Policy Brief:
How do different livestock types, sizes and breeds differ in their greenhouse gas emissions?

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Background
Farmers in Scotland produce the food that we eat, but in the process also contribute to the emission of greenhouse gases. If we want to lower the emissions from meat production, a first step is to understand what is currently known about the animals that we rear in Scotland, and how greenhouse gas emissions vary between breeds.

Key Findings
1. Since cattle have not been bred on the basis of their emissions, any differences are based on feed intake or production system, and no clear difference was found between breeds.
2. For breeds that have high productivity, methane emissions may be lower per kilogram of beef produced because they consume a smaller amount of feed. In the same way, an animal that can digest its food more quickly will generate fewer emissions as there is less time for processing in the stomach. So, breeds selected for higher production will have reduced greenhouse gas emissions, particularly when expressed relative to production;
3. On the other hand, the evidence shows that selective breeding can be linked with problems of ill health, increased death rates and reduced fertility, and so overall reductions in greenhouse gas emissions will depend on minimising these risks – for example by having an appropriate breed for the environment or management system.
4. We found evidence of significant genetic variation in greenhouse gas emissions within all breeds. This means there is potential to reduce emissions of some gases (e.g. nitrous oxide and ammonia), but shows less promise for methane.
5. It is not clear whether selecting animals for their ability to convert feed efficiently will have a beneficial effect on methane. Whilst there are relatively few studies, the current evidence suggests that selection for feed efficiency may increase emissions from livestock based on a high-forage diet.
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Evidence Base

Agriculture accounts for the second-largest greenhouse gas (GHG) emissions in Scotland, and the Scottish Government is exploring different ways that this can be tackled. It is important to understand differences that can be detected between different breeds of livestock, as options are developed, and this report reviews the evidence. The focus of this report is on work with cattle, though some relevant work with sheep is also included.

The evidence for the effects of breeds on greenhouse gas emissions intensity and its components is presented against six different criteria:

1. Breed differences
2. Effects of production level
3. Health and fertility effects
4. Variations within breeds
5. Matching breeds to environments
6. Effects related to feed conversion efficiency

Point 1: Breed Differences

Since cattle have not been selected directly for methane emissions or Nitrogen-use efficiency (NUE), there is no reason to expect much difference between breeds in these traits - apart from small effects related to selection for production level (see point 2). The following sections set out evidence from direct comparisons of cattle (and sheep) breeds and crosses:

Methane emissions

Nine recent studies comparing methane yield of different breeds/crosses were identified (3 with beef cattle, 1 with dairy cows, 1 with dairy and dairy beef crosses, and 4 with sheep). These studies showed that differences in methane emissions are attributed to the production system, diet type and dry matter feed intake (DMI) of the animal and no breed effects were identified. The relevant conclusions are quoted directly from the papers:

1. De Mulder et al. 2018: Holstein-Friesian (HF) vs. Belgian Blue (BB) heifers: “After correcting for DMI, the methane yield was not significantly different between HF and BB heifers, though numerically HF heifers had an 8% lower methane yield (CH₄ per DMI) as compared to BB heifers……. Our results suggest that breed related factors influence the bacterial community composition, while the variation in methane emission levels can be attributed mainly to the feed intake of the animals.”

2. Duthie et al. 2017 (study conducted in Scotland): Charolais crosses vs. Luing steers: “The experiment was of a 2×2 factorial design, comprising two breeds (crossbred Charolais (CHX); purebred Luing (LU)) and two diets (concentrate-straw or silage-based). …. Breed of steer did not influence methane production.”

3. Fraser et al. 2015: Welsh Mountain vs. Texel cross lambs: “Although total daily CH₄ emissions were lower for the WM lambs than for the TexX lambs (13·3 v. 15·7 g/day, respectively) when offered fresh forage, the yield of CH₄ per unit DMI was similar for the two breed types (16·4 v. 17·7 g CH₄/kg DMI).”

4. Fraser et al. 2014: Limousin cross vs. Welsh Black steers: “While emissions per unit feed intake were similar for the lowland and upland systems, CH₄ emissions per unit of live-weight gain (LWG) were substantially higher when the steers grazed the poorer quality hill pasture (760 vs 214 g kg⁻¹ LWG; s.e.d. =133.5 g kg⁻¹ LWG; P<0.001). Overall any effects of breed type were relatively small relative to the combined influence of pasture type and location.”
5. Zhao et al (2017): **Scottish Blackface vs. Swaledale x Scottish Blackface ewes:** “Genotypes of sheep had no effect on any variable in feed intake, digestibility, CH₄ emissions or N utilization.”

