Is the EBI breeding for more environmentally responsible cows and what, if anything, can be done better

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Introduction

The economic breeding index (EBI), as the name suggests, is economic-based. The change in relative emphasis on traits within the EBI since its launch in 2001 is shown in Figure 1, while the 2019 economic weights applied to the traits within the EBI are shown in Table 1. The economic weight on a given trait is the expected change in profit per incremental increase in the trait under consideration. For example, the economic value of €5.88 on protein yield within the EBI (Table 1) implies that, for the average spring-calving farm, profit per lactation will increase by €5.88 per lactation for every extra kg of protein produced, holding all other traits in the EBI constant; this figure accounts for the value generated for that extra kilogram but also the cost of producing it. Similarly, the economic value of -€12.59 on calving interval implies that a one day delay in calving interval costs the average Irish spring-calving dairy farmer €12.59 per lactation; this is due to a change in the milk lactation profile and underlying feed budget as well as a small impact on livestock sales.

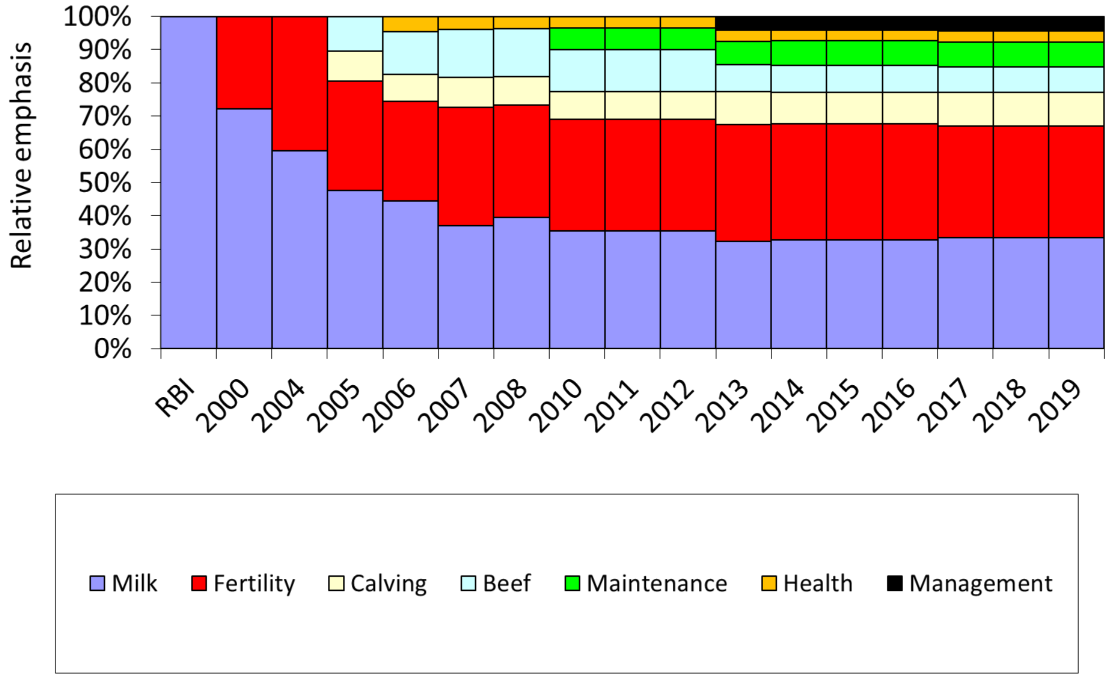


Figure 1. *Evolution in the change in relative emphasis on individual sub-indexes within the EBI since its launch in 2001.*

Table 1. *Economic weight and associated relative emphasis on each trait within the current EBI*

Sub-index	Trait	Weight (€)	Emphasis	Emphasis
Production	Milk (kg)	-0.09	9%	34%
	Fat (kg)	2.08	7%	
	Protein (kg)	5.88	18%	
Fertility	Calving interval (d)	-12.59	23%	34%
	Survival (%)	12.43	11%	
Calving	Calving diff direct (%)	-4.19	3%	10%
	Calving diff maternal (%)	-2.13	2%	
	Gestation (d)	-7.93	4%	
	Calf mortality (%)	-2.58	1%	
Maintenance	Cow (kg)	-1.65	7%	7%
Beef	Carcass weight (kg)	1.38	5%	9%
	Carcass conformation (units)	10.32	2%	
	Carcass fat (units)	-11.71	1%	
	Cull cow carcass weight (kg)	0.15	1%	
Health	Lameness (%)	-72.47	1%	4%
	Mastitis (%)	-82.65	1%	
	SCC (Log_e)	-43.49	2%	
Management	Milking duration (seconds)	-0.31	3%	5%
	Temperament (units)	-35.86	2%	

The suite of traits currently missing or poorly represented within the EBI include

- product quality (both milk and meat quality),
- feed intake and efficiency,
- health and well-being, and
- environmental hoofprint.

