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Establishing a manure/slurry exchange in Scotland – a feasibility study

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1 Executive summary

1.1 Aims and background

Scotland's Climate Change Plan includes a policy commitment to reduce emissions from the use and storage of manure and slurry[1].

Agriculture and associated land use account for 24% of greenhouse gas (GHG) emissions in Scotland, with methane the most significant proportion of this at 44%. Methane comes from enteric fermentation and from manures. The management of manures is therefore a critical element in mitigating the sector's GHG emissions.

This study examines the feasibility of developing manure exchanges (slurries and farmyard manures) to reduce these emissions.

The use of nitrogen fertilisers from both organic and manufactured sources is critical in supporting agricultural production in Scotland. However, excess nitrogen can lead to wider environmental impacts including increased emissions. Exporting manures between farms can offer a solution to managing excess nitrogen on livestock farms while supporting better utilisation of nutrients across the agricultural sector as a whole.

Our literature review found just eight peer-reviewed scientific papers relating to manure exchanges. We drew on additional sources including websites, farming press and farming support organisations such as the Agriculture and Horticulture Development Board (AHDB). Our search for evidence was directed towards locations with broadly similar climate and farming systems, coming mainly from North America, Denmark and the UK.

1.2 Key findings

- The arisings of manure in Scotland indicate a total available nitrogen supply of 14,700 tonnes per annum from manure, compared with a total utilisation of applied nitrogen of approximately 152,000 tonnes.
- A significant proportion of manures could potentially be part of a manure exchange, with just 6% of manure arisings currently reported as being exported from source.

[1] Climate Change Plan 2018, p201

- The potential abatement of GHG emissions by offsetting manufactured nitrogen through the substitution of organic manure is limited. Under the most favourable scenario modelled, the potential saving is equivalent to just 0.68% of annual agricultural emissions.
- We found three broad examples of schemes which support the movement of manures and would be relevant within the Scottish context: muck-for-straw, manure exports and movement of livestock.
- Requirements for nitrogen are greater in all major regions of Scotland than can be supplied by manure sources.
- Compared with other European countries, Scotland does not have a significant oversupply of livestock manures at a regional level.
- There are environmental challenges associated with manure and slurry production and storage at an enterprise level, particularly for water quality. The potential for local surpluses has therefore been the focus of this study.
- Surpluses of manure can lead to localised environmental impacts if they are not managed correctly. The factors influencing the success of manure exchanges rely on the recognition of costs and barriers and on investment in establishing agreements.

1.3 Conclusion

A strategic, regional or national scale exchange model is unlikely to be cost effective for greenhouse gas abatement. However, there is some potential to support exchanges of manure through improved local distribution (i.e. within a holding or with close neighbours).

Our model design has therefore focused on factors involved in the effective establishment of local exchanges involving one-to-one relationships between exporting and importing farms, and based on the key drivers and factors at an individual enterprise/exchange level.

The most useful measures are those that focus on the utilisation of manure nutrient value and that form part of an integrated policy alongside other drivers such as water quality (Water Framework Directive), Nitrate Vulnerable Zones, air quality and productivity.

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1 Manure arisings and uses in Scotland

The relatively temperate and wet climate in Scotland supports livestock farming with conditions supporting extensive grassland and more intensive, improved pasture. The livestock sector produces manures, which can be a valuable nutrient source for production of crops and pasture. Improved grassland makes up 25% of the land area and supports more intensive beef, dairy and sheep production. Production of cereal and horticultural crops are a significant feature of Scottish agricultural production accounting for 10% of land use. These areas receive inputs of nutrients, both from manufactured fertiliser and manures.

Manures arising from a livestock system can provide benefits in terms of nutrient recycling, improving soil quality, reducing the need for synthetic fertiliser and ensuring soils are able to provide multiple services. However, to achieve some of these benefits there needs to be careful planning of manure management, nutrient use, and field application.

The term manure, in this report, refers to manure in the form of slurry, farmyard manure or poultry manure.

Slurry arises on farms where little or no bedding is used in livestock houses, and the excreta, a mix of urine and faeces, is in a liquid form, usually with added water that has been used for washing down floors and yards. Slurry has a dry matter content between 2% and 10%, and more typically between 4% and 6% (AHDB, 2020). Slurry can be managed as a liquid (i.e. it can be pumped and moved using hoses and tankers). Some of the suspended solids can be separated out and handled separately. Storage is in tanks, pits or lagoons, and agitation is usually needed to facilitate movement and spreading to land. The nitrogen content of slurry can range from 1.5 to 5 kg N per tonne (AHDB, 2020).

Farmyard manure arises where bedding is used, usually straw, and results in a material that is handled as a solid, stacked in piles or heaps for storage. Dry matter content is typically around 25% for farmyard manure from cattle and sheep (AHDB, 2020), but is highly variable depending on the degree of drying or wetting in storage. The nitrogen content of farmyard manure is typically in the range 5 to 10 kg N per tonne (AHDB, 2020).

Poultry manure (not usually referred to as farmyard manure) is also handled as a solid and has a higher dry matter, typically 20% to 80% (AHDB, 2020). The nitrogen content is typically in the range 9 to 37 kg N per tonne (AHDB, 2020).

Solid manures have a lower water content and higher nitrogen content than slurry, and are easier to store on farms which import the manure. These factors result in solid manures being preferred over slurry by arable farmers.

The most recent update for Scottish Greenhouse Gas Emissions (Scottish Government, 2019b) shows agriculture and associated land use accounted for 24% of all greenhouse gas emissions, with methane the most significant proportion of this at 44%. Methane comes from enteric fermentation and from manures. The management of manures is therefore a critical element in mitigating greenhouse gas emissions from the sector.

There are specific proposals within the Climate Change Plan (Scottish Government, 2018) to improve the utilisation of nitrogen and manage soils better. This report responds to the commitment in Policy Outcome 4 to undertake a feasibility study into the establishment of a slurry/manure exchange programme. By establishing exchanges there is potential for better utilisation of slurries and manures, providing both organic matter and nutrients, reducing reliance on synthetic fertilisers, and reducing direct emissions from overapplication of manures on livestock holdings.

National summary data are available from the Scottish Government (Scottish Government, 2016a) showing that in 2016 1,250kt of manures were exported from farms, which is 6% of the manure spread to land. This leaves a significant proportion of manure arisings that could potentially be part of a manure exchange.

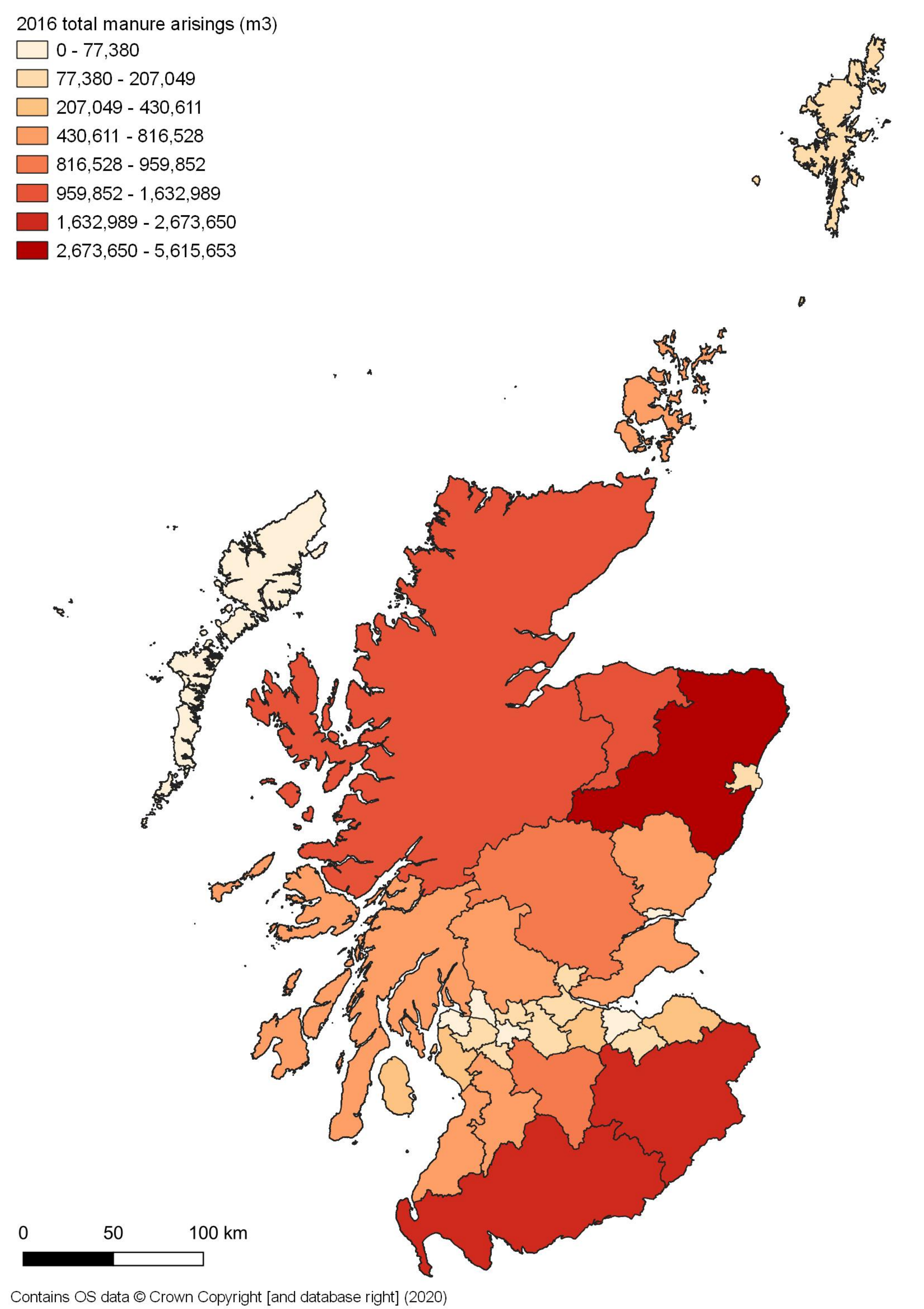
The livestock sector in Scotland comprised 1.73 million cattle, 6.77 million sheep, 319,000 pigs and 14.9 million poultry in 2018 (Scottish Government, 2019a). Data on manure arisings are presented in Table 1 and Figure 1; additional analysis is also provided in Appendix 7. In this report we consider manure arisings from all these main types of farmed livestock, but the focus for exchanges tends to be on cattle manures. This is because the data on manure arisings show that pig and poultry are mainly in areas where there is plenty of arable land, and it is likely that manure arisings are already used on that arable land. These systems are typically co-located with arable holdings or as discreet systems and will be required to have appropriate areas to store and spread manures. The greatest need for improved nutrient use is on farms with housed cattle (dairy and beef), in areas that have high manure arisings, a high area of grassland, but relatively little arable land.

Table 1: Manure arisings by region and source 2016.

Livestock source	Region (note: map of regions as presented in Scottish Government, 2016a is shown in Appendix 1: Location of Scottish sub-regions.)				
	North East (m^3)	North West (m^3)	South East (m^3)	South West (m^3)	**Scotland** (m^3)
Dairy	257,579	138,067	497,557	3,060,409	**3,985,494**
Beef	5,050,287	2,000,702	3,625,206	4,487,615	**15,331,844**
Sheep	57,034	242,378	441,160	290,590	**1,047,152**
Pigs	1,426,543	61,455	648,939	42,494	**2,179,430**
Poultry	73,495	7,081	453,695	128,031	**847,876**

Data derived from Ricardo report: Farmyard Manure and Slurry Management and Anaerobic Digestion in Scotland – Practical Application on Farm (Ricardo, 2017).