6. Flay et al (2019): **Holstein-Friesian vs. Jersey heifers:** “Jersey heifers produced less CH₄/d, but not CH₄/kg of DMI or CH₄/kg of BWg”

7. Zhao et al (2016): **Scottish Blackface vs. Swaledale x Scottish Blackface hoggetts:** “There was no significant difference in CH₄ emission rate or N utilisation efficiency when compared between Scottish Blackface and Swaledale x Scottish Blackface.”

8. Zhao et al (2015): **Texel vs. Highlander lambs:** “Texels produced more CH₄/DMI (g/kg) than Highlanders (P = 0.044)…… Neither breed nor sex had an effect on N utilization efficiency (P > 0.05).” [though note that this was only 21.9 versus 21.0 g methane per kg DMI]

9. Richmond et al (2015): **Holstein-Friesian vs. Charolais cross steers and heifers:** “Mean daily CH₄ emissions, expressed as g/kg DMI, were not significantly different between the UG and LG sites. Furthermore, there were no significant differences between experimental periods, genders or breeds and no significant interactions for these parameters.”

In their large meta-analysis of 89 studies with dairy and beef cattle conducted around the world between 1992 and 2015 (217 treatment means), Liu et al. (2017) identified significant differences in methane emissions between breeds as follows (values expressed as a % of Gross Energy intake): Thai native (5 studies; 8.4%); Brown Swiss (10 studies; 7.0%); Brahman (9 studies; 6.8%); Charolais (6 studies; 6.6%); Hereford (1 study; 6.3%); Angus (13 studies; 6.0%); Simmental (2 studies; 5.8%); Jersey (4 studies; 5.6%); Holstein (52 studies; 5.3%); Swedish Red (5 studies; 4.7%); Yak (3 studies; 4.8%); and Nellore (6 studies; 3.3%). However, most of the variation was related to differences in the diets and management of cattle rather than breed per se. Feeding practices are well-known to affect methane emissions intensity and rates of Nitrogen excretion – effects which have been the subject of previous comprehensive reviews (e.g. Knapp et al. (2014) for methane emissions intensity and Spek et al. (2013) for Nitrogen excretion). It is also apparent that the mean values for common breeds in Scotland were all close to 6% of Gross Energy intake.

**Nitrogen-use efficiency (NUE)**

Few studies were identified comparing NUE between breeds. Two studies found no difference between Jersey, Holstein-Friesian and Holstein-Friesian x Jersey cows (Rius et al, 2010; Kristensen et al, 2015). A further two studies found no difference in NUE between sheep breeds (Zhao et al, 2015, 2016). No studies relevant to Scotland (or the UK) were identified for beef cattle. A review of energy and N use efficiency in dairy cows (Phuong et al, 2013) highlighted the lack of studies which consider breed as a factor.

Overall there is little evidence for differences in emissions intensity between breeds, when compared at a similar level of production (see point 2). The absence of direct selection means that there may still be considerable between-animal variation within breeds (see point 4).

**Point 2: Effects of production level**

There are two mechanisms related to production level that can lead to a reduction in greenhouse gas emissions, expressed per kg DMlor per kg of product (milk or meat):

1. *The ‘dilution of maintenance’ effect – at higher levels of production a smaller proportion of feed intake (and hence methane emissions) relates to animal maintenance costs.*

2. *Higher rates of passage of feed through the rumen of higher producing animals means that there is less potential for fermentation (and hence less production of methane).*
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The effect of production level is more pronounced when methane emissions are expressed relative to production (i.e. per L milk or kg of beef) because of the ‘dilution of maintenance’ effect whereby a greater proportion of energy intake is directed towards productive as opposed to maintenance functions.

Analysis of results from the Langhill Breeding Experiment by Ross et al. (2014) showed that both genetic and management approaches to increasing milk production can lead to a reduction in greenhouse gas emissions intensity. Improving genetic merit led to a 9% reduction, whilst implementing a low forage (high concentrate) diet led to a 16% reduction in emissions intensity.

