WORK PACKAGE 4

System level impacts of environmental and socio-economic optimization – Expert analysis of the CCCfarming outcomes

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CCCfarming: System level impacts of environmental and socio-economic optimization – Expert analysis of the CCCfarming outcomes

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Summary
This report provides an evaluation of farm systems included in the Climate Care Cattle project optimizing socio-economic and environmental outcomes. To achieve this we have utilised research outputs from different work packages and used a workshop of project partners to provide expert analysis of a wide range of management interventions in different countries. Farm systems were also analysed on a regional basis with four farm systems (Intensive, Extensive, Organic and Visionair) in each region. The systems vary between regions in Europe in order to support locally appropriate farming systems and climates. The study demonstrates that despite high levels of efficiency within European dairy farming, more can be done to reduce greenhouse gas emissions and improve economic and environmental outcomes for the sector.

Introduction
Dairy farming is a critically important to food security, and on a global basis is the fifth largest provider of energy and the third largest source of protein in the human diet (OECD-FAO) agreement. The industry is dependent on large resource inputs in the form of fertilisers, energy, water and land, and as a consequence it has a large environmental footprint. In particular, dairy farming across Europe is under pressure to reduce greenhouse gas emissions in response to ambitious policy targets being implemented in response to the Paris Climate change (Leahy *et al.* 2020). Greenhouse gas emissions from dairy farming result from emissions of methane from cattle and slurry storage, from nitrous oxide as a result of nitrogen management and from carbon dioxide originating from machinery use and soils. Dairy farming also makes a significant contribution to national ammonia emissions, which is a pollutant in its own right but also acts as an indirect greenhouse gas, because in soils and water, microbial transformations of ammonia result in the release of nitrous oxide (Buckingham et al 2032). Improved farm and management can help to reduce these emissions but also provide wider environmental and economic benefits for the dairy farming sector.

The CCC farming project has explored multiple options for the mitigation of greenhouse gas and ammonia emissions from dairy systems across Europe. In this report we synthesise the results of this work in the form of outputs from a workshop that was held involving project participants but also drawing on the wider research findings of the programme.

Methodology
In the final year of the project, a workshop was organised involving project partners to evaluate management options for improving the environmental outcomes of European dairy farming. A structured questionnaire was prepared that divided management option into the following groups:

- Livestock management
- Pasture and soil management
- Housing design and manure management
- Energy

Groups of 3-6 participants were allocated to each group in accordance with their expertise and region. Groups were then asked to evaluate management options in terms of the extent to which they have been implemented in different countries and the likely impact on different outcomes relating to productivity and the environment. Participants were asked to score management strategies for current levels of uptake on farms in different countries (with scores ranging from not important (1) to applied on more than 10% of farms. In this exercise groups also assessed the impacts of different management strategies on CO_2 and ammonia emissions (on and off farm) economics, net farm income, efficiency (animal and field), soil, biodiversity and animal welfare. A scoring system of 1-5 was used where 1 was much better, 2 was better, 3 was neutral, 4 was worse, and 5 was much worse.

In a second exercise participants were asked to develop regionally based scenarios for different farm system strategies on a regional basis. The participants were asked to use their expertise and information gathered as a result of the research undertaken in the CCC farming project to respond to questions. Again scoring system of 1-5 was used where 1 was much better, 2 was better, 3 was neutral, 4 was worse, and 5 was much worse. Results were compiled by the organisers (Paul Galama and Bob Rees) and used as a basis for preparation of this report.

Results

Management Approaches and Priorities in different countries

Livestock management

The workshop results for animal management are summarised in Tables 1a and 1b. Increased animal numbers and higher stocking resulted in more emissions both on and off farm, because more animals produce more NH_3, CH_4, and CO_2, and there is a need more forage and concentrates. It was also negative for economic investment, because of the need bigger machines and equipment, but positive for income, as it should produce more milk (depends). Increased animal numbers were neutral for efficiency, but there are circumstance in which this could be better. More animals could give more health problems (more ill cows, too small barn, not enough food, etc.). It was worse for soil and biodiversity, because it is more intensive. Animal welfare could be better or worse, and depends on how management is implimented.

Less young stock was positive or neutral in every aspect, because less animals create less emissions. Longevity is good for stable milk production, less heifers (don't produce milk). Older cows are worse for animal welfare (depends on farmer management). This is a measure that has been widely adopted across European countries (Table 1a).