Figure 1: Manure arisings by local authority, 2016



2 Review of manure exchanges

2.1 Types of exchanges in the UK and beyond

The literature review did not identify a significant number of scientific papers relating to manure exchanges - just eight peer reviewed papers. However, due to the informal nature of many of the examples found we have drawn on additional sources including websites, farming press and farming support organisations such as the Agriculture and Horticulture Development Board (AHDB). Additionally, there are several formal reports which include reference to manure exchanges as examples of mitigations for water quality or greenhouse gas (GHG) mitigation. A summary of the literature is presented in Table 2 with a full list presented in Appendix 3.

Our search for evidence was directed towards locations with broadly similar climate and farming systems, and the evidence we found came mainly from North America, Denmark and the UK.

We have identified three broad examples of schemes which support the movement of manures and would be relevant within the Scottish context. These are summarised as follows:

Muck-for-straw – There are many examples of muck-for-straw exchanges; they are the most common type described in the literature and in the insight provided by both the project team and stakeholder feedback. These are characterised by informal (most often local) arrangements between livestock and arable enterprises. They involve the supply of straw (usually for bedding material) from the arable enterprise with the corresponding return of the straw based manure, which is then used as a nutrient and organic material source within the cropping system. It is believed muck-for-straw is the most common exchange taking place between businesses, although as this is often done unofficially between neighbouring farmers or friends, it is not formally documented.

Manure exports – These arrangements tend to fall into two distinct groups but with the common themes of external actors exerting pressure or influence to encourage exchanges of manures to mitigate a surplus of nutrient.

- Government/legislative drivers, involving many enterprises. Examples found within the review include legislative driven exchanges in Denmark: Nitrate Vulnerable Zone (NVZ) regulations have encouraged export of slurries and manures with over 50% of livestock enterprises engaged. In Romania, the government provided collection and management facilities supporting very small-scale units with poor infrastructure to improve manure management and reduce diffuse pollution impacting on Water Framework Directive (WFD) requirements.
- The second grouping here are characterised by the facilitation of exchanges by a third sector with interests outside agriculture e.g. catchment management charities. They often include services supporting the offering - and seeking - of manures and form a part of a wider programme of engagement and activity within the interested parties' influence. Examples include website-based exchanges and tend to be involved in catchment management. These exchanges (examples we found were in North America) are characterised by relatively small volumes of exchange forming a small element of wider work programmes.

Movement of livestock, or away-wintering – We have identified a third category of exchange which is relevant to Scotland but less typical of the pure exchanges of manures. We are aware of this activity happening in England and Scotland, although we did not search more widely for this activity in other countries. The movement of livestock from the West of Scotland to the East for finishing is a well-established practice in Scotland. This is driven by the physical characteristics of the climate and land capability, offering the opportunity to locate livestock closer to overwintering feed stock in a more favourable climatic area. These overwintering schemes, however, also provide the benefit of reducing movements of feed and bedding while also creating manure sources adjacent to arable areas able to utilise them. While not in the truest sense a manure exchange, the impact is the same: manure production is moved away from areas without capacity to manage and utilise the manure to those that are able to use them.

Table 2: Examples of types of exchange found in research (full list in Appendices)

Type of exchange	Source	Location	Businesses involved	Volume exchanged	Driver
Muck-for-straw	FarmersGuide.co.uk (2013)	Suffolk	Pig and arable Dairy and arable	3.5 tonne pig muck for 1 tonne of straw. 1 trailer of dairy muck for 3 acres of straw.	Nutrient need; excess material; improved soil quality
	FarmersWeekly.co.uk (2012)	Fife	Livestock and arable	200ha spring barley straw for 1,000-1,200t muck	Arable without infrastructure to support livestock and a need for organic nutrients.
Exporting manure	Asai et al. (2014b)	Denmark	Dairy and arable	Not specified	Policy, Nutrient Directive, water quality
	Deschutes soil and water conservation district – Manure exchange program (2020) (Online portal)	Oregon	Livestock farmers (Horse, cattle, sheep) and gardeners/arable farmers	5-100 cubic yards (3.8-76.5m^3)	To share resources, connect farmers, improve soil health, overcome manure storage challenges
Away-wintering	Colin MacPhail (phone interview, April 2020)	Lothians & North Ayrshire	Cattle and arable	Herd of 50 cattle to graze	Cattle farmer looking for alternative wintering options, arable looking to improve soil health.

2.2 Supply and Demand Factors influencing exchanges

While there are clear potential benefits both in terms of environment impact and improved nutrient management, the key factors influencing the success of manure exchanges relate to the individual enterprise and the willingness and ability to either export or receive manures. Although the policy drivers are focused on sector-level opportunities for reductions in GHG emissions, the critical factors influencing the success of exchanges are very locally focused. Details of the key supply and demand factors influencing the establishment and success of manure exchanges are presented in Table 3 and Table 4 below.

Table 3: Supply factors influencing exchanges

Factor	Description	Mitigation	Evidence
Manure type - Slurry/Manure	Manure type (farmyard manure (FYM) or slurry and livestock type: cattle, pig, poultry) will influence the opportunities and arrangement of exchanges. Slurry is generally more difficult to manage and transport long distances so the exporter will need suitable infrastructure and equipment. FYM is a solid material requiring less specialist equipment for transportation.	Support for investment in infrastructure and in developing collaborative partnerships to facilitate exchanges. Supporting advice/information to identify opportunities and recognise the value of the benefits that can be provided through exchanges.	(Waterton, et al., 2018) (EIP-AGRI, 2017)
Transport distance/Logistical costs	This factor depends on the material being transported. The energy/nutritional value of manures can drive the viable logistical opportunities of exchanges, in some examples, FYM can be transported reasonable distances (up to 40km). However, examples of slurry transportation report much lower distances of <10km. Dry matter content has been identified as a critical driver of logistics costs and therefore viable exchanges.	Additional information provided to potential exporters on the logistics and economics of transport cost will help to support movement of manures. Low value and high transport costs will constrain exchanges, alternative approaches such as dewatering, composting, moving livestock and supporting local exchanges should mitigate these limitations, but may add additional costs and constraints.	Asai et al, 2014a
Cost/value of manures	Nutrient values are often not rewarded to livestock farmer, either marginal value paid by the receiving farm or increased costs are incurred by the exporter with either little or no value exchanged. Livestock and muck-for-straw exchanges provide value for both parties, but it is important to consider the costs associated with transporting manures which may constrain the establishment of exchange agreements.	Support to partner local exchanges and to identify value for all parties.	Asai et al, 2014b (EIP-AGRI, 2017)

Factor	Description	Mitigation	Evidence
Consistency of materials	Composition of manures can be variable. The method of storage, age of manure and species all effect the nutritional composition. Demand for consistent and known quality materials can add costs and complexity to exporters due to payments for testing or nutrient management plans.	Encouraging understanding and valuation as part of nutritional planning can add value within the farm enterprise as well as for facilitation of exchange arrangement. Supporting farmers to recognise the savings and value of manure within their own business will also support their exchange of surplus manures off site.	EIP-AGRI, 2017 MacLeod, 2016
Handling, storage, spreading infrastructure	Manure suppliers are often expected to shoulder the burden of transport, handling and spreading of the manures. It is important to clearly outline responsibilities in the exchange to reduce excessive burden, responsibility and constraints to the manure supplier. Receiving farms have high expectations for the exporters to fit with their requirements; the perceived low value of manures and difficulty in their handling often support a unbalanced perspective in exchanges.	Careful planning and set up of agreements can help to establish responsibilities and also help in recognition of value within the chains. These agreements are critical in all new exchanges.	Farmers Guide, 2013 Asai, et al., 2014a
Skills, labour and equipment	The infrastructure involved in the collection, storage, movement and spreading of manures as well as the skills and experience are located within the livestock sector. Exports to arable farming systems can therefore involve sharing of these resources or a requirement for exporters to support the receiving farms. This can add burden on the exporting business, often not recognised of valued. Conversely, the nutritional value in manures is often not fully recognised within the livestock sector. T this leads to the manures being undervalued, and the potential for mis-management.	Providing information to both livestock and arable business to help in the recognition and identification of the value of manures for both enterprises, and the processes involved in exchange to identify the opportunities and responsibilities, should help increase awareness and support increasing exchanges.	EIP-AGRI, 2017 Farmers Guide, 2013 Asai, et al., 2014a

Factor	Description	Mitigation	Evidence
Transaction costs	These relate primarily to the investment in time, money and formal agreement on the side of the supplier. Significant time and cost can be incurred in seeking and agreeing the terms of exchange. Perceptions of manure exporters influence their willingness and strategies to enter into exchanges and vary according to the unique characteristic of each farm; these include farmer age, agricultural education, farm size, farm type, labour availability and social relationships.	Support for transactional arrangements, including: • information, guarantees, partnering opportunities and logistical support to reduce time commitment; • meeting information demands of exporters by de-risking and clarifying many of the time-consuming elements of investing in developing exchanges.	Asai et al, 2014a

Table 4: Demand factors influencing exchanges

Factor	Description	Mitigation	Evidence
Manure type-Slurry/Manure	The type of manure can influence the opportunities and ease of arrangement of exchanges. Many farmers report a reluctance to receive slurries, preferring FYM. Reasons for this include easier management, storage and spreading opportunities.	Processing or outside influences can support investment in infrastructure and in developing collaborative partnerships to facilitate exchanges. Supporting information would be useful to highlight the value of the benefits provided through exchanges.	EIP-AGR, 2017
Transport distance/ Logistics costs	The energy/nutritional value of manures can drive the viable logistical opportunities of exchanges. Dry matter content has been identified as critical to logistical costs and therefore viable exchanges. Multiple sources identify this as a critical element in exchanges: high nutrient and dry matter content manures can be transported reasonable distances (up to 40km). In some examples, however, slurries can only be transported relatively short distances <10km. The impact of this factor would be determined by whether the provider would deliver material, or if it is down to the receiving side to collect it.	Additional information provided to potential exporters on the logistics and economics of transport cost will help to support movement of manures. Low value and high transport costs will constrain exchanges. Alternative approaches such as dewatering, composting, moving livestock and supporting local exchanges should mitigate these limitations, but may add additional costs and constraints.	EIP-AGR, 2017 Asai et al, 2014a

Factor	Description	Mitigation	Evidence
Cost of manures	Evidence suggests manure/slurry is a relatively low value product. Through exchanges such as muck-for-straw, value is provided to both parties, but consideration is needed on transport and handling costs. Manure/slurry is a natural product with variable consistency, so the price must be low to compete with traditional mineral fertilisers. This value must consider: higher logistics cost (transport and application), less predictable nutrient content and availability, physical parameters (compatibility with handling and spreading equipment) and potential nuisance (odour, dust) for neighbours. It could be difficult to sell manure for a high price unless there is evidence to show the nutrient content and therefore value.	Support to partner local exchanges and to identify value for all parties.	EIP-AGRI, 2017
Consistency of materials	The importance of consistency of manure would depend on the demand side. For example, organic farming requires full traceability to ensure no contamination whereas other businesses may be willing to accept material without information regarding nutrient value. But it is clear that bio-based fertilisers are highly valued by all farmers for their content of organic matter and contribution to soil quality, yielding a certain soil amelioration value.	Encouraging understanding and valuation as part of nutritional planning can add value within the farm enterprise as well as for facilitation of exchange arrangement.	EIP-AGRI, 2017
Handling, storage, spreading infrastructure	It is important to outline who will be responsible for each role in the exchange; this will be determined by who has the equipment and skills. This will reduce excessive burden on one side.	Careful planning and set up of agreements can help to establish responsibilities and also help in recognition of value within the chains. These agreements are critical in all new exchanges.	EIP-AGRI, 2017