Given a) Ireland's reliance on export markets for its beef and dairy products, and b) the growing awareness of consumers of their diet, product quality is becoming increasingly discussed and challenged. The importance of feed efficiency is well accepted and thus merits inclusion within the EBI since it does impact farm profit. The modern consumer is becoming increasingly engrossed into how their food has been produced and especially how the animal has been treated during its lifetime – growing demands are being placed on the food chain to address any potential issues associated with animal health and well-being. Notwithstanding that, Ireland has committed legally to a reduction in carbon and it has just set down targets for agriculture through the Climate Action Plan. It is imperative that agricultural research gives Irish farmers all of the tools available to reduce emissions.

The contribution of breeding to improving animal performance has been well recognised across a range of different species. Using a controlled experimental study in broiler chickens, it was reported that up to 90% of the gains in performance in recent decades could be attributable to genetic improvement. Unlike many of the required interventions to improve animal performance or reduce carbon footprint (e.g., complementary feed, vaccination), the gains achieved through breeding are cumulative and permanent. This implies that improvements achieved are compounded each generation. In direct contrast, however, any deleterious (indirect) consequences of breeding are also compounded with successive generations. A well-publicised example of such indirect unfavourable consequences of selection, which particularly hit home for dairy producers, is the documented deterioration in reproductive performance in dairy cows concurrent with aggressive genetic selection for increased milk production. It is therefore imperative the breeding schemes are optimised to, where possible, achieve gains in performance at a holistic level. Moreover, because of the long generation interval in cattle, cognisance needs to be taken of the likely conditions that will prevail in the future and, not only what animal characteristics will be important, but also their degree of importance, relative to other traits. Therefore when breeding animals for the future we want animals that are resilient and can adapt to climate change while also having animals that produce less emissions per unit of product and in total.

What exactly are the greenhouse gasses?

Much like the glass of a glasshouse/greenhouse, atmospheric gasses sustain life on earth by trapping the sun's heat. These atmospheric gases facilitate the sun's rays passing through warming the earth, but prevent the warmth subsequently escaping into space. Greenhouse gasses are gases that absorb infrared radiation (net heat energy) emitted from earth's surface, reradiating it back to earth's surface; this contributes to the greenhouse effect. Without greenhouse gases, the average temperature of the earth's surface would be about −18 °C.

There are six main greenhouse gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride; water vapour is also considered a greenhouse gas. Of these six gases, three are of primary concern because they are closely associated with human activities. These are nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4). Today's atmosphere contains 42 per cent more carbon dioxide than it did at the start of the industrial era. The levels of methane and carbon dioxide are at their highest in nearly half a million years.

Increasing carbon dioxide concentration in the air is due to a combination of both burning of fossil fuels and deforestation. Land use change (mainly deforestation in the tropics) account for up to one third of total anthropogenic carbon dioxide emissions globally; considerable deforestation has already happened in past centuries. Methane is produced naturally when vegetation is burned, digested or rotted without the presence of oxygen. Large amounts of methane are released by cattle, waste dumps, rice farming and the production of oil and gas. Many of the newer style fully vented septic systems that enhance and target the fermentation process are also sources of atmospheric methane. Nitrous oxide is released by chemical fertilizers, animal slurry and urine deposition as well as diesel engines. Agriculture contributes approximately 18% of global greenhouse gas emissions globally. Relative to total emissions from Ireland, agriculture contributes approximately 33%.

A Global Warming Potential (GWP) statistic is generated for each greenhouse gas to facilitate a fair comparison of the global warming impact of the different gases. Specifically, GWP measures how much energy the emission of 1 ton of the gas in question will absorb over a given period of time, relative to the emission of 1 ton of carbon dioxide. The greater the GWP of a gas, the more that gas warms the earth compared to carbon dioxide over that time period. The time period usually used for GWPs is 100 years. Nitrous oxide has a GWP 265–298 times that of CO_2 for a 100-year timescale while methane is estimated to have a GWP of 25–36 over 100 years. These multipliers change over time as more information becomes available. It is accepted that the different gasses have different half lives in the atmosphere with methane having a much shorter presence.

The MACC curve

The marginal abatement cost curve (MACC; Figure 2) is a graph which depicts, visually, the abatement potential of different greenhouse gas mitigation measures, as well as the relative costs associated with each of these measures individually. Two pieces of information are depicted within the MACC.

