D1) • SRF - Poor cash flow (Martin et al., 2020 D1) • Uncertain profitability in comparison to land-uses that are better known (Martin et al., 2020 D1) • Many farmers regard SRC willow as a financially risky (Warren et al., 2016 D2) • liquidity constraints hinder adoption (Bocquého, G., 2017 D3) • There are no stable markets for Miscanthus biomass and relevant applications are low-value (Lewandowski, I., J. Clifton-Brown, et al. 2016).
Social	• Miscanthus- planting and annual harvesting will require supportive contractor and other local	• SRF -Negative publicity regarding the benefits of energy crops (Martin et al., 2020 D1)

	employment services. (Martin et al., 2020 D1) • Local economic activity related to employment opportunities. Local employment at conversion plant and associated activities (Thornley, P., 2006.)	• SRF- Objections to planning applications for biomass power stations leads to limited feedstock market and demand (Martin et al., 2020 D1) • Attitudes can take longer to change than awareness (Brown et al 2016 D2) • Farmers cited a range of 'moral' (e.g. should not be using land for energy crops when there is a shortage of food), land quality, knowledge, profit and current farming practice comments as reasons for not growing DECs (Glithero et al., 2013)
Technical	• The energy crop market displays path dependence, arising from the reinforcement of the location of plant construction and energy crop selection, based on the locations of the previous plants and energy crops. Once a plant has been built at a location, and a number of farmers have adopted to produce supply for that plant, that area is more likely to be selected for further plant development, and associated energy crop growth (Alexander et al 2015 D14). • SRC- modern machinery, with high efficiency, working in fields with a larger area, reduces costs significantly (Kwaśniewski et al 2021 D17)	• SRF-Limited specialist machinery for SRF management (Martin et al., 2020 D1) • need for smaller harvest equipment adapted to small-and-medium-scale area plantations of SRWC (Savoie et al 2013 B) • SRC - technical lack of knowledge (Wolbert-Haverkamp, M. and Musshoff, O., 2014).
Legal	• Private long-term production contracts between farmers and biomass processors can act as a risk barrier (Bocquého, G., 2017 D3)	• SRF-Irreversible land conversion-Reversion to farming use may not be allowed once SRF is planted as deemed change of use (Martin et al., 2020 D1) • legal conditions? (e.g., cultivation licenses) (Ostwald 2013) • Long-term contracts and legal restrictions may become obstacles in the establishment of SRC (Long-termland contracts, which are essential for establishing SRC plantations, are one of the biggest obstacles for farmers engaging in SRC projects. Consequently, annual payments are an important compensation) (Fürtner et al 2022 D9)
Environmental	• careful allocation of perennial cropping systems into a cropland could produce positive impacts on climate, water, and biodiversity (foster multiple ecosystem services	• SRC- Establishment on high organic/peaty soils (upland areas) potentially detrimental to soil carbon levels, soil damage and erosion. (Martin et al., 2020 D1)

	and mitigate ecosystem disservices (Anejionu, O.C. and Woods, J., 2019 D3) • long term weed control (Glithero et al., 2013) • The second-generation bioenergy crop Miscanthus almost always has a smaller environmental footprint than first generation annual bioenergy ones (Hastings et al., 2017).	• SRC-cannot be planted on land with soils that are water-logged (Martin et al., 2020 D1) • Miscanthus-Winterhardiness of Miscanthus is a major constraint (can halt growth, causing diminished achievable yield) (Martin et al., 2020 D1) • Current varieties of Miscanthus are constrained by climate to the south and south east of Scotland (Martin et al., 2020 D1) • Miscanthus- have lower or similar SOC (soil carbon stocks) when compared to grassland controls (Holder et al., 2019 D1) • Direct emissions can occur in the production, transport, handling and processing, while indirect emissions are associated with land use change potentially causing SOC changes (Alexander et al., 2015 D14). • The response to climate change scenarios further favours Miscanthus, suggesting that Miscanthus supply increases under future climate, while SRC willow supply is expected to reduce (Alexander, P., D. Moran, et al. 2014) • large-scale bioenergy production and associated additional demand for irrigation may further intensify existing pressures on water resources (Popp et al 2011) • The reduction of management intensity originating from converting agricultural land use to SRC cultivation results in additional environmental benefits, especially in soil protection and the enhancement of soil life (Schiberna et al., 2021 D9)

22 Appendix K: Biomass plants included for proximity analysis

Operator	Site Name	Installed Capacity (MWel)	CHP	Development Status
RWE	Markinch Biomass CHP Plant	65.00	Yes	Operational
E.ON	Stevens Croft	50.40	No	Operational
SIMEC/ Liberty House	Liberty Steel Dalzell	17.00		Operational
Norbord (West Fraser)	Cowie Biomass Facility	15.00	No	Operational
EPR Scotland	Westfield Biomass Power Station	12.50	No	Operational
Speyside Renewable Energy Partnership	Speyside Biomass CHP Plant	12.50	Yes	Operational
Scottish Bio-Power	Rothes Bio-Plant	8.30	Yes	Operational
University of St Andrews	Sustainable Power and Research Campus	6.50	Yes	Operational

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