Factor	Description	Mitigation	Evidence
Skills and equipment	The demand side would usually be an arable-based system, which may not always have suitable equipment to manage livestock manure. Consideration would be needed on how to mitigate this issue, for example, through negotiations with the livestock farmer to agree a labour input or shared equipment.	Careful planning and set up of agreements can help to establish responsibilities.	EIP-AGRI, 2017
Traceability	Traceability is important for organic farms receiving manure. Without this, there may be a reluctance to engage in exchanges and accept material. Information is required on the production chain highlighting any risk of contamination with manure from non-certified sources. This is unlikely to be an issue for conventional farms at present, but traceability requirements might expand to these farms in the future.	Encouraging understanding and valuation as part of nutritional planning can add value within the farm enterprise as well as for facilitation of exchange arrangements. Organic certification schemes and supply chain protocols are driving some of these concerns.	EIP-AGRI, 2017
Communications /Accessibility Relationships	If engaging in a long-term collaboration for exchange, it is important both parties are communicating effectively with each other to maintain trust. This will include the supplier notifying the demand side of any land management changes that may impact quality or volume of material available.	Careful planning and set up of agreements can help to establish responsibilities and also help in recognition of value within the chains.	Asai et al, 2014b

Factor	Description	Mitigation	Evidence
Transaction costs	These relate primarily to the investment in time, money and formal agreement on the side of the supplier. However, both parties will invest significant time and cost in seeking and agreeing the terms of exchanges. Perceptions of manure exporters influence their willingness and strategies to enter into exchanges and vary according to the unique characteristic of each farm. These include farmer age, agricultural education, farm size, farm type, labour availability and social relationships.	Support for transactional arrangements, including: • information, guarantees, partnering opportunities and logistical support to reduce time commitment; • meeting information demands of exporters by de-risking and clarifying many of the time-consuming elements of investing in developing exchanges.	Asai et al, 2014a

3 Greenhouse gas abatement potential

3.1 Scenario definitions

We have defined three scenarios, representing low, medium and high levels of engagement by farm businesses, to allow illustrative estimates of GHG savings.

Estimates of GHG emissions changes are based on the overall assumption that exported manures are applied to arable land, and if they had not been exported, they would have been applied to grassland where the supply of nitrogen is above the optimum. In this situation, the exported manure is not replaced by inorganic nitrogen fertiliser, with savings in soil emissions of the greenhouse gas nitrous oxide. It is assumed that the import of manures does displace inorganic fertiliser on the arable land, with savings in greenhouse gas emissions from fertiliser manufacture. The level of displacement is based on the available nitrogen content of the manures.

We used three scenarios (Low, Medium and High engagement) defined as 30%, 50% and 70% of land in Scotland on farms with housed cattle being involved in manure export. The scenarios focus on where there is greatest need for improved nutrient use. Farms with housed cattle (dairy and beef) are the main types of farm in this situation, for example, in the south-west of Scotland. Therefore, our scenarios include only exchange of manures from housed dairy and beef cattle.

Details of the scenarios are given in Appendix 8.

3.2 Estimates of changes in greenhouse gas emissions

Estimates of the change in GHG emissions (increase/decrease in emissions) for each scenario, compared with business as usual, and at a Scotland level are shown in Table 5. These results are presented in the context of agricultural GHG emissions in Scotland. They show the net savings as percentages of total GHG emissions for the agriculture sector in Scotland in 2017 (National Atmospheric Emissions Inventory outputs for Devolved administrations[2]).

These estimates of GHG emissions change include consideration of soil emissions of nitrous oxide, savings in manufactured fertiliser used, and additional transport. Details of the methods and assumptions used in the calculation of the GHG emissions are presented in Appendix 8: Greenhouse gas abatement potential: scenarios.

The results show GHG mitigation at a level that is small relative to Scotland's agriculture emissions.

The highest net greenhouse gas emission saving is for Scenario 3 (70% engagement): for 50% of arisings being exported, the estimated net greenhouse gas saving is 51.6 kt CO_2e per year, which is 0.68% of Scotland's agriculture emissions in 2017.

[2] https://naei.beis.gov.uk/reports/reports?report_id=991

Table 5: Change in displacement of inorganic N fertiliser and associated greenhouse gas emissions for three scenarios of farm engagement in manure exchange schemes (30%, 50% and 70% of farms engaged in manure exchange activities compared with business as usual of 6%), per percentage point of manure exported from engaged farms, and for 50% of manure exported from engaged farms.

	Change per 1% of manure exported from engaged farms			Change if 50% of manure exported from engaged farms		
Scenario	S1 30% engagement	S2 50% engagement	S3 70% engagement	S1 30% engagement	S2 50% engagement	S3 70% engagement
Inorganic N displaced (t)	51	85	119	2,558	4,263	5,969
N_2O emission saving (t CO_2e/y)	317	529	741	15,872	26,454	37,036
Fertiliser manufacture saving (t CO_2e/y)	172	286	401	8,584	14,307	20,029
Transport emissions (t CO_2e/y)	47	78	109	2,346	3,910	5,475
Net saving in GHG emission (t CO_2e/y)	442	737	1032	22,110	36,850	51,590
Net GHG saving (proportion of Scotland agriculture GHG emissions)	0.0058	0.0097	0.0136	0.2923	0.4871	0.6819

4 Analysis of manure exchanges and alternative approaches

4.1 Strengths, weaknesses, opportunities and threats (SWOT)

Analysis of strengths, weaknesses, opportunities and threats (SWOT) is presented in Appendix 4. Here we present a summary of that analysis in Tables 6 to 8.

SWOT Summary Findings

Exchanges offer multiple benefits to both parties: they ease the challenges of manure management and storage on farms producing manure, reduce emissions and provide potential benefits to soil health, biodiversity, water and air. They can lead to cost savings and can support better compliance with regulatory measures such as NVZs or General Binding Rules.

Our analysis also identifies barriers in the successful establishment of manure exchanges including: logistical costs; perceived low value; increased management time; and risks relating to regulatory compliance, relationships, agronomic considerations and biosecurity. These barriers all increase the resistance to investing in exchanges.

Table 6: Muck-for-straw: strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• Multiple benefits to both parties • Reduces the need for artificial fertilisers, thereby reducing GHG emissions • Reduced chemical input can benefit biodiversity • Benefits for soil health	• Depends on good relationships between partners • Carting manure to neighbours and bringing back straw is time consuming and can be expensive • There is a short application window between harvesting and drilling for application of manure to land • Quality of manure/slurry can be variable • Manure bulky to transport • Manure is a relatively low-value product
Opportunities	**Threats**
• Improved soil fertility • Makes use of excess material, reducing waste • Cost savings through reduced fertiliser use • Supply of trace elements that may not be in conventional fertiliser • More work for transport contractors	• If located in an NVZ, rules make it difficult to store solid manure in a heap before spreading • Importing weed seeds in manures and straw (e.g. blackgrass) • Lack of understanding of nutrient needs • A lag time between application and soil benefits • Increased need for bioenergy feedstock competes with use of straw as livestock bedding

Table 7: Exporting manure, strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• Decreases storage requirements • Enables compliance with regulations, e.g. in nitrate vulnerable zones • Supplies nutrients to receiving farms	• Often this is a one-way transaction rather than an exchange • Exporters are typically not paid the full nutrient value of the manure • Online portals do not encourage strong collaboration between farmers
Opportunities	**Threats**
• Online portals are a way of reaching a wider scale audience and sharing information • Encourages sustainable nutrient management • Promotes water quality management • Contributes to pollution abatement targets	• Odour complaints following application to land away from the livestock farm • Low engagement and lack of trust between partners

Table 8: Away wintering, strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• Improved soil health and fertility • Provides an outlet for manure during the winter • Avoids spreading manure at the wrong time • Reduced chemical input can benefit biodiversity	• Access to advice • Lack of necessary skills • Investment needed for infrastructure such as housing, fencing and water supply
Opportunities	**Threats**
• Improved herd health and fertility increases cattle value • Better use of resources • More resilient soils through increased organic matter content and the presence of cattle	• Arable businesses may have a lag of a few years before they see some of the benefits • Health challenges such as ticks • Increased workload at overwintering farms

4.2 Political, economic, social, technological, environmental and legal (PESTEL) analysis

Analysis of political, economic, social, technological, environmental and legal/regulatory (PESTEL) factors is presented in Appendix 5. We present a summary in Table 9.

PESTEL summary findings

There are opportunities to meet multiple policy objectives through the establishment of agreements that lead to better utilisation of manure nutrient resources. These can lead to better targeting of nutrients and reductions in requirements for inorganic fertilisers. Improved nutrient use efficiency would have a positive impact on GHG emissions and on losses of nutrients to the environment (water and air), and help build soil organic matter. Effective collaboration between farmers is a critical component in the successful implementation of any form of manure exchange; this often requires facilitation and advice to ensure the needs of all parties involved are met. The PESTEL analysis highlights many opportunities for forming these relationships but as highlighted, communicating these benefits can be challenging. The ‘hassle factor’ relating to communication, organisation and planning in the busy lives of farmers with low perceived or immediate benefits is a significant barrier in the establishment of exchanges.

Necessity has driven an effective form of manure exchange in Scotland with the movement of store animals to finishing farms. This is often the movement of animals from upland to lowland farms which makes best use of the resources available and results in manure ending up in places where it is needed. It is facilitated by a network of markets trading the animals between farmers. At present, there is no facilitation available for the movement of manure and slurry which is a potential barrier to exploiting the opportunity of moving it to where it can be most valuable. A considerable barrier to this is the relative low value compared to the volume of the material and the planning and organisation required to get it to the right place at the right time.

The PESTEL analysis highlights many benefits of the manure exchange concept but the constraints relating to relationships and collaboration can be challenging to overcome when the perception of value is low.

Table 9: Summary PESTEL analysis: All exchange types

	Opportunities	Constraints	Potential mitigation measures
Political	• Benefits multiple agriculture policy objectives relating to, GHG, water, air, soil • Circular economy objectives • Contributing to priority catchments objectives	• Lack of clear specific policy objective • Biomass energy policy incentivising alternative uses of straw	• Future policy support for integrated climate, air and water policy • Facilitation through advice services
Economic	• Cost savings for both sides; through reduced cost of fertiliser/bedding material • Productivity and Yield improvements	• Scope limited by logistical costs • Full value of manures not compensated for (seen as low value by receivers); cost burdens for exporters • Perception and understanding of the benefits compared to the 'hassle factor'	• Establishing long-term contractual relationship between the parties • Improved facilitation and advice on benefits
Social	• Opportunity to build and strengthen relationship with surrounding farmers • Bringing two businesses together to share workload will free up time and resources if done effectively	• Experience of a failed collaboration could make businesses reluctant to engage with the process again • Increase management and support required (reduced free time)	• External facilitation to assist the collaboration and preparation of agreements
Technological	• Increased nutrient performance • Reducing volume and concentrating nutrient content and consistency	• Reliability of other businesses to provide material • Availability of equipment and skills and associated cost of accessing them	• Support for infrastructure • Advice and guidance on new technologies and their application
Environmental	• Improve soil health and resilience • Reduced inputs will benefit biodiversity, air and water • Improved habitat through reduced eutrophication nitrate deposition	• Risk of contamination, heavy metals, and pathogens/weeds • Environmental capacity, lack of suitable land locally to receive manures without environmental impact	• Careful planning and utilisation of manures with specific reference to nutrient requirements and risks

	Opportunities	Constraints	Potential mitigation measures
Legal/Regulatory	• Improved compliance e.g. Cross Compliance, General Binding Rules, Nitrate Vulnerable Zone regulations and Water Framework Directive	• Odour complaints from people in the surrounding area • Trust between partners and potential disputes both formal and informal • Potential increased noncompliance on receiving farms due to lack of planning or awareness of relevant regulations	• A written agreement is between farmers. Contractual responsibilities should be clear to all

5 Factors influencing model design

At a national level, policies seek to reduce the impact of agriculture on the environment. In this study the primary policy driver is the better use of manures to reduce the need for inorganic nitrogen fertilisers and thus cut GHG emissions.