1. The cost-benefit of each measure. Measures under the horizontal line have a favourable cost-benefit while those above the line have an unfavourable cost-benefit (i.e., the cost of implementation is larger than the economic return under the current market conditions)

2. Abatement potential. The magnitude of the abatement potential is reflected by the width of the vertical bar associated with each measure. The wider the bar along the horizontal X-axis, the greater the expected abatement potential.

Many MACC constructions also consider a cost or price of carbon credit. Cost-neutral measures are measures that carry zero cost in the long term while measures that cost money (above the horizontal x-axis), but the cost is less than the price of carbon, are called “cost-effective measures”, since their implementation is cheaper than the purchase of carbon credits. However at present, agriculture is part of the non-Emissions Trading Sector and therefore carbon cannot be traded from agriculture unless through voluntary schemes.

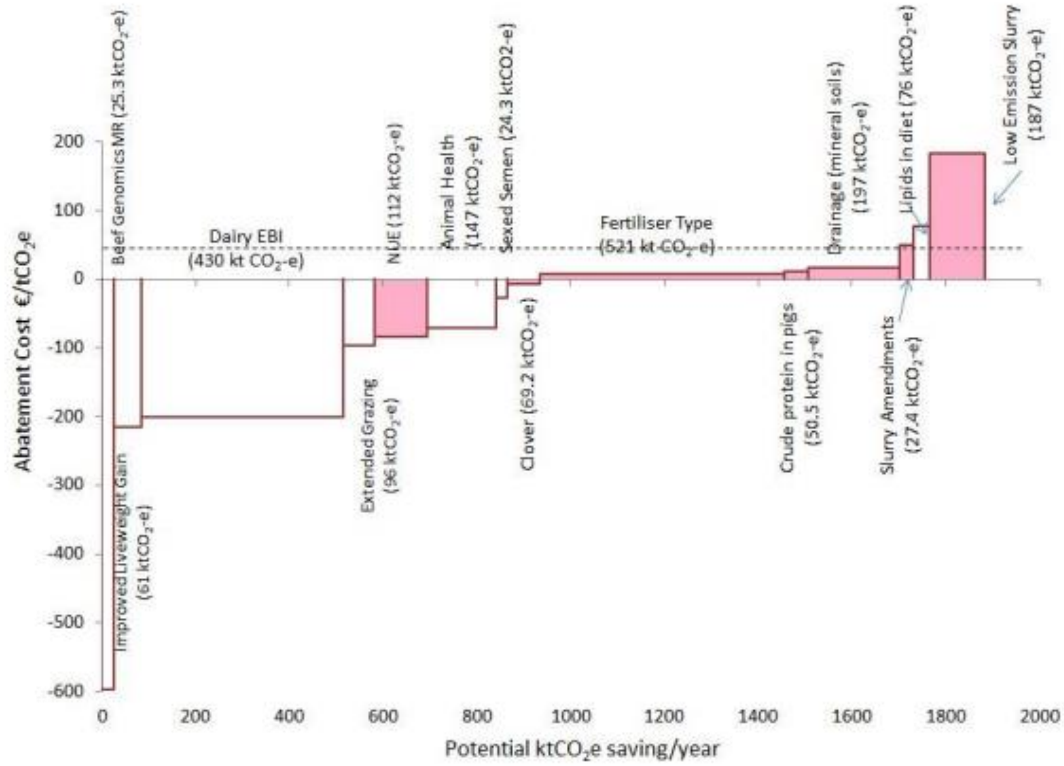


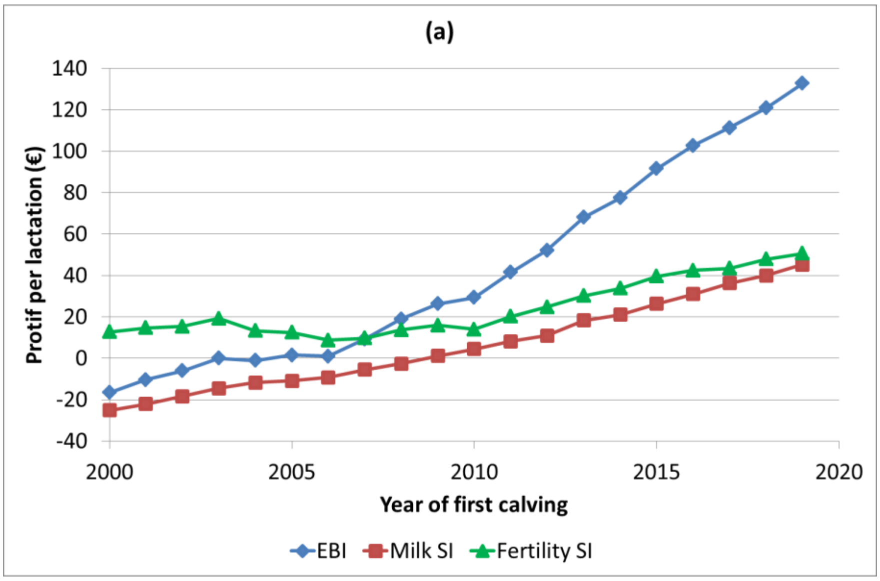
Figure 2. *Marginal abatement cost curve for Ireland (2018); measures extending under the horizontal line have a favourable cost-benefit and the wider the bar along the horizontal, the greater the expected abatement potential.*