A number of studies have brought together results from many experiments in order to identify the underlying relationship between methane emissions and production (or feed intake level). These analyses confirmed the anticipated reduction in methane (g/kg DM intake) with increasing production (feed intake) level:

1. The Meta-analysis of Dewhurst et al. (2019) from studies with grazing cattle identified the following relationship:
   
   \[
   \text{Methane (g/kg DMI)} = 31.7 \pm 1.25 - 1.13 \pm 0.126 \times \text{DMI (kg/day)} \\
   \text{R}^2 = 55.2; \text{ residual s.d.} = 3.37; P < 0.001; n = 65
   \]

2. The much larger meta-analysis conducted by Liu et al. (2017) brought together results from 89 peer-reviewed studies with dairy or beef cattle reported between 1992 and 2015 (217 treatment means from grazing or housed cattle) and concluded: “Higher energy digestibility of feed and higher energy intake level of cattle resulted in a lower percentage of digestible energy intake being converted to CH4.”

The observed reduction in methane emissions with increasing production level with cattle was confirmed in sheep by Zhao et al (2016, 2017).

A similar effect of production level also applies to NUE, though again effects will be small within the range of breeds used in Scotland and the UK. In an Irish study, Prendiville et al (2009) showed that Holstein Friesian cows produced less milk solids per Kg DMI compared to Jersey and Jersey cross HF cows and this would have a small effect on NUE.

Point 3: Health and fertility effects

Inefficiencies related to infertility, ill health and mortality will all lead to increased GHG emissions intensity since emissions are spread across less output of milk or meat. Rauw et al (1998) reviewed the potential undesirable side-effects of genetic selection for increased productivity of dairy cattle. As a result of some early negative experiences, most breeders and Breed Societies are well aware of these potential issues and so promote multi-trait approaches to breeding and selection indices that incorporate many traits. Nonetheless, there remains the potential for correlated genetic effects to build up slowly over time and breeders need to be vigilant.

The history of the Holstein-Friesian breed illustrates that reductions in emissions intensity (g/L milk) will only be achieved if the benefits of increased production levels are not offset by increased health problems, mortality, infertility etc. Examples of issues which may reduce the positive effects of selection for increased productivity (milk yield or growth rate) on GHG emissions intensity include:

- The decreased fertility and consequent increased involuntary culling rate of Holstein-Friesian cattle as a consequence of single trait selection for milk production during the later decades of the last century (Royal et al. 2000).

- Fetomaternal disproportion (calves too large for natural birth) is a problem associated with double muscled breeds such as Belgian and British Blue (Kolkman et al, 2010). Belgian Blues have a high rate of dystocia (difficult calvings), particularly for bull calves (Bleul, 2011). Difficult calvings can lead to death or premature culling of the cow and high mortality or poor performance of the calf.
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Point 4: Variation within breeds

Whilst the above evidence confirms that there are only small differences between livestock breeds in GHG emissions, there is a growing body of evidence of genetic variation in GHG emissions (methane or N) within breeds:

- **Jonker et al (2018)** – presented heritabilities for methane emissions from sheep in a New Zealand breeding programme;
- **Kittelmann et al (2014)** – showed differences in bacterial communities in the rumen of high- and low-methane emitting sheep, suggesting that there is animal genetic control over the rumen and its microbial community;
- **Pszczola et al (2018)** – showed that genes involved in controlling development of the ruminant digestive tract are related to genetic differences in methane emissions of dairy cows;
- **Difford et al (2018)** – demonstrated separate effects of the rumen metagenome and cow genome on methane emissions;
- **Roehe et al (2016)** – demonstrated differences in methane emissions from sire progeny groups (beef steers);

Although the above studies show considerable promise in selecting for genetic variation in methane emissions, they have often shown negative effects on other aspects of productivity that may mean that there is no overall effect on methane emissions intensity. For example:

- **Pinares-Patino et al (2003)** concluded: “These results suggest that sheep with lower rumen particulate FOR (i.e. longer rumen retention times) had larger rumen fills and higher fibre digestibilities and CH₄ yields.”
- **Goopy et al. (2014)**: showed reduced rumen volume and reduced rumen retention time (so potentially reduced diet digestibility) in low emitting sheep selected from a large-scale genetic study with Australian breeds.
- **Lambe et al. (2019)** showed a negative relationship between rumen volume of Scottish Blackface ewes and methane emissions – confirming the danger of losing capacity to ferment fibrous feeds (forages) by selecting for low emitting sheep.
- **Bond et al (2019)**: “Daily CH₄ emission (g/day) increased significantly (P < 0.001) with an increasing dry-matter intake (DMI) and reticulo-rumen volume (P < 0.001). Lower methane yield (g CH₄/kg DMI) was associated with shorter mean retention times of liquid (r = 0.59; P < 0.05) and particle (r = 0.63; P < 0.05) phases of the digesta in the rumen.”