Supply and demand can function at two distinct scales. In the context of this review the main considerations are the requirements for the nutrient nitrogen, the production of manures and the value of these manures in offsetting the purchase and utilisation of manufactured nitrogen fertilisers. In our analysis of the nutrient requirements and the nutrient provision from manure arisings in Scotland, we have identified that at a sectoral and regional level there are no significant surpluses in organic nitrogen supply (Appendix 7). The analysis of the nutrient requirements by region indicate that there are greater requirements for nitrogen in all areas of Scotland than can be supplied by manure sources.

Our analysis of the potential for climate mitigation from the offsetting of manufactured fertilisers has identified that potential savings in GHG emissions, through strategic and large-scale movements of manures across Scotland, are small relative to emissions from the agriculture sector (Table 5).

From the reviews we have identified, we can see that the drivers in some other parts of Europe, e.g. Denmark and the Netherlands, are not of the same scale in Scotland. In Scotland, there is not a significant oversupply of livestock manures that requires a strategic response to mitigate impacts on water and to encourage distribution of manures in large volumes.

While there is not a strategic driver to distribute manures more equitably across Scotland, there do undoubtably remain local drivers to improve the management and utilisation of manures. At an enterprise level, there are challenges associated with manure and slurry production and storage. Locally, manures can and do pose problems for the environment, particularly for water quality. These problems can come from both the quantity and the timings of manure applications. Therefore, supporting the exchanges of manure through improved local distribution (i.e. within a holding or with close neighbours) should be the focus of model design.

The factors which limit the entry into exchanges have been identified in Table 3 and 4. The design of any scheme to encourage the increased exchange of manures should focus on the barriers identified. A key finding from Asai et al (2014a) indicates that the focus on the logistical and economic factors of exchanges, while important, has led to the neglecting of more fundamental constraints which may influence exchange establishment. The drivers and constraints can be very varied and depend upon the specific circumstances and values and experiences of each enterprise. The critical factors that should be considered in the design of any manure exchange are summarised in Table 10.

As the drivers for exchanges are unlikely to warrant significant investment in new support programmes, the model design could be based around current mechanisms supporting agriculture. These could provide a low cost and established service to support improved practice and uptake. The services available, for example, through the Climate Change Plan or Farming Advisory Service, could provide these facilities.

Table 10: Factors influencing model design

Factor	Design requirement	Possible Mitigation Measure
Manure type Slurry/Manure	Influences desirability and nutrient content. Reports that arable farmers prefer to receive farmyard manure indicate a requirement to explore and expand the potential for slurry utilisation. The model will have to provide transparency on the opportunities for both exporters and receivers of all manure types.	Potential supporting policies through air quality management e.g. increased contractor provision of improved spreading equipment.

Factor	Design requirement	Possible Mitigation Measure
Transport distance/Logistics costs	The large volumes, but potential low value, of manures constrain the distance they can be viably transported. This is a primary blocker and any models will have to facilitate and improve transparency of the costs and infrastructure.	A review of the economics and cost benefits of all manure movements (including straw, slurry and manures as well as livestock) could provide reliable data on providers, costs and opportunities to improve understanding and planning.

Factor	Design requirement	Possible Mitigation Measure
Cost/value of manures	Many farmers perceive that exporters do not receive the true value of manures in exchanges. On the other hand, arable importers do not perceive significant value in the manures they receive. Presenting the value to both sides will be crucial in supporting agreement design and equitable distribution of value. The value of organic materials is influenced both by their logistical constraints but also by sludge and digestate practices. In the wastewater and Anaerobic Digestion sectors these organic materials are waste by-products of the primary process and so have been supplied as low or no cost to farms, often without full recognition of the benefits they can offer.	A review of the costs and values of manures for both exporters and receivers to improve understanding for potential agreements.
Handling, storage, spreading infrastructure	The infrastructure to manage manures exists within the livestock businesses. Arable farmers see the lack of infrastructure as a barrier to utilising manures. Model design will need to deal with these constraints; infrastructure will need to be shared or made available through contracting arrangements.	Seek to review with other policy mechanisms (WFD and Clean Air) if improved spreading and storage facilities could be developed as part of more integrated policy delivery – this could include increased access to facilitate better local nutrient distribution.
Skills, labour and equipment	Lack of skills relating to the management of both manures and livestock can be a significant barrier to all types of exchange. Supporting the sharing of skills and equipment or upskilling of receiving farmers will be required to maximise opportunities and remove barriers to new exchanges. Labour and equipment burdens often lie with the exporters.	Provide supporting information on the skills and labour requirements.

Factor	Design requirement	Possible Mitigation Measure
Transaction costs	Transaction costs relate to the time, cost and emotional investment in setting up the exchange. This aspect is often not considered in the development of exchange models but is perhaps the most critical in ensuring effective exchanges are firmly established. While the process is unique for each enterprise, support is a critical element of model design. Consideration of model agreements and the use of facilitators should also be considered.	Information explaining the processes and considerations in the establishment of agreements should help to provide clarity and confidence in the process. Develop guidance and facilities to support the identification and establishment of partners and of agreements will help resolve any barriers identified.
Relationships	Most exchanges begin from relationships that are already established. However, the establishment of trust and continued relationship management is needed to ensure a successful exchange in the medium to longer term.	A review of the mechanisms and support that will ensure identification of suitable partnerships should be undertaken to inform model design. The role of agreements, facilitation and mechanisms to identify potential partnerships should be included.
Communications	Frequent, open and honest communications with ease of access and punctuality have all been identified as key elements of successful exchanges. This should be considered alongside any relationship management and transaction development. Supporting the establishment of effective communications, particularly in the early stages of an exchange should be included in model design.	Clear expectations in terms of frequency, method and formality of communications should be included in supporting information. Clear supporting guidance and facilitation should be included in model design. Consider the use of case studies as part of this supporting material to bring the model to “life”.
Planning	Understanding of the key processes and requirements for all parties involved needs to be set out in the transaction stages. Supporting the careful planning of the movement, timing and logistics of the exchange will be critical to ensure the environmental and production benefits are realised. Planning elements should be included within model design to ensure exchanges make best use of the opportunities.	Guidance on best practice nutrient management of manures and nutrients should be included. Consider the inclusion of advice and support to ensure skills and expertise are available.

Factor	Design requirement	Possible Mitigation Measure
Regulatory issues	While there are clear regulatory drivers which support the establishment of exchanges, there are risks that both receivers and exporters could be exposed to additional regulatory requirements they are unfamiliar with, e.g. general binding rules, animal welfare requirements, and additional cross compliance requirements. Inclusion of the opportunities and considerations for compliance should be included within the transaction discussions.	Provision of clear guidance on the movement and use of slurries in the context of exchanges, recognising that this knowledge may not exist in the receiving business.

We have intentionally not limited the model design considerations to the specific exchange models explored in section 2. It is clear from the evidence that the individual circumstances and actors involved in exchanges will drive the specific requirements and design. The above factors are applicable to the successful and long-term establishment of any type of manure exchange. Additional analysis of the opportunities and constraints has been done through SWOT and PESTEL analysis in Appendix 4 and Appendix 5.

6 Conclusions

Our analysis of manure arisings indicates the drivers for manure exchanges in Scotland vary to those identified in other European examples (Denmark and Flanders/France) where large-scale intensive livestock production has led to significant nitrogen surpluses and associated impacts on water quality and ecosystems.

The regional analysis of manure arisings and nutrient requirements in Scotland indicate that there are no substantial strategic requirements for the movement of manures from surplus to deficit areas at this scale. The analysis of the GHG mitigation potential indicate that manure exchanges are likely to deliver small percentage reductions in Scotland's agriculture emissions. In our scenario analysis, the highest net greenhouse gas emission saving is 51.6 kt CO_2e per year, which is 0.68% of Scotland's agriculture emissions in 2017. This was for a scenario with 70% engagement of farms with housed cattle engaged in manure exchange activity, and with 50% of manure arisings from engaged farms being exported.

The relatively low abatement potential and lack of surpluses at the macro-regional level indicate there is likely to be a poor cost effectiveness in developing policy measures to implement or encourage national scale uptake of manure exchanges.

However, there remains value in reviewing the potential of manure exchange schemes in support of improved manure management both within an enterprise (ensuring manure value is spread across an entire holding) and through increased participation in local exchange agreements. While a more detailed assessment of the localised surpluses at a sub-regional or enterprise scale was outwith the scope of this research, there is evidence that optimising manure use within a farm itself is often currently limited by logistics. Several studies show that fields close to animal housing tend to accumulate nutrients while fields at the edge of a holding become depleted. (MacLeod, 2016). This suggests that local surpluses do exist and can have significant consequences for the local environment (Waterton, et al., 2018). Improvements in the management of manures on farm offers potential to mitigate a number of environmental impacts including greenhouse gas emissions.

Model design has therefore focused on factors involved in the effective establishment of local exchanges involving one-to-one relationships between exporting and importing farms, and based on the key drivers and factors at an individual enterprise/exchange level.