The MACC for Irish agriculture produced by Teagasc (Lanigan et al., 2018) is illustrated in Figure 2. After fertiliser type, the bar reflecting EBI is widest suggesting it has the second largest abatement potential; this is despite the fact that the curve in Figure 2 is for all agriculture and not just dairy. Importantly however, unlike fertiliser type, the EBI bar extends below the x-axis implying that the economic return from exploiting EBI far out-weights the cost. It should always be borne in mind when comparing breeding to non-breeding technologies or solutions that breeding is cumulative and permanent. Therefore, unlike many abatement strategies which can revert to baseline if not continuously implemented (at a cost), the benefit of EBI accumulates over time. Interestingly the benefit in mitigation against greenhouses gasses from selection on EBI is without any direct explicit consideration of greenhouse gasses in the EBI and is based on research carried out in Moorepark. One key consideration when evaluating mitigation strategies is that they must be capable of being captured within the national inventory in order for benefits to be captured within the national emissions balance sheet. Therefore it is not the EBI itself that is captured within the inventory but the impact of the EBI on emissions.

Past genetic trends from selection on EBI

The rate of genetic gain by year of first calving for the EBI and its component indexes are in Figure 3. EBI is increasing linearly by €10 per year since the year 2005; milk subindex and fertility subindex is increasing by €4.11 and €3.24 annually over the same time period. The calving, health and management indexes are improving since 2005. While the reduction in profit from beef merit and cow maintenance is noted, the actual reduction is small with the subindex value of heifers calving in 2019 being just €4.74 and €1.65 less that those calving in 2005, respectively.

While solutions to reducing methane emissions from ruminants generally revolve around altering rumen function, one of the easiest and lowest cost approaches to improving environmental efficiency is actually to improve (gross) efficiency. Although this does not necessarily confer to an improvement in net efficiency, it is an improvement in efficiency nonetheless and is largely the process which was historically used to improve efficiency in pigs and poultry for decades. In a simulation representative of the UK dairy industry, Garnsworthy (2004) concluded that restoring fertility of the national herd to 1995 levels (from that in 2000-2002) was predicted to reduce methane emissions by 10–11% and ammonia emissions by about 9%. Garnsworthy (2004) continued by stating that further improvements in fertility could reduce methane emissions by up to 24% and ammonia emissions by about 17%. Using on a similar approach, modelling the change in herd characteristics based on the national EBI of Irish cows calving in 2001-2003 versus those calving in 2014-2016, the kg carbon dioxide equivalent per kg fat and protein corrected milk was 14% lower. Hence, considerable benefit can be accrued from selection on improved efficiency at a holistic level, and more importantly, these improvements are concomitant with an increase in profit. However, as we look to the future we must look to try to reduce total emissions as well as emissions intensity.