Point 5: Matching breeds to environments

Breeds have been developed to perform best under specific management and/or environmental conditions and matching breeds to systems will have important effects on emissions intensity though effects on things like health, mortality, fertility, litter sizes and production rates.

The analysis of results from the Langhill Breeding Study by Ross et al (2014) showed that the effects of genetic line (9%) and feeding strategy (16%) on methane emissions intensity can come together to deliver an overall 24% reduction in offering the best diet to the highly selected cows.

Earlier maturing beef breeds (e.g. Aberdeen Angus) are often considered to be better adapted to upland systems than later maturing breeds (e.g. Charolais) (Rook et al, 2014). However, there are no Scotland (or UK) relevant examples in the literature of matching breeds to environments. The majority of the literature in this area focuses on British/European beef breeds in tropical environments, where they are...
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found to perform less well and be less fertile than in temperate climates. They are also more susceptible to environmental stressors (e.g. ticks, worms and heat) than breeds that are selected for tropical environments (Burrow, 2012).

There is some older evidence (> 10 years) supporting the statement that management system is important to maximise production efficiency. Suckler beef (Lewis et al, 1990), beef animals of dairy origin (Keane and Allen, 1998; McGee et al, 2005) and dairy bulls (Therkildsen et al, 1998, McGee et al, 2005) were found to be more efficient (and so produce less methane per kg of product) under intensive management systems than extensive systems.

Beef and dairy cattle were 6-7 months older at slaughter in extensive compared to intensive systems (Lewis et al, 1990; Keane and Allen, 1998; McGee et al, 2005). Furthermore, carcass outputs were greater from intensively managed cattle compared to extensively managed cattle (Keane and Allen, 1998; McGee et al, 2005).

Examples of studies looking to match breeds and systems are given below – from which it is clear that breeds and systems resulting in higher growth rates will result in reduced methane emissions intensity, but this may not always maximise profitability and product quality:

Lewis et al (1990): Charolais crosses in US - “Cattle from the Ext system were heavier (P < 0.01) before (388 vs 233 kg) and after (595 vs 531 kg) the finishing phase than Intensive system cattle. During finishing, cattle from the Extensive system made more rapid gains (1.70 vs 1.36 kg/d) and consumed more feed (12.4 vs 8.5 kg/d, 2.52 vs 2.194 of average BW) but were less efficient (0.137 vs 0.160, gain/feed) than cattle from the Intensive system (P <0.05). Extensive systems of beef production produced more total kilograms of beef per animal but they were 196 d older at slaughter”.

Keane and Allen (1998): Charolais x Friesian in Ireland - “The three production systems were (i) young bulls finished on silage plus concentrates and slaughtered at about 19 months of age (Intensive), (ii) steers finished on silage plus concentrates and slaughtered at about 24 months of age (Conventional), and (iii) steers finished off pasture and slaughtered at about 29 months of age (Extensive). The two slaughter weights were 640 kg (Light) and 720 kg (Heavy). All measures of carcass and muscle fatness were higher (P < 0.05) for the Conventional system than for the other two systems which were similar in composition. Carcass output per ha was two-fold and three-fold higher for the Conventional and Intensive systems respectively, than for the Extensive system, but gross margin per animal and per ha was highest for the Extensive system”.

Therkildsen et al (1998) Friesian bulls (Germany) - “Extensively managed (wintered indoors on forage and finished at pasture) bulls slaughtered directly from pasture had a lower dressing percentage (p < 0.05), a higher lean content (p < 0.05), a much lower fat content (p < 0.05) and darker meat colour (p < 0.05) than intensively managed (housed in tie- stalls, offered concentrates ad libitum) bulls. Finishing- fed extensive bulls (same as extensive + additional 10 weeks on concentrates after pasture) showed no sign of compensatory gain after the grazing period. The finishing period improved the carcass quality of Extensive bulls, but the Extensive bulls were leaner (p < 0.05) and had a darker meat colour (p < 0.05) than the Intensive bulls of similar live weight (460 kg). It is concluded that a finishing period of minimum 10 weeks following the grazing period is necessary to obtain a satisfactory carcass quality of the extensively produced young bulls.”