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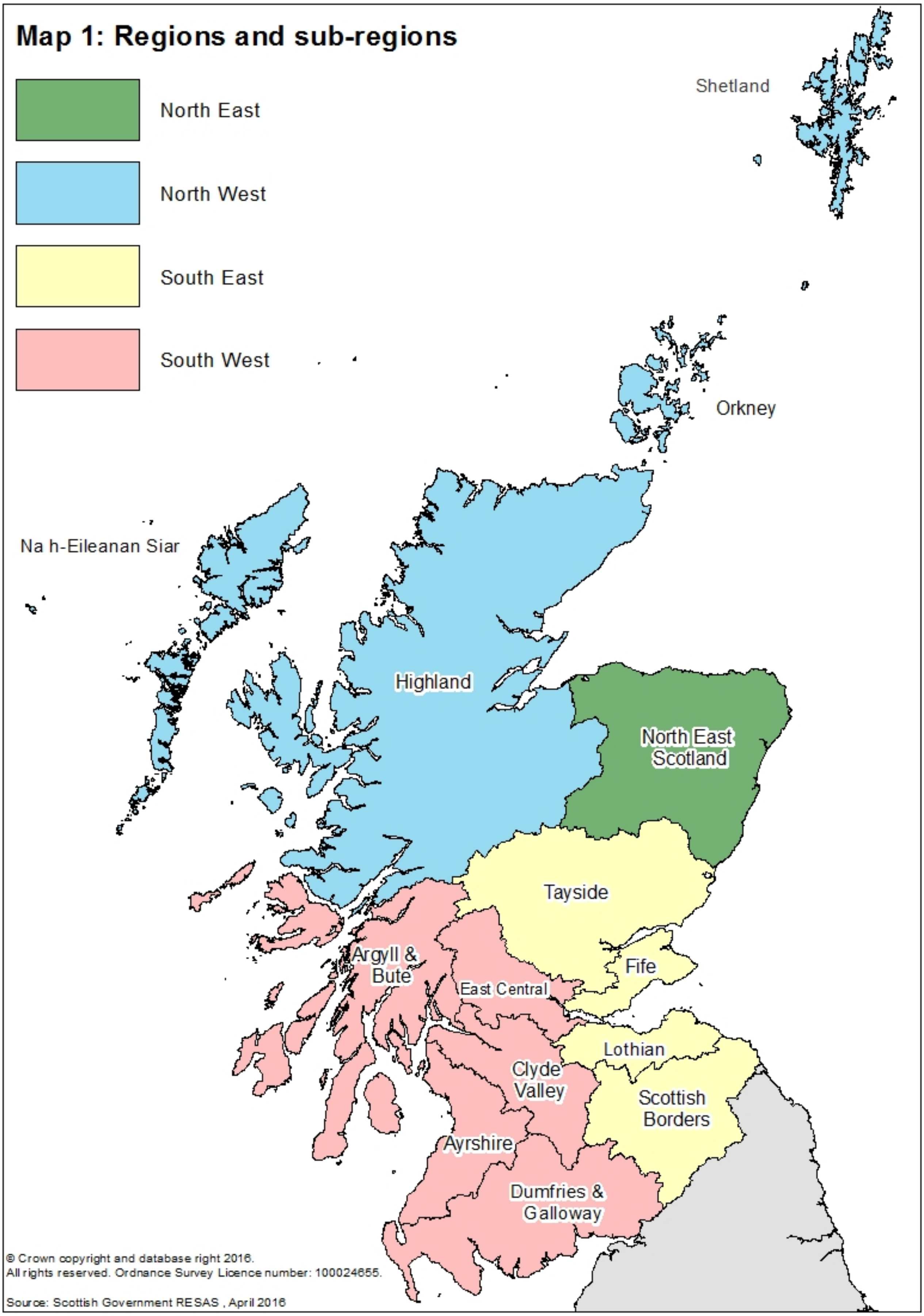
8 Appendix 1: Location of Scottish sub- regions.



9 Appendix 2: Livestock locations

Figure 2: Cattle per hectare in parish, 2015

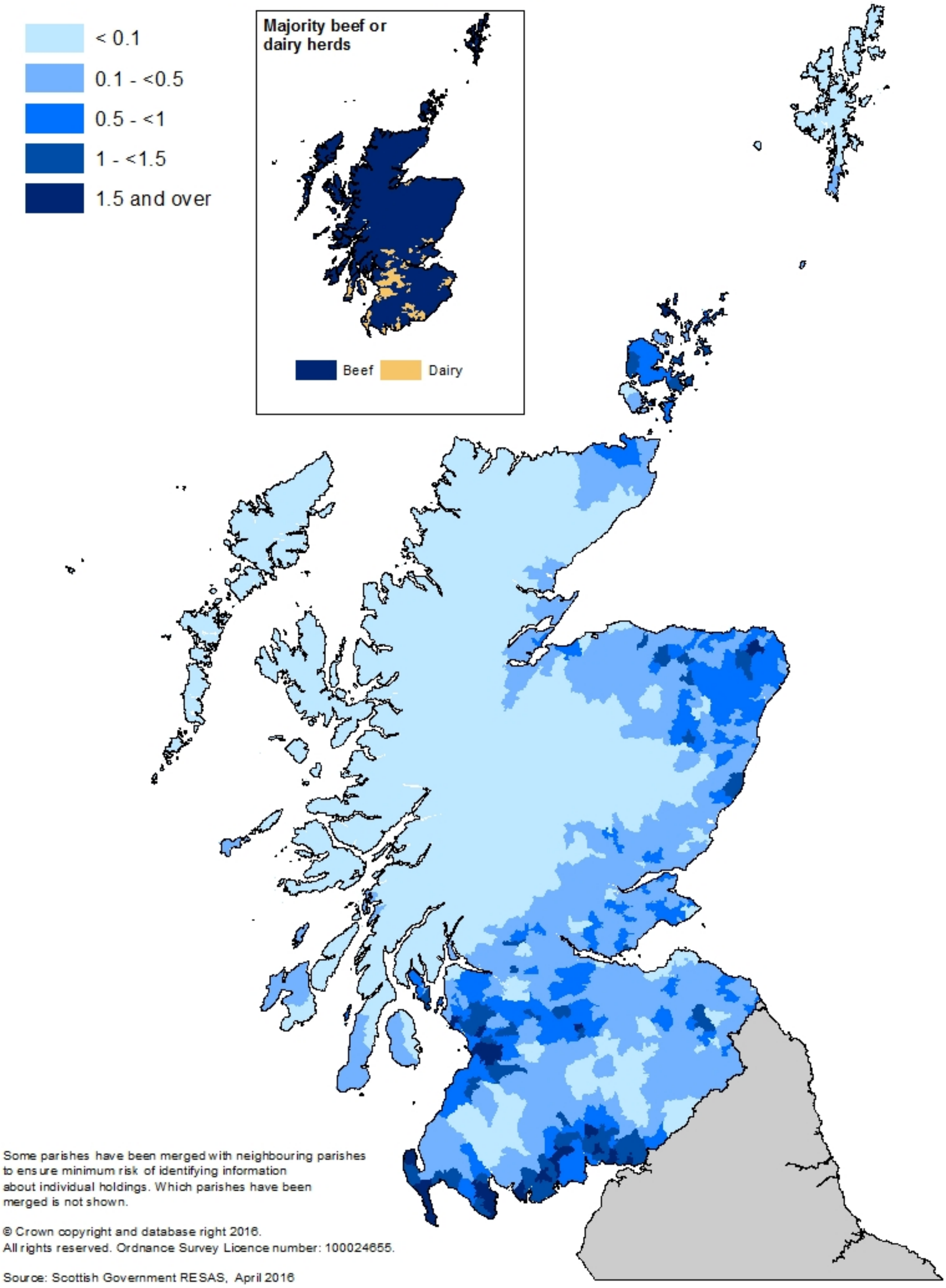
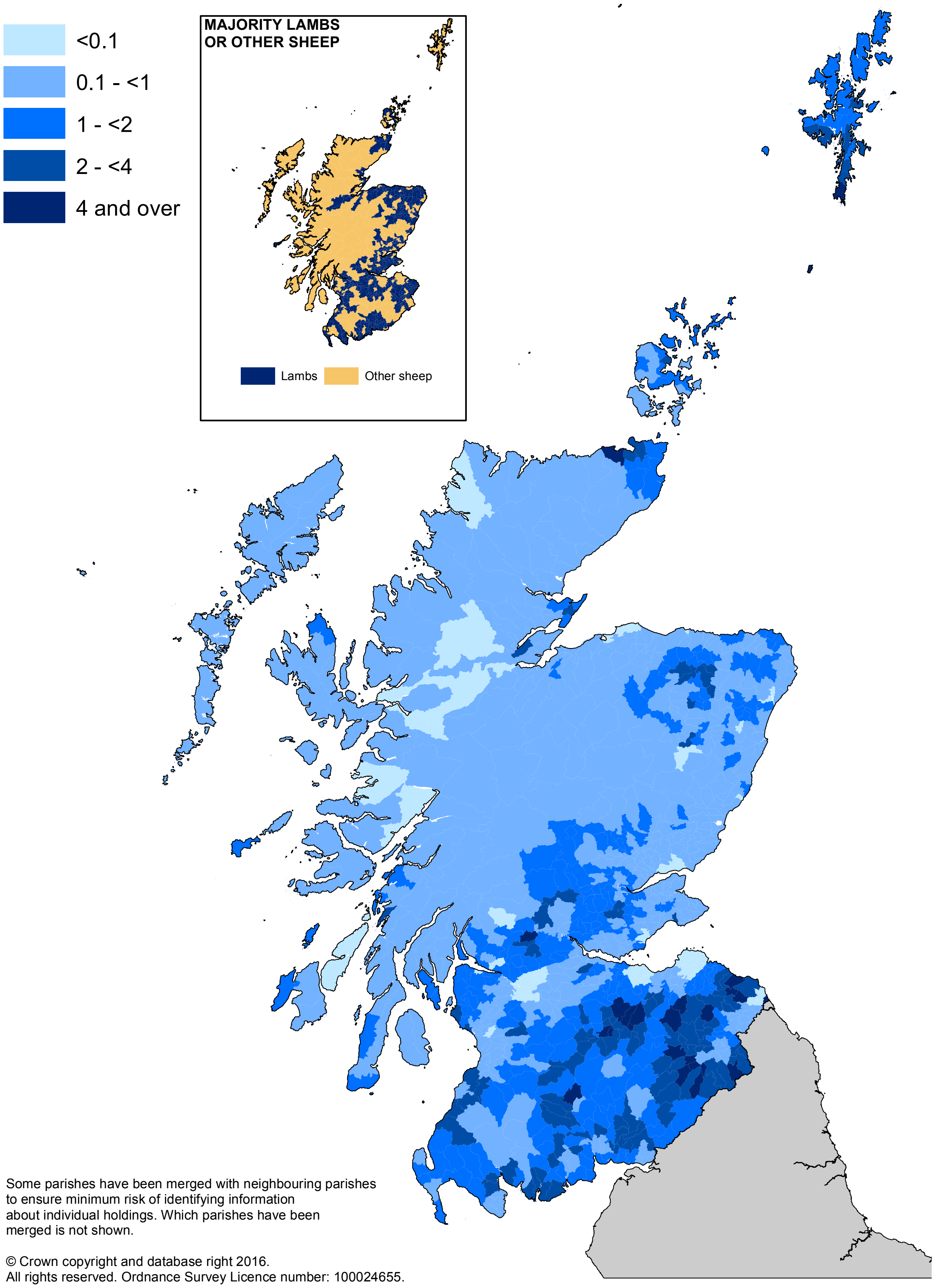


Figure 3: Sheep per hectare in parish, 2015



Some parishes have been merged with neighbouring parishes to ensure minimum risk of identifying information about individual holdings. Which parishes have been merged is not shown.