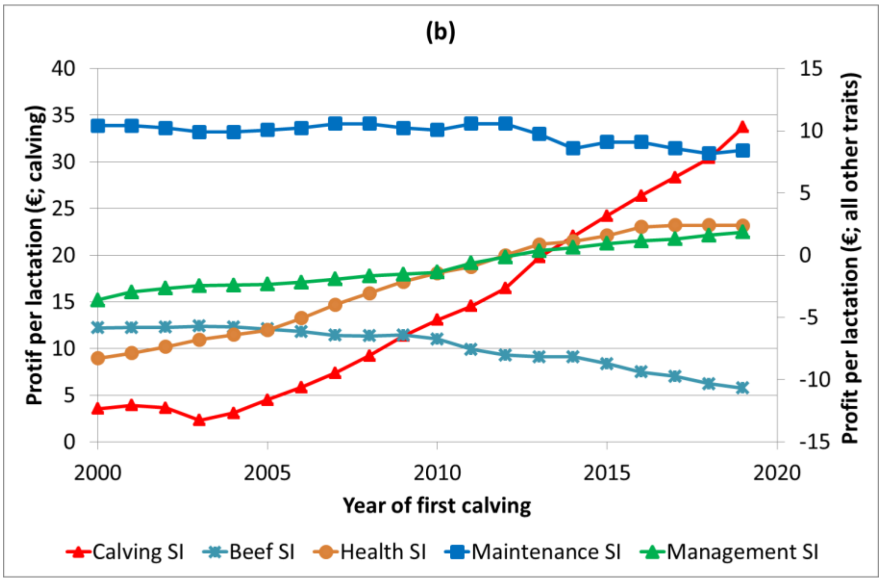


Figure 3. *Genetic trends by year of first calving for a) EBI, milk subindex, and fertility subindex, as well as b) calving, beef, health, maintenance and management subindexes.*

A carbon breeding index based on current traits in the EBI

The carbon emissions per lactation can be derived from bioeconomic models as currently used for the derivation of economic values in the EBI; such bioeconomic models are used in most countries for the calculation of economic values in dairy cow breeding indexes. The model used here was that used for the EBI with the same base population statistics. The output from the model was the carbon emissions per farm per unit change in each trait in the EBI holding all other traits constant; carbon emissions were derived based on a complete life cycle analysis. This enabled the carbon emissions per lactation to be subsequently derived; again, this is the same as what is currently used in the EBI. As with the EBI, these carbon values per trait are multiplied by the genetic merit of each bull and summed across traits to generate a single value per sire:

$$CBI = Carbon_{MILK} \times PTA_{MILK} + Carbon_{SURVIVAL} \times PTA_{SURVIVAL} \ldots\ldots$$

where CBI is the carbon breeding index represented as a single value per animal reflecting the expected carbon emissions per lactation of the progeny from that animal, $Carbon_X$ is the expected carbon emissions per unit change in trait X, and PTA_X is the genetic merit (i.e., predicted transmitting ability) of the animal for trait X as currently used within the EBI. This is the same construction as used in the EBI except that the carbon value per trait has replaced the economic value.

How the EBI and CBI relate to each other is in Figure 4 for each breed separately. A strong correlation exists within breed ranging from -0.87 to -0.44 in the different breeds. What this means, is that, on average higher EBI animals are expected to produce less carbon per lactation; this is a very favourable relationship. In fact, in Holsteins, each €10 improvement in EBI is associated with a reduction of 61.7 kg CO_2 equivalents per lactation. While higher milk production per lactation is associated with greater total carbon emissions, improved survival and calving interval are associated with a reduced requirement for replacements as well as an altered feed budget towards *in situ* grazed grass. The correlation between the individual animal monetary value of the milk sub-index and its relative carbon value was 0.83 substantiating that greater milk solids per cow from selection on just higher genetic merit for milk solids will contribute to greater carbon emissions.