Animal breeding was almost neutral for all aspects. Animal welfare could be worse for breeding "low emission" cows in circumstances where such breeding has unintended impacts on welfare.

Increased feed efficiency was generally positive-neutral. Efficiency improves resource use, but to produce higher quality forage concentrate), the farmer needs more fuel, fertilizers, pesticides. It could be worse for emissions, biodiversity and soil. Impacts on animal welfare should be neutral.

Low protein diets were positive for NH_3 emissions, and neutral for CO_2. They were worse for economics, with lower milk production and expensive additives. They were worse for milk efficiency because of lower milk production. They were also worse for soil, because of the need to grow more maize, which requires soil tillage resulting in carbon loss, and potential reductions in soil quality.

Three-NOP was neutral for NH_3, but positive for CO_2, because of the CH_4 inhibitor. It was worse for economics, because of the cost (costs are not offset by increased production). It was neutral for efficiency, soil and biodiversity. It was worse for animal welfare because of the change in the microbiome. The long term effect of animal health are poorly understood. Methane blockers have so far been used largely as a research tool with very little uptake on farms across Europe (Table 1a).

Pro biotics were positive - neutral, because there is less NH_3 and CH_4, with more energy saving for cows allowing them to produce more. There was no effect on biodiversity. Probiotics may be better manure quality and so better for soil. It was positive for cow health. There was a negative economic effect because of costs.

More maize was good to reduce NH_3 emissions, because there is less nitrogen in the feed ration. More dry matter harvest, more fertilizer technology is needed for maize. Efficiency should be better; maize is good energy for cows – milk production will increase. It is worse for soil and biodiversity, since maize reduces soil quality (more tillage). It is worse for animal welfare, since too much maize causes low rumen pH.

Higher production per cow was neutral for NH_3, but better for CO_2. It may be worse for economics, because of the need to buy more concentrates. Because more milk is produced there is more income. Cows are more efficient when they produce more milk. There was no effect on biodiversity. It may be worse for animal welfare, because of mastitis. Ill cows are more sensitive.

Table 1a The level of implementation of livestock management in different countries

	Emission		**Readiness in each country**							
Mitigation category, and related practices	NH3	GHG	Po	Lt	La	It	Fr	Ge	Sc	Nl
Animal - amount										
Less young stock, lower replacement cows (longevity)	X	X	5	4	3	4	3	5	3	5
Performance increases, reduction of breeding animals	X	X	5	5	3	5	4	5	3	5
Animal - breeding										
Genetic selection feed efficiency, health, low emission	X	X	1	5	2	4	1	3	3	4
Animal - feeding										
Low protein diets	X		2	1	4	3	1	3	2	4
Low phosphate in diets	X		1	1	1	1		1	1	4
Feed more maize	X	X?	5	5	3	5	1		2	4
Feed more concentrates		X?	5	3	4	5	1	1	2	4
High digestible diet	X	X	4	5	3	5	1	5	3	5
More balanced feed and feed additives	X	X	5	5	3	5		5	3	4
Use of probiotics in the barn	X		2	4	2	5		1	2	1
Methane blocker as feed additive		X	1	1	1	3	1	1	3	3
Precision feeding tools and techniques	X	X	4	5	4	4	1	5	3	4

Key

Po Poland, Lt Lithuania, La Latvia, It Italy, Fr France, Ge Germany, Sc Scotland, Nl Netherlands
Level of Readiness (R): 1, Not important in our country, 2 Applied on less than 10 farms, 3, Applied on 0.5 to 1 % of farms, 4, Applied on 1 to 10% of farms, 5, Applied on more than 10% of farms.

Level of Readiness (R) 1 Not important in our country; 2 Applied on less than 10 farms; 3 Applied on 0.5 to 1 % of farms; 4 Applied on 1 to 10% of farms; 5 Applied on more than 10% of farms

Table 1b The effect of livestock management on farm level outcomes

	Emission				Other indicators						
Strategy	NH3-barn per LU	NH3 field per ha	CO2 off farm/kg FPCM	CO2 on farm/kg FPCM	economics-investment	net farm income	Efficiency - field	Efficiency animals	soil	biodiversity	animal welfare
Animal-numbers											
higher stocking rate	5	5	3	4	4	2	2	2	4	4	2
less young stock (less replacement)	2	2	2	3	2	2	3	2	2	2	2
Animal -breeding	3	3	3	3	3	2	3	2	3	3	4
Animal-feeding											
Increase feed efficiency	2	2	2	2	3	2	2	2	3	3	3
Low protein diets	1	1	3	3	4	4	3	4	4	3	3
3-NOP (methane inhibitor)	3	3	1	1	4	4	3	3	3	3	4
Pro biotics	2	3	3	2	4	4	3	2	2	3	2
More maize feeding	2	4	3	3	3	2	2	2	4	4	4
Higher production per cow	3	3	2	2	4	2	3	2	3	3	4