Source: Scottish Government RESAS, April 2016

10 Appendix 3: Full list of types of exchange found in the evidence review

Table 11: Full list of types of exchange found in evidence review

Type of exchange	Source(s)	Location	Businesses involved	Volume exchanged	Driver
Muck-for-straw	(Farmers Guide, 2013)	Suffolk	Pig and arable Dairy and arable	3.5 tonne pig muck for 1 tonne of straw. 1 trailer of dairy muck for 3 acres of straw.	Nutrient need; excess material; improved soil quality
	FarmersWeekly.co.uk (2012)	Not specified	Pig and arable	Not specified	To reduce need for compound fertiliser
	FarmersWeekly.co.uk (2012)	Fife	Livestock (not specified) and arable	200ha spring barley straw for 1,000-1,200t muck	Arable not having infrastructure to support livestock and a need for organic nutrients.
Exporting manure	Asai, 2013	Denmark	Cattle, pig and arable (mix between conventional and organic)	Not specified	Policy, Nutrient Directive, water quality
	Asai, et al., 2014a	Denmark	Cattle, pig, arable (mix between conventional and organic)	Not specified	Policy, Nutrient Directive, water quality, shortage of land
	Asai, et al, 2014b	Denmark	Dairy and arable (organic and conventional)	Not specified	Policy, Nutrient Directive, water quality
	Asai et al., 2014b	Denmark	Arable, conventional dairy, organic dairy and organic pigs	Not specified	Policy, Nutrient Directive, water quality

	Battel, 2006	Michigan	Not specified	Not specified	Nutrient management, reducing phosphorus offloading into surface waters
	Illinois Extension, 2020 (Online portal)	Illinois	Livestock farmers to gardeners/landscapers	Not specified	Excess manure, nutrient need for gardeners
	Clark Conservation District, 2020 (Online portal)	Washington State	Livestock farmers (horse, cow, llama, goat) and gardeners/landscapers	Given in variable units, expressed as truck loads, or square yards	Excess manure, nutrient need for gardeners
	Pierce Conservation District, 2020 (Online portal)	Washington State	Livestock farmers (horse, alpaca, chicken) and gardeners/arable farmers	Not specified	Maintaining quality of local waterways and groundwater, better use of excess manure
	Deschutes Soil and Water Conservation District, 2020 (Online portal)	Oregon	Livestock farmers (horse, cattle, sheep) and gardeners/arable farmers	5-100 cubic yards (3.8-76.5m^3)	To share resources, connect farmers, improve soil health, overcome manure storage challenges
Away-wintering	Colin MacPhail (phone interview, April 2020)	Lothians & North Ayrshire	Cattle and arable	Herd of 50 cattle to graze	Cattle farmer looking for alternative wintering options, arable looking to improve soil health.

11 Appendix 4: SWOT analysis

Table 12: Muck-for-straw: strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• If the collaboration is organised effectively, both parties involved will benefit (Farmers Guide, 2013). • Multiple benefits to both parties • FYM is a more cost effective way to obtain resources for bedding or fertiliser (Farmers Guide, 2013). • Reduces the need for artificial fertilisers on arable farms (Farmers Guide, 2013).reduces the need for artificial fertiliser, reducing GHG emissions and improving biodiversity • Reduced chemical input will benefit biodiversity and gradually reduce greenhouse gas emissions associated with fertiliser (Nowak, et al., 2013). • Benefits to soil health are becoming a more significant driver, farmers are recognising the need to add organic material to their soils. (Bell et al, 2018) Benefits to soil health	• Strength of collaboration depends on the relationship between farmers, if this is not good then an exchange won't be successful. (Asai, et al., 2014a) • Depends on good relationships between partners • Carting muck to neighbours land and bringing back straw is time consuming and can be expensive (Farmers Guide, 2013). • Timing: short application window between application of manure/slurry and harvesting and drilling, if manure/slurry is not received in time the exchange won't work. • Quality of manure/slurry can be variable (Battel, 2006) • Manure can be quite difficult to transport in mass volume so a large scale exchange is unlikely to be successful (Nowak, et al., 2013). • Muck is a relatively low-value product, businesses will need to be located nearby to each other to see most benefit (Bell et al, 2018)

• Opportunities	• Threats
• Arable farmers to improve soil fertility after swapping artificial fertiliser for muck – improving yields. • Effective way to make use of excess material, reducing waste (Farmers Guide, 2013). • Cost savings through reduced fertiliser usage (Farmers Guide, 2013). • Improved soil quality by using organic matter, improving microbial life and soil structure. This will improve the long-term soil quality (Farmers Guide, 2013). • Trace elements present in slurry/manures that may not be in conventional fertiliser (Farmers Guide, 2013). • More work for contractors specialising in transporting straw/manure (Farmers Guide, 2013).	• If located in an NVZ, rules make it difficult to store muck in a heap while waiting for spreading (Farmers Guide, 2013). • Risk of importing weed seeds in manures and straw (e.g. blackgrass) (Farmers Guide, 2013). • Lack of understanding of nutrient need from the arable side, the lag time from application to soil benefits may deter arable businesses (MacPhail, 2020). • Increased need for green feedstock for bio-burners may encourage arable businesses to sell straw rather than swap for manure (MacPhail, 2020).

Table 13: Exporting manure , strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• Beneficial if slurry/manure storage is limited (Waterton, et al., 2018). • Enable compliance with regulation e.g NVZ and WFD. (Asai, et al., 2014a) • Online portals are a quick way to access contact details for businesses with excess manure. • Exporting manure assists regions that are nutrient deficit. • Online portals allow information to be shared easily, such as age of manure, volume available, animal type, whether loading/delivery is available. • Reduce contamination of local water supplies by making use of excess nutrients (Pierce Conservation District, 2020).	• Often a one-way exchange which may not have equal benefits. • The exporters are typically not paid the full nutrient value of the manure • Online portals are basic, it would be difficult to form a strong collaboration between farmers using this format. • Information uploaded to online systems may not be updated often. • Online format appear to be a one-off exchange, less likely to form long-term successful collaborations. • Drivers required from outside parties to encourage and facilitate exchanges due to the one sided nature of benefits (e.g. regulation, catchment management)
Opportunities	**Threats**
• Online portals are a way of reaching a wider scale audience. • Exporting manure is a way to achieve sustainable nutrient management and promote water quality issues (Asai, et al., 2014a; Pierce Conservation District, 2020). • Reducing pollution by exporting manure contributes to meeting pollution targets set out by governments (e.g. Nitrate Directive in Denmark, NVZ rules) (Asai, et al., 2014a).	• Concerns over neighbours complaining about the odour of manure applications on fields that normally receive artificial fertiliser (Battel, 2006). • Trust is required between partners, without this they may act in self-interest, reducing integrity of the collaboration (Asai, et al., 2014a).

Table 14: Away wintering, strengths, weaknesses, opportunities and threats (SWOT)

Strengths	Weaknesses
• Improved soil health and fertility through increased application of organic matter (MacPhail, 2020). • Effective way for livestock businesses to reduce problems of removing slurry/manure from housing during the winter (MacPhail, 2020). • Making use of nutrients that would otherwise be wasted, some businesses are spreading manure at the wrong time just to get rid of waste (MacPhail, 2020). • Cattle improve biodiversity in hills and uplands (MacPhail et al, 2020). • Reduced chemical input will benefit biodiversity and gradually reduce greenhouse gas emissions associated with fertiliser (Nowak, et al., 2013).	• An adviser or external party familiar with both businesses may be needed to bring the businesses together, not all farmers have access to this (MacPhail, 2020). • People with the right skills are needed for this to be a success, those who have a knowledge of livestock and arable production are often specialised and skills will need to be shared between enterprises or brought in (MacPhail, 2020). • The correct infrastructure is required to keep livestock on land where they wouldn't normally, therefore investment may be needed for fencing and water sources (MacPhail, 2020). •
Opportunities	**Threats**
• Improved herd health and fertility, this will therefore increase value of cattle (MacPhail, 2020). • Better use of resources, making farming more economically viable in hills and uplands (MacPhail, 2020). • Creating more resilient soils through increased organic matter content and the presence of cattle. This is particularly important considering variable weather conditions in recent years (MacPhail, 2020). • Increase the presence of cattle in regions where they are no longer farmed (MacPhail, 2020).	• Livestock farmers will see the immediate benefits of this collaboration, but arable businesses will have a lag of a few years before they see any benefits, this may deter them from becoming involved as they have nothing tangible to measure in the short term (MacPhail, 2020). • Livestock may be moving to land bringing health challenges such as ticks or nutrient deficits from new land (MacPhail, 2020). • The work balance between the two businesses risks being uneven due to increased maintenance required for cattle (MacPhail et al,, 2020).

12 Appendix 5: PESTEL analysis

Table 15: Muck-for-straw

	Opportunities	Constraints	Potential mitigation measures
Political	• Benefits multiple agriculture policy objectives relating to, GHG water, air, soil • Circular economy objectives • Contributing to priority catchments objectives	• Lack of clear specific policy objective • Biomass energy policy incentivising alternative uses of straw.	• Future policy support for integrated climate, air and water policy. • Facilitation through advice services
Economic	• Cost savings for both sides; through reduced cost of fertiliser/bedding material • Productivity – yield	• Competitive usage of straw in bio-burners • Scope limited by logistical costs	• Establishing long-term contractual relationship between the parties
Social	• Opportunity to build and strengthen relationship with surrounding farmers. • Bringing two businesses together to share workload will free up time and resources if done effectively.	• Experience of a failed collaboration could make businesses reluctant to engage with the process again. • Increase transport time and cost • Potential odour impacts on neighbours • Perception and understanding of the benefits compared to the 'hassle factor'	• External facilitation to assist the collaboration and prepare an agreement. .
Technol ogical	• Increased nutrient performance is a developing technology	• Reliability of other businesses to provide material	• Support for infrastructure – links to other policy drivers to ensure high cost benefit of support.

	• Reducing volume and concentrating nutrient content and consistency	• Availability of equipment and skills and associated cost of accessing them	
Environmental	• Using FYM instead of using artificial fertilisers will help improve the soil health (Farmers Guide, 2013). • Reduced chemical input will benefit biodiversity and gradually reduce greenhouse gas emissions associated with fertiliser (Nowak, et al., 2013). • Better management and distribution of phosphate Reduced eutrophication, water and air quality and ecosystem impacts	• Reluctancy to receive manure due to perceived risk of manure containing weed seeds (Battel, 2006). • Environmental capacity, lack of suitable land locally to receive manures without environmental impact.	• Support trusted relationships with clear objective and responsibilities. • Careful planning and utilisation of manures with specific reference to nutrient requirements and risks.
Legal/Regulatory	• Improved compliance with Cross Compliance, General Binding Rules, Nitrate Vulnerable Zone regulations and Water Framework Directive	• Odour complaints from people in the surrounding area due to manure applications on fields where it is not usually applied (Battel, 2006). • Trust between partners is integral for the collaboration to work.. This includes effective communication and keeping each other fully informed of any management changes or changes in land use (Asai, et al., 2014a; MacPhail, 2020). • Potential increased non compliance on receiving farms	• A written agreement is between farmers is recommended . This should detail how much material is exchanged and who will be doing what role (AHDB, 2018).

		due to lack of planning or awareness of regulations	

Table 16: Exporting manure

	Opportunities	Constraints	Potential mitigation measures
Political	• Reductions in GHG and improvements relating to, water, air, soil and circular economy objectives as well as contributing to priority catchments objectives	• Lack of specific policy driver • Biomass energy policy incentivising alternative uses of straw	• Future policy support for integrated climate, air and water policy
Economic	• Lower manure storage and management costs at the providers' premises • Reduced costs through optimised nutrient efficiency • Decreasing costs of water quality issues associated with manure	• Manure providers often not paid the full value for their manure and they also may incur additional costs for example transport, handling and spreading • Limited storage and application equipment of receiving farms, investment in infrastructure will increase cost and reduce likelihood of exchanges occurring (relates primarily to slurry)	• Improved facilitation between providers and recipients improving the efficiency of the nation-wide manure distribution
Social	• Opportunity to build and strengthen relationship with surrounding farmers • Bringing two businesses together to share workload will free up time and resources if done effectively	• Experience of a failed collaboration could make businesses reluctant to engage with the process again • Increase transport time and costs • Potential odour impacts on neighbours • Perception and understanding of the benefits compared to the 'hassle factor' • Reliability of other businesses to provide material	• External facilitation to assist the collaboration and prepare an agreement