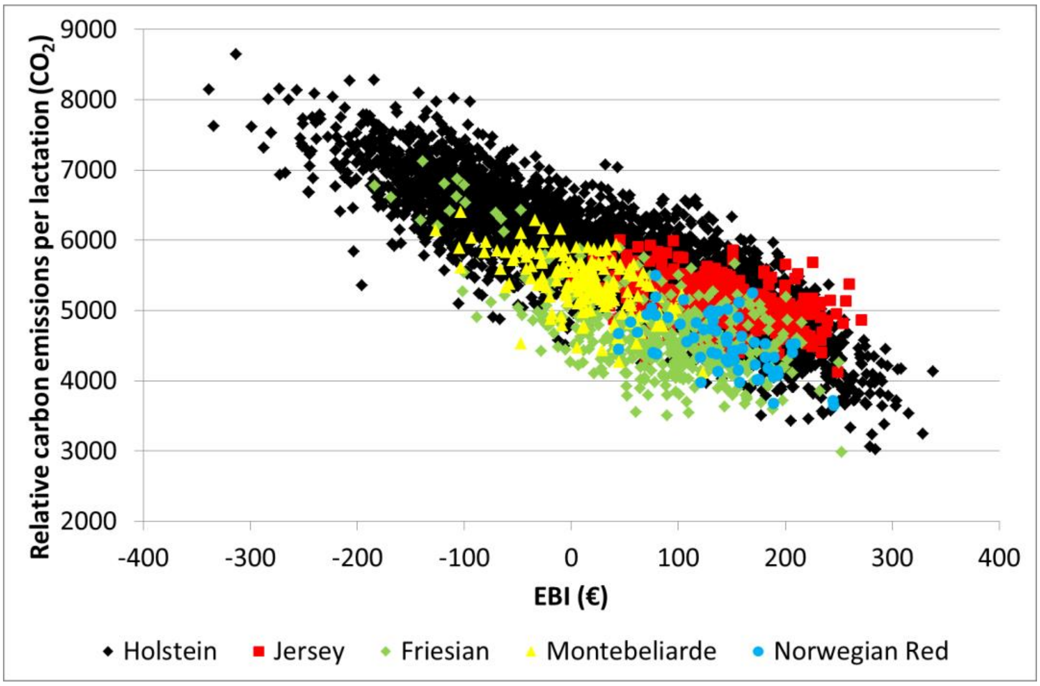


Figure 4. *Scatter plot of the association between the current economic breeding index (EBI; profit per lactation) value and the carbon breeding index (CBI; relative carbon emissions value per lactation) for AI dairy sires of a selection of dairy breeds.*

The mean expected carbon output per daughter by sire year of birth for Holstein sires is in Figure 5. Minimal change in expected carbon output was evident up until the introduction of the EBI in 2001. The expected reduction in carbon output was initially rapid but has since slowed down. Nonetheless, considerable exploitable variability still exists among sires. The extent of variability within breed is also demonstrated in Figure 6. Clear differences exist between breeds and within breeds when comparing the worst and best 20 emitters of carbon.

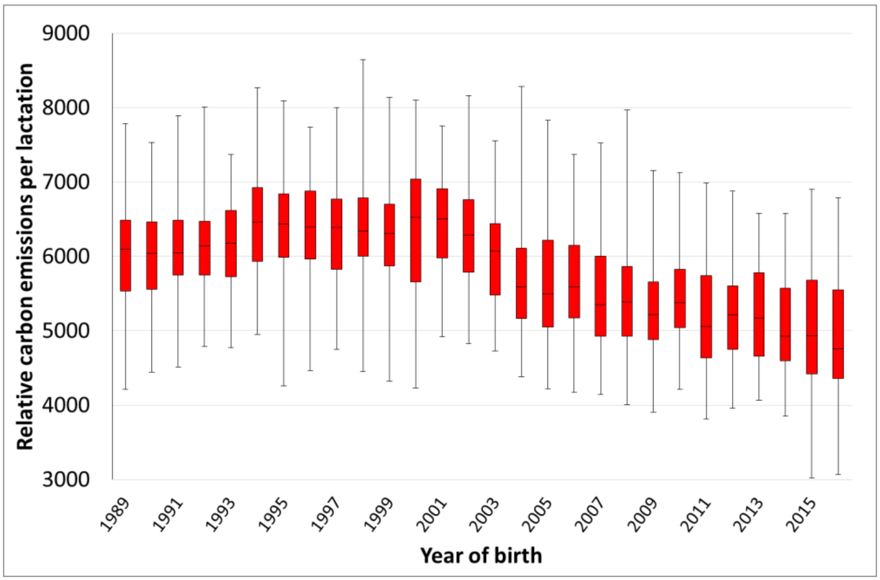


Figure 5. *Box and whisker plot of the relative carbon emissions for Holstein-Friesian AI sires by year of birth; the horizontal line in the red box represents the median, 50% of the sires exist within the range of the red vertical bar with the remaining 50% located between the top/bottom of the red bar and the end of the whisker.*

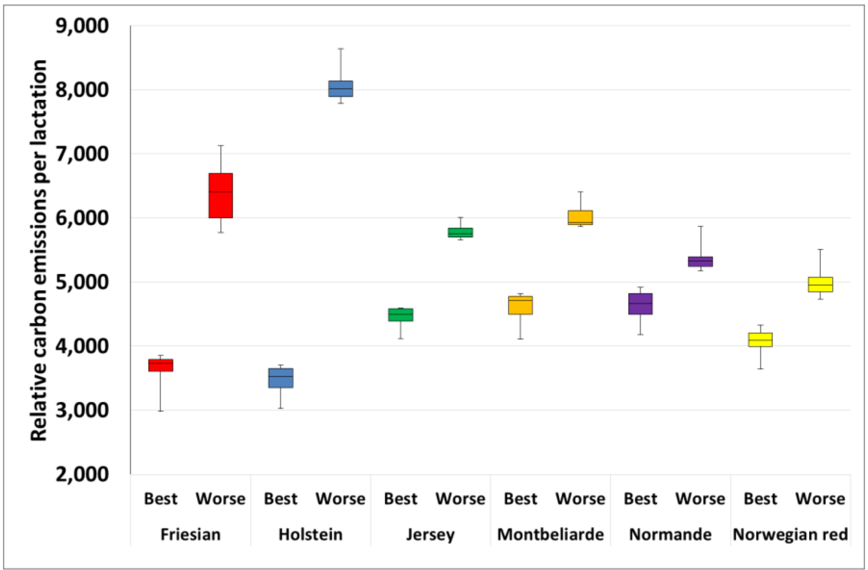


Figure 6. *Box-and-whisker plot of the relative carbon emissions per lactation for the best and worst 20 AI sires per breed ranked on CBI.*