McGee et al (2005): high genetic merit Holstein, Friesian and Charolais x Holstein-Friesian bulls (Ireland) - “Compared with the intensive system (free-housed on slats – 19 month bull beef), animals on the extensive system (castrated, wintered in tie stalls, summer grazed – 25 month slaughter) had a lower (P < 0.001) daily live-weight gain, kill-out proportion and a lower muscle proportion in the pistol”

Point 6: Effects related to feed conversion efficiency

There is a lot of current activity concerned with defining and selecting livestock for feed conversion efficiency (FCE). It has been suggested that increased FCE means that animals consume less feed per L of milk produced or per kg of meat produced, which implies that there would be a beneficial effect on
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GHG emissions intensity since there is a very close association between DMI and GHG emissions. Residual feed intake (RFI) is an alternative feed efficiency trait (the difference between actual feed intake and intake predicted from the observed growth rate). RFI is moderately heritable (0.26 to 0.43) in both beef and dairy cattle (Basarab, et al., 2013), and selection for this trait would inherently reduce methane emissions per kg of product. There is also limited evidence in the literature of breed differences in RFI. For instance, Luining steers have been shown to be more efficient than Charolais steers over a finishing period on two contrasting diets (high concentrate or forage based, Duthie et al., 2016). Also, early maturing breeds have been shown to have higher RFI (be less efficient) than late maturing breeds (Crowley et al., 2010; Berry and Crowley, 2012). This aspect needs further work to clarify effects.

Despite the above logic for a positive effect of selecting for FCE (or RFI) on GHG emissions intensity the first studies to look for such an effect have been equivocal:

**Reduction in methane emissions**

Paganoni et al (2017) working with sheep concluded: “Selecting to decrease feed intake or residual feed intake will decrease methane (genetic correlation range 0.76 to 0.90)…….Given these results, the hypothesis that making sheep more feed efficient will decrease their methane production can be accepted.”

There were positive relationships between RFI and CH₄ production in the studies with beef cattle conducted by Nkrumah et al. (2006), Hegarty et al. (2007) and Fitzsimons et al. (2013). Methane emissions intensity was 15% lower in low RFI (high feed efficiency) compared to high RFI groups.

**Increase in methane emissions**

Methane emissions intensity was 10% higher in low RFI Limousin x Friesian steers compared to high RFI groups in the study of McDonnell et al. (2016).

Flay et al (2019) concluded: “low RFI heifers (i.e. high feed conversion efficiency heifers) had a greater CH₄ yield (g/kg of DMI) on a high forage diet.”

These latter authors suggested that the above discrepancy may be a consequence of the different basal diets offered in different studies. There was a negative effect of selecting for FCE on methane emissions with a high concentrate diet (Nkrumah et al (2006) and Hegarty et al (2007), whilst their own study involved a high fibre diet (dried Lucerne cubes) where the ability of rumen microorganisms to ferment fibre would be more important for feed utilisation.

This is a particular issue for Scottish production systems involving high levels of grass and forage feeding where it would be problematic if selection for FCE led to increased fibre fermentation and so increased methane emissions. Modelling work conducted in Scotland (Wall et al., 2010) has suggested reductions in GHG emissions intensity with selection for FCE, but has not yet taken into account the potential effects of increased fibre fermentability and methane production noted above. Scottish studies in which FCE and methane emission were measured in parallel (e.g. Rooke et al.,2014; Troy et al., 2015; Duthie et al., 2016, 2017) were directed at effects of dietary treatments rather than genetic effects – new studies would be required to explore this further in a Scottish context.

**Conclusions**

There is no evidence for significant differences between breeds in digestion and metabolism associated with the production of methane, utilisation of absorbed protein and excretion of urinary Nitrogen when operating at the same level of production. Differences between breeds in GHG emissions intensity may result from differences in production level (as a result of more energy being directed to productive (as opposed to maintenance) functions and increased rates of passage from the rumen). Other differences may be related to the suitability of a breed to a particular environment or management system (with effects mediated by, for example, differences in feed efficiency, fertility or mortality).
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For many of the traits contributing to overall GHG emissions intensity, it is more important to consider variability within breeds, as well as between breeds. There is much current interest in selecting cattle based on FCE, but anticipated reductions in GHG emissions intensity may not materialise if increased FCE results from increased fermentability of forage fibre in the rumen. Similarly, great care is needed in breeding for reduced methane emissions as this has been associated with reduced rumen capacity or function – important traits for traditional Scottish systems based on grass and forages.
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