	Opportunities	Constraints	Potential mitigation measures
Technological (including agronomic)	• Separation and processing to concentrate the liquids • Circular economy	• Arable farmers reluctant to receive manure due to risk of heavy manure application machinery damaging land (Asai, et al., 2014a) • Arable farmers may have a preference to mineral fertiliser due to nutrient content, application timing and odour (Asai, et al., 2014a)	• Support for infrastructure – links to other policy drivers to ensure high cost benefit of support
Environmental	• FYM instead of using artificial fertilisers will help improve the soil health (Farmers Guide, 2013) • Reduced chemical input will benefit biodiversity and gradually reduce greenhouse gas emissions associated with fertiliser (Nowak, et al., 2013) • Better management/distribution of phosphateReduced eutrophication, water and air quality and ecosystem impacts	• Reluctancy to receive manure due to perceived risk of manure containing weed seeds (Battel, 2006) • Environmental capacity, lack of suitable land locally to receive manures without environmental impact	• Support trusted relationships with clear objective and responsibilities • Careful planning and utilisation of manures with specific reference to nutrient requirements and risks
Legal/Regulatory	• Improved compliance with Cross Compliance, General Binding Rules, Nitrate Vulnerable Zone regulations and Water Framework Directive	• Trust between partners is integral for the collaboration to work.This includes effective communication and keeping each other fully informed of any management changes or changes in land use (Asai, et al., 2014a; MacPhail, 2020) • Odour complaints from people in the surrounding area due to manure applications on fields where it is not usually applied (Battel, 2006) • Potential increased non compliance on receiving farms due to lack of planning or awareness of regulations	• A written agreement is required between farmers before the exchange starts. This should detail how much material is exchanged and who will be doing what role (AHDB, 2018)

Table 17: Away wintering

Type	Opportunities	Constraints	Potential mitigation measures
Political	• Can support a thriving livestock sector and the ambition to increase high quality food from Scotland • Reductions in GHG and improvements in productivity • Co-benefits relating to, water, air, soil and Circular economy objectives as well as contributing to Priority catchments objectives	• Lack of specific policy driver • Biomass energy policy incentivising alternative uses of straw. • Could result in livestock being moved from low risk to high risk areas	• Future policy support for integrated climate, air and water policy • Integrated agricultural, environmental and animal welfare policies could support these exchanges
Economic	• Reduced greenhouse gas emissions associated with fertilisers • Increased efficiency in finishing cattle • Cost savings on fertiliser • Increased farming yields	• Receiving farms do not gain a significant benefit for a number of years, perception of value can be low as a result	• Facilitators or advisers to support collaboration between parties
Social	• Providing jobs and possible entry opportunities into the sector • Bringing two businesses together to share workload will free up time and resources if done effectively.	• Experience of a failed collaboration could make businesses reluctant to engage with the process again • Increase transport nuisance • Odour impacts on neighbours	• An adviser or professional body familiar with both businesses should assist the collaboration to ensure shared objectives and mutual understanding of agreements
Technological (including agronomic)	• Improved nutrient and soil management through more sustainable nutrient sources and soil management	• Suitability of fields may be vary between businesses requiring new infrastructure to facilitate livestock movements (Asai, et al., 2014a)	• Advice and support through grants should help to understand the requirements and to identify suitable technological solutions

Type	Opportunities	Constraints	Potential mitigation measures
Environmental	• Improved soil health and fertility, this will improve overall soil resilience in the long term. This is particularly important considering recent extreme weather events • Reduced chemical input will benefit biodiversity and gradually reduce greenhouse gas emissions associated with fertiliser (Nowak, et al., 2013)	• Environmental capacity, lack of suitable land locally to receive manures without environmental impact. • Lack of suitable land to receive livestock could lead to impacts of soil and water	• Support trusted relationships with clear objective and responsibilities. • Careful planning and with specific reference to nutrient requirements and risks and animal welfare requirements
Legal/Regulatory	• Improved compliance with Cross Compliance, General Binding Rules, Nitrate Vulnerable Zone regulations and Water Framework Directive	• Trust between partners is integral for the collaboration to work,. This includes effective communication and keeping each other fully informed of any management changes or changes in land use (Asai, et al., 2014a; MacPhail, 2020) • Potential increased noncompliance on receiving farms due to lack of planning or awareness of regulations	• A written agreement needs to be put together outlining what has been agreed between both parties, preferably with input from an adviser (MacPhail, 2020)

13 Appendix 6: Case study exchange examples.

Case study 1: Muck-for-straw

Location

This case study is not location-specific as muck-for-straw exchanges are often conducted around an informal agreement. The details outlined here are based on information found during the evidence review and relevant to muck-for-straw exchanges in general.

Who is involved

A muck-for-straw agreement will involve a partnership between a livestock business and an arable business. Ideally situated locally to one another.

Description

An arrangement between a livestock farmer and an arable farmer where straw for bedding is provided in exchange for livestock manure for fertiliser. Based on the research for this study, it is believed this is a very common exchange taking place at a small scale, often between farmers who are relatives or neighbours. If agreements on quantities are put in place, this is a relatively straightforward exchange where both parties should benefit.

Why does it happen

The priorities of the two businesses will differ. Key drivers found in the evidence review are as follows:

- Livestock farmers may look for collaboration to reduce waste from excess manure/slurry if storage is limited, and also to receive bedding for livestock, reducing costs associated with purchasing bedding.
- Arable businesses are driven by nutrient requirement for crops, nutrients received through manures may reduce the need for chemical fertilisers, therefore reducing costs in the long term. Applying organic manures to land also helps improve soil resilience, providing long term benefits.

Challenges

The strength of the collaboration between businesses is dependent on trust between businesses, it is important that an agreement is put in place outlining volumes of material that will be exchange between businesses to avoid conflict. It is also important that the businesses are located within a reasonable distance to each other: muck is a relatively low-value product, so transporting it far will reduce the benefits of the exchange. A prominent challenge identified through stakeholders was that arable businesses will have a lag time between receiving manure and the subsequent benefits, while livestock farmer benefits will be fairly immediate. Therefore, it is important arable businesses are aware of the benefits to encourage their involvement. Because of this, there is a risk that arable businesses may choose to sell green feedstock to bio-burners rather than swap for manure. The uncertainty in the quality of manure could also be a risk, for example, weed seeds could be brought onto land, the consequences of this could be severe, particularly with blackgrass.

Evaluation of success

Based on discussions with stakeholders, this collaboration can be very successful. But this is based on businesses trusting each other and agreements in place regarding volume of material exchanged. Some of the associated benefits found include reduced costs on both sides, improved biodiversity and soil health associated with reduced chemical input.

Relevance in Scotland

This exchange is highly relevant in Scotland. Examples found in the evidence review included those in Scotland and were reported to be successful exchanges. Although a number of challenges have been identified, with appropriate mitigation, these can be relatively simple to overcome.

Case study 2: Exporting manures, online portal

Location

The Pierce Conservation District (PCD) is located in North West Washington, USA. The manure exchange program provides contacts for farmers and landowners across this region, near to Seattle.

Who is involved

The PCD is the facilitator in this manure exchange. It works with local landowners and public agencies to maintain natural resources in NW Washington, including promoting sustainable agriculture. The target audience for this exchange is livestock farmers with excess manure to give away or sell to gardeners or arable farmers with a need for nutrients.

Description

The exchange program aims to prevent groundwater contamination by providing a platform for livestock farmers to advertise their excess manure. A downloadable list has been put together of livestock farmers who have manure to give away or sell. The list provides contact information, location, type of manure and some commentary with information on the bedding type, whether loading and/or delivery is available and if there is a cost involved. This is a one-way exchange of material, but some farmers providing manure have requested payment (it is assumed this will be agreed when contacted as no details are online).

The online portal is easy to access by searching online, and is simple and user-friendly.

Why does it happen

The drivers for this exchange will vary depending on the business/individual:

- As facilitator, the PCD aim is to prevent pollution of local water sources.
- From the livestock farmer perspective, this program will resolve problems of excess manure on farm and reduce wasted nutrients.
- The gardeners/arable farmers looking for excess manure will gain access to nutrients and organic matter aiding growth of produce.

Challenges

It is not clear how often the contacts for those with excess manure is updated, and there is little information about the amounts available, so there is risk of outdated information being stored online. A one-way exchange may not have equal benefits. Farmers providing the manure may also be asked to deliver it using their own equipment. The online format could make it complicated to form a strong collaboration between businesses, instead having a one-off short term exchange. This format on a wider scale may be challenging, as each online portal could only serve a certain radius to be efficient and reduce excessive transportation distances; enough businesses in each region would need to register to justify the portal. Another challenge is that businesses would need to be aware of the system to join, and some may be reluctant to do so. This could be associated with limited experience in using online systems, or they feel they are able to export sufficient manure by other means e.g. word of mouth or leaving bags outside farms for people to collect.

Evaluation of success

This is difficult to measure as we are just viewing a snapshot of the online portal and do not know how widely it is being used . Some associated benefits with using this system could include improved water quality through reduced run-off and improved soil health.

Relevance in Scotland

This type of platform could be rolled out in Scotland, although attention would need to be paid to the challenges associated with getting businesses to register for the system and ensuring sufficient numbers to justify the system.

Case study 3: Away-wintering

Location

This collaboration involved bringing together a livestock business in the West (North Ayreshire) and two host arable farmers in the East of Scotland (Lothians).

Who is involved

Norman Stirrat at Skelmore Mains Farm in the West, a livestock farmer with a Luing suckler herd, collaborated with an existing partnership between two arable farmers in the East, Bill Gray at Prestonall Farm and Peter Eccles at Saughland Farm. Bill and Peter farm on different estates but have partnered as host farmers. The collaboration of these businesses was facilitated by Colin Macphail (MacPhail consulting) and Fergus Younger (SAOS)

Description

This project involved moving cattle from the West of Scotland to land in the East of Scotland. The cattle were moved in October 2019 and returned in March 2020. They were moved onto fields in the East where they strip-grazed stubble crops, while being provided with silage and straw (provided by Saughland Farm) and occasionally mineral buckets (provided by Skelmore Mains Farm) as feed. This pilot project focused on moving livestock instead of moving forage, trialling a low cost system with better utilisation of grazing ground. The project involved the businesses forming trusting relationships with the aim of achieving mutual benefits.

Before the collaboration began, the responsibilities of each partner were clearly laid out in a written agreement. At the host farms, all livestock management responsibilities were allocated to Saughland Farm; this included feeding and daily stock checks. Prestonhall Farm was not expected to have any involvement with livestock management. Any stock illness requiring more than a one-off treatment was the responsibility of Skelmore Mains Farm, as was any cost incurred due to fallen stock.

Why does it happen?

Drivers to this exchange will vary depending on priorities of the business. In this instance, objectives of each business involved were clearly stated:

Norman was looking for alternative wintering options for his herd of Luing cattle, driven by the challenges involved in housing cattle on the farm during this time. This included the winter labour requirement to clear out manure/slurry and feed silage. Norman was also looking to free up some time in the winter to work on diversification projects. Additional drivers include improving the quality of the cattle herd which will in turn, improve financial and environmental viability. The outcome of this trial would help gage whether this is something that would be done on an annual basis.

Peter and Bill collaborated as the host farmers: between them they had sufficient land, feed and labour resources to successfully outwinter the cattle. Coming from an arable perspective, their drivers were improved soil health and nutrient content, in turn creating more resilient soils and contributing to increased yields in future crops. There was also some financial benefit through straw and silage sales to Norman.