Inclusion of additional traits in the EBI

For a trait to be considered in a breeding goal, such as the EBI, it must fulfil three criteria:

- Must be important – either economic, socially or environmentally
- Must exhibit genetic variability
- Must be (ideally easily) measurable or correlated with a measurable trait

While much of the interest among dairy farmers has traditionally focused on the milking herd, cognisance must now be given to the surplus animals both as surplus dairy-bred males but also the beef animals which still inherit half their genes from the dairy herd.

1. Must be important

While importance heretofore generally revolved around economic importance, greater demands are being placed on producers to fulfil their stewardship of both the environment and animal well-being. Although such traits may currently not have an explicit monetary value, adhering to the ever-growing regulatory demands may become a license to sell. Moreover, nationally the Irish government has stated that carbon will have a value of €80/tonne by 2030. If this figure was placed on the carbon index, the GHG emissions index could be introduced into the overall EBI through a sub-index. Irrespective, carbon footprint is important warranting explicit consideration within the EBI. It should be noted, however, that the inclusion of an additional trait within the EBI will slow down the rate of genetic gain for all other traits within the EBI. At best, this is because of a reduction in the intensity of selection for each of the other traits individually.

2. Must exhibit genetic variability

Data are lacking in Ireland in sufficient numbers to help quantify the extent of genetic variability in direct measures of environmental traits such as methane emissions but also other traits like nitrogen excretion. However, data are currently being collected at Moorepark with the vision that, once sufficient data are collected, the extent of genetic variability methane emissions will be quantified. Of greater interest though, is the capacity to reduce environmental load without compromising cow (milk) performance. While data on individual cow methane emissions are very limited from Ireland, some estimates of variability exist internationally based on small datasets. Heritable exploitable genetic variation has been demonstrated to exist for dairy cows. Making inference of such variability from other populations (i.e., different genetics and feeding systems) to grazing systems in Ireland would not, however, be sensible. Therefore, it will be some time before good estimates of the inter-animal genetic variability in methane emissions are available for grazing Irish cows, especially the variability independent of milk yield (and live-weight).

3. Measurable or correlated with a measureable trait

The gold standard for measuring methane emissions in dairy cows is via calorimeters. Calorimeters cost approximately €0.25m each and are resource intensive to use; each calorimeter can only measure one cow at a time. No calorimeter exists in the Republic of Ireland. One serious disadvantage of the calorimeter is that it takes the animal out of her natural environment. The other approaches to measuring methane emissions include the SF_6 method and the GreenFeeds system. The SF_6 method was the traditional method of quantifying methane emission in grazing animals and involved a vacuum “back-pack” on cows to capture exhaled methane emissions and comparing it to a tracer gas released from a small bolus placed within the animal. While less accurate at measuring methane compared to the calorimeters, is was possible for the animal to remain in its natural environment rather than being enclosed for several days within an air tight chamber as would need to be the case for the calorimeters. With sufficient equipment, it was possible to measure methane on approximately 15 animals consecutively using the SF_6 method. Nonetheless, it was labour intensive with a high consumables cost thus making it a costly exercise.

The latest method being used to measure methane in grazing dairy cows is through the GreenFeeds system (Figure 7). Each machine costs approximately €125,000 and can measure methane emissions on approximately 15-20 grazing animals at a time. The GreenFeed system is a non-intrusive system for estimating methane and carbon dioxide fluxes from the cattle who visit the units. Each GreenFeed is mounted on wheels which enable it to be moved between paddocks with the cows. Pellets are dropped down into the hood (Figure 7) every 20 seconds for 3-4 minutes and, while the cow is eating with her head in the hood, the gases in her breath are measured. Animal visits are monitored and restrictions can be put in place to prevent excessive use. A fan pulls air past the animal's muzzle into ducting where airflow rates are measured and subsampled for determination of methane and carbon dioxide concentration. Emissions are calculated from air flow and concentrations of gases in air passing the sensors, with correction for background concentrations. Daily estimates of methane and carbon dioxide emissions are made from a number of short measurements, usually over 2-3 weeks. Each measurement is only 2-7 minutes in duration and cows usually visit 1-3 times daily. The VistaMilk SFI Research Center has recently purchased the only two GreenFeed machines for using in grazing animals in Ireland and measurement of methane emissions on dairy cows is now well underway.

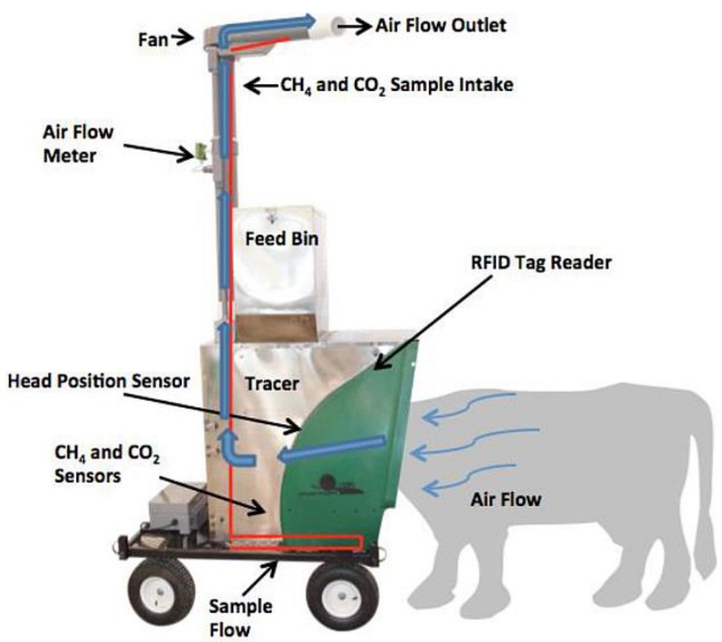


Figure 7. *Illustration of the Greenfeed equipment for measuring methane.*

Irrespective of the method to measure methane in cows, all are expensive and thus not amenable to measurement on several hundred thousand of animals annually. One less expensive option could be to measure just the daily methane of all AI bulls, but how these differences translate into genetic differences at the level of the cow is unknown. Another possible alternative being evaluated is the ability to use data generated from spectral analysis of milk samples to predict methane output. Milk fatty acids synthesized within the rumen from acetate, which are derived from fiber fermentation, have been positively associated with ruminal methane production. Forage type in ruminant diets can affect methane production as well as milk fatty acid patterns. Likewise, high starch content favours propionate synthesis, which can reduce methane production. The milk fatty acid groups of long-chain unsaturated fatty acids and the individual C18:0 originate from plant fat-derived unsaturated fatty acids are either directly transferred into milk fat (e.g., C18:3n-3) or influence rumen fermentation, thereby altering the pattern and level of precursors for milk fatty acid synthesis. Therefore several studies have used milk fatty acid concentration to develop equations to predict methane emissions in dairy cows.

Teagasc has already developed equations to predict milk fatty acid concentration from milk samples. Hence, there is a strong biological theory at least as to how methane production could be predicted from milk samples and some preliminary analyses confirm this hypothesis. The advantage of using this approach to predict methane from milk samples is that, if successful, predicted methane could be derived from all milk recording cows several times during lactation at minimal marginal cost. These data could then be used to derive estimates of genetic merit for methane production. This must all be developed and validated.

To where from here?

Evidence from simulation models suggest that the EBI is selecting for animals with a lower carbon footprint. Little data exists, however, on individual cow methane emissions. These data are needed to validate if EBI is indeed selecting for lower emitters. The dataset being compiled from the GreenFeed system will help answer this question. The mean methane emissions of animals divergent for EBI will be quantified. This approach is not that dissimilar to the Moorepark Next Generation Herd or such genotype-based controlled herds that went before it. The mean performance (or methane emissions) of the high versus low EBI group can be very useful in deducing the expected response to selection on EBI. Concurrent with this will be an evaluation of the accuracy of predicting methane emissions from the infrared spectral data of milk samples. Should predictions be proven to be accurate, then genetic evaluations will be undertaken and validated. If satisfactory then consideration will be given to the generation of national genetic evaluations for methane emissions. It could therefore be possible for a trait explicitly reflecting methane emissions to be directly included within the EBI.

Conclusions

The carbon footprint of agriculture, and especially dairy production, is coming to the fore and cannot be ignored. Breeding programs have proven that they can deliver consistent gains in both performance and functional traits. Modelling of carbon output per farm has revealed that selection on EBI will lead to a continuing reduction in carbon output per lactation. While knowledge of the extent of genetic variability in methane emissions is lacking, results from international populations have demonstrated the presence of exploitable genetic variability; methane data are currently being collected on grazing Irish dairy cows to fill this gap in knowledge. The greater barrier to deployment of genetic evaluation for methane emissions will be the routine access to individual animal data on methane emissions from a large population; research is, nonetheless, underway to investigate the feasibility of such.

Acknowledgement

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