Challenges

The key challenge to this type of exchange being successful is finding the farmers who have the correct skill set and who will be open with each other, building trust and mutual respect. With this outwintering project, the businesses were brought together by external professionals, Colin MacPhail (MacPhail Consulting) and Fergus Younger (SAOS), who facilitated a formal agreement. The collaborating businesses decided what would be involved in the exchange, overseen by Colin and Fergus. Another significant challenge in this type of agreement is that the livestock farmer will see an immediate benefit to collaboration whereas the arable business may not see any benefit for a number of years. This risks arable farmers being reluctant to engage.

Evaluation of success

Based on a telephone interview with Colin MacPhail, this collaboration for away-wintering was very successful, but as this project has only recently been completed, the full outcomes are not yet available. Expected benefits include reduced transport costs, lower risk of overloading manure stores, improved soil health and resilience, and improved biodiversity in hills and uplands due to presence of cattle.

Relevance in Scotland

This project is highly relevant to farming practices in Scotland. The aims of this trial collaboration are to produce an evaluation of the likelihood of this type of exchange being rolled out on a wider scale. This will be particularly beneficial to ensure livestock farming remains possible in disadvantaged areas.

14 Appendix 7: Manure nutrient arisings and nitrogen requirements for Scotland.

The annual arisings of manure-sourced nitrogen and an estimate of the nitrogen requirement supporting current practice in Scotland have been calculated. Details are presented below. These data support both the assessment of the greenhouse gas abatement potential, as described in Appendix 8, and an assessment of the supply and demand for nitrogen (including organic nitrogen) and its distribution across Scotland by region.

Method – Manure nitrogen arisings.

The data presented in Table 1 were sourced from a previous Ricardo study undertaken for ClimateXChange (Ricardo, 2017) and show the total arisings of manure in Scotland. These use the 2016 June agricultural census data and apply per capita figures for manure or slurry production. Default values for nitrogen content by manure type and livestock species, based on the current nutrient management guidance in Scotland, have been applied to the total manure arisings to calculate the total and available nitrogen contained within the manures. This facilitates a direct assessment of the nutrient value of manures against nutrient requirements and use of manufactured fertiliser.

The standard nitrogen content factors were sourced from the Technical note TN650 Optimising the application of bulky organic fertilisers (SRUC, 2013) and reflect the values used in Scotland for nutrient management planning purposes.

The resulting manure nitrogen content quantities by area and by source are presented in Table 18. This table provides both the total nitrogen content and the readily available nitrogen. For the purposes of this report, the readily available nitrogen values have been used to estimate nitrogen source substitution and for the consideration of agronomic response. Total nitrogen availability will increase over time but this process relies on the mineralisation of organic nitrogen and should be considered a longer term process and not directly related to the in-year substitution of inorganic fertiliser. It should be accounted for, however, in the planning of nitrogen requirements.

Method – Nitrogen use by crop type and area

Data on cropping were derived from the Economic Report on Scottish Agriculture 2016 Edition (Scottish Government, 2016b), and data on the typical nitrogen fertiliser practices in Scotland from the British Survey of Fertiliser Practice (BSFP) 2018 (Defra, 2019). Nutrient utilisation in Scotland was derived by applying the area-based nutrient practice as reported in BSFP to the area of crop grown as derived from the Economic Report on Scottish Agriculture. The analysis is presented in Table 19.

Table 18: Nutrient N Values in Scottish Manures (kg) (based on data from 2016 and 2018)

Sector	System	North East - Manure Nitrogen		North West - Manure Nitrogen		Sum of South East regional total		Sum of South West regional total		Scotland	
		Total N	Available N	Total N	Available N	Total N	Available N	Total N	Available N	Total N (kg)	Available N (kg)
		(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg)
Dairy	Slurry	423,333	195,385	145,859	67,319	609,949	281,515	6,606,826	3,049,304	7,785,967	3,593,523
	FYM	341,130	34,113	295,085	29,508	1,061,434	106,143	1,869,559	186,956	3,567,208	356,721
Beef	Slurry	695,677	321,081	1,808,958	834,904	964,874	445,326	3,207,717	1,480,485	6,677,225	3,081,796
	FYM	17,217,789	1,721,779	4,697,816	469,782	12,319,687	1,231,969	11,713,960	1,171,396	45,949,251	4,594,925
Sheep	Slurry	0	0	198,362	79,345	10,523	4,209	0	0	208,886	83,554
	FYM	205,324	20,532	668,532	66,853	1,634,912	163,491	1,046,125	104,613	3,554,893	355,489
Pigs	Slurry	1,369,222	950,849	221,236	153,636	889,349	617,604	152,682	106,029	2,632,490	1,828,118
	FYM	3,766,332	376,633	0	0	1,446,832	144,683	295	30	5,213,459	521,346
Poultry	FYM	264,581	26,458	25,491	2,549	2,301,371	230,137	460,911	46,091	3,052,354	305,235
									Total (kg)	78,641,732	14,720,708
									tonnes	**78,642**	**14,721**

Table 19:Nutrient N requirements in Scotland by land use (kg)

	North West Total	North East Total	South East Total	South West Total	Scotland Total
Crops and fallow:	*kg*	*kg*	*kg*	*kg*	*kg*
Wheat	577,121	2,629,506	13,425,291	1,445,862	18,077,780
Barley Winter	205,098	2,974,800	3,661,860	825,796	7,667,554
Barley Spring	2,604,477	10,740,582	9,931,542	2,567,087	25,843,688
Oats, triticale and mixed grain	249,739	495,977	1,329,287	346,013	2,421,015
Rape for oilseed and linseed	381,449	2,024,201	4,148,730	131,948	6,686,347
Potatoes	254,720	863,607	2,975,500	105,754	4,199,581
Peas and beans for combining	9,629	33,753	264,963	33,635	341,980
Stockfeeding crops(1)	170,299	269,002	343,064	317,972	1,100,331
Vegetables for human consumption	39,687	174,854	1,175,916	26,639	1,417,086
Orchard and soft fruit	5,563	22,606	208,115	7,468	243,751
Bulbs, flowers and nursery stock	1,934	23,957	29,847	2,945	58,680
All other crops	47,728	163,283	395,796	100,961	707,761
Total crops (kg)	**4,547,442**	**20,416,127**	**37,889,910**	**5,912,079**	**68,765,553**
tonnes	**4,547**	**20,416**	**37,890**	**5,912**	**68,766**
Grass and rough grazing:					
Grass under 5 years old	3,200,442	6,089,328	6,288,156	6,783,273	22,361,189
Grass 5 years old and over	12,555,594	7,879,194	12,882,634	27,592,596	60,910,045
Sole right grazing	assumes unimproved i.e. no fertiliser application				
Common grazing(2)	assumes unimproved i.e. no fertiliser application				
Total Grass	**15,756,036**	**13,968,522**	**19,170,790**	**34,375,869**	**83,271,234**
tonnes	**15,756**	**13,969**	**19,171**	**34,376**	**83,271**
Scotland all land use					
Total Nutrient N (kg)	**20,303,478**	**34,384,649**	**57,060,700**	**40,287,948**	**152,036,786**
Tonnes	**20,303**	**34,385**	**57,061**	**40,288**	**152,037**

15 Appendix 8: Greenhouse gas abatement potential: scenarios

Scenario definitions

We have defined three scenarios, representing low, medium and high levels of engagement by farm businesses, to allow illustrative estimates of GHG savings.

Estimates of GHG emissions changes are based on the overall assumption that exported manures are applied to arable land. If not exported, they would have been applied to grassland in a situation where the supply of nitrogen to the grassland is above the optimum. Therefore, it is not replaced by inorganic nitrogen fertiliser, with savings in soil emissions of the greenhouse gas nitrous oxide. On the arable land, it is assumed that the import of manures does displace inorganic fertiliser, with savings in GHG emissions from fertiliser manufacture. The level of displacement is based on the available nitrogen content of the manures; these values assume that all exported manure is exported and used within one year of production.

Types of exchanges

Types of manure/slurry exchanges included are as follows:

- *Muck-for-straw exchanges*
  This is a genuine exchange between businesses, with scope for increased engagement.
- *Movement of livestock for finishing*
  This is not driven primarily by nutrient excess or demand but has other market drivers; it could be incentivised for greenhouse gas savings.
- *Manure exports in exchange for collection and spreading*
  The exchange is in effect, manure for labour, with the recipient taking away from the donor the work involved in spreading to land, and the risk of environmental damage. Probably this will remain small scale but could contribute to manure redistribution with greenhouse gas savings.

Each of these types of exchange, and any other type identified in the literature review, can contribute to the scenario outcomes, as we are not specifying in the scenarios the mechanism of manure redistribution.

Types of livestock

The data on manure arisings show that pigs and poultry are mainly reared in areas where there is plenty of arable land, and it is likely that manure arisings are already used on arable land. These systems are typically co-located with arable holdings or as discreet systems and will be required to have appropriate areas to store and spread manures.

The main concern is in areas that have high manure arisings, a high area of grassland, but relatively little arable land. In these areas, there can be a tendency for sub-optimal usage (overapplication, application at sub-optimal times) to some grassland. Our scenarios therefore focus on this situation, which is where there is greatest need for improved nutrient use. Farms with housed cattle (dairy and beef) are the main types of farm in this situation, for example, in the south-west of Scotland.

Therefore, our scenarios include only exchange of manures from housed dairy and beef cattle.

Temporal constraints

Arisings are seasonal, but manures are stored, giving availability throughout the year in principle. We have not constrained our analysis by the seasonal timing of availability.

Level of farm engagement

Scenarios are defined by percentages of manures involved in exchange activities, representing differing levels of engagement by livestock farms.

We used three scenarios Low, Medium and High engagement (defined as 30%, 50% and 70% respectively) of land in Scotland on farms with housed cattle being involved in manure export. The high level of engagement (70%) is based on levels of export amongst organic farmers in Denmark (Asaiet al, , 2014b), and the low and medium levels were selected arbitrarily to provide a range.

To estimate the current level of activity, we used data from the Scottish Survey of Farm Structure and Methods, 2016 (Scottish Government, 2016a). We used the reported tonnage of manures exported from farms as a percentage of the total tonnage spread to land, which was 6%.

Haulage assumptions

For all scenarios we used a haulage distance range of 10 to 40 km, with a mid-point of 25 km. This represents a relatively long transport distance: Asai et al. (2014a) reported that high dry matter manure can viably be transported within a 40 km radius of the production site, and low dry matter manure can viably be transported within a 10 km radius of the production site.

We assumed that a mix of vehicles would be used with an average load of 20 tonnes. We applied a conversion factor from Defra greenhouse gas reporting: conversion factors 2019 (https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019). From this data set we used a value of 0.83824 kg CO2e per km, which as a value for “All HGVs”, 50% laden, on the assumption that the return journey is without a load.

Other factors that may influence greenhouse gas emissions

Other factors that may influence GHG emissions when manures are exported from a livestock farm for use elsewhere include soil organic carbon stock change and effects on water quality. We did not find data to enable us to estimate these effects. We expect any effects to have high uncertainty and to be small relative to the effects on soil emissions and emissions from fertiliser manufacture.

In the case of soil organic carbon stock change, there may be effects through the change from applying manures to grassland (likely for many farms that might export manures) to arable land application (likely for many farms receiving manures). On arable land, manures are usually incorporated into the soil, but this is not done on grassland; this could lead to a change, possibly an increase in soil organic carbon accumulation. On the other hand, cultivation of arable land can lead to loss of soil organic carbon, so there are competing processes at work.