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Pasture and soil management

Pasture and soil management offer the opportunity to reduce emissions of ammonia and nitrous oxide from the soil, to increase carbon sequestration and to indirectly influence methane emissions through effects on pasture quality (Table 2). Four measures were identified as contributing to both ammonia and GHH mitigation, these were increased grazing hours, silage of higher nutritional value, more home grown protein and increased efficiency in crop farming.

Increased grazing was identified in Latvia and the Netherlands as being the most important strategy for reducing emissions of ammonia and GHGs. The assumption would be that increased grazing reduces the amounts of slurry produced and given that emissions associated with excreta produced in the pasture are lower than those from slurry this would lead to lower overall emissions. Both the Netherlands and Latvia currently use long periods of housing for dairy production allowing the opportunity for increased grazing.

In Latvia mowing younger grass was considered an important mitigation strategy, which provides cattle with feed of higher nutritional value, contributing to lower methane emissions. The more general practice of silages of increased nutritional value (higher ME) was recognised in Poland, Lithuania Italy and the Netherlands as being important. Again this would be expected to contribute to lower methane emissions.

Increased maize production was identified as a priority action in Poland and Germany. This approach provides a high quality feedstock reducing emissions of methane and potentially contributing to higher levels of productivity.

More homegrown protein was identified as a priority in Poland, Latvia, Italy and Germany. This measure would be expected to reduce the quantity of imported feed and thereby financial costs, but would also lower the carbon footprint of the system by avoiding the use of synthetically fixed fertiliser nitrogen and the associated emissions.

Increased efficiency in work process is was identified as a priority in Poland, Lithuania, and Germany. This recognises the importance of tailoring system level inputs precisely to the requirements of that system for optimal growth and production thereby avoiding waste and increasing economic and environmental efficiencies. One specific example of this identified as a priority in Lithuania and Germany was more efficient roughage production, which was defined as more output per unit of input to the system.

Cover crops provide coverage of bare soils between phases of a rotation and can help conserve nutrients and improve soil quality. These were identified as being important in Poland and in Germany.

Soil and water management were seen as having less opportunity for improvements in system level outcomes. However, water level management in Latvia and reduced tillage in Germany were considered to have significant opportunities to deliver better economic and environmental outcomes.

Table 2a. The level of implementation of pasture and crop management in different countries

	Emission		Readiness in each country							
Mitigation category, and related practices	NH3	GHG	Po	Lt	La	It	Fr	Ge	Sc	Nl
Grazing and grassland										
More hours grazing	X	X	3	3	5	3	4	1	2	5
Mowing younger grass	-	X?	1	5	3	4	4	1	2	4
Silages of high nutritional value	X	X	5	5	3	5	1	5	3	5
Crops										
Grow more maize	X		5	5	2			5	1	4
Grow own concentrates (sugar beets, grain)	?	X?	4	5	4	3	4	4	2	3
More self produced protein (e.g. mixture grass and legumes)	X	X	5	5	4	5	3	5	3	3
Increasing efficiency in work processes in crop farming	X	X?	5	5	3	4	2	5	2	4
More efficient roughage production (more output/input)		X?	3	5	3	4		5	3	5
Covercrops			5	4	4	4	4	5	2	5
Soil and water										
Higher groundwater level peat ground		X	1	3	5	1		1	2	3
Wetland management		X	3	3	2		3	1	2	2
Reduced tillage and restored pastures		X	4	4	3	4	2	5	2	4

Key

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Table 2b. The effect of crop management on farm level outcomes

	Emission				**Other indicators**						
Strategy **Grazing and grassland**	NH3-barn per LU	NH3 field per ha	CO2 off farm/kg FPCM	CO2 on farm/kg FPCM	economics-investment	net farm income	Efficiency - field	Efficiency animals	soil	biodiversity	animal welfare
More grazing	1	3	2	5	2	3	3	4	4	3	2
Grass species	3	3	3	2	3	2	2	2	2	2	2
Crops											
High digestable diet	4	3	4	3	4	3	3	2	4	4	3
Nitrification inhibitor	3	3	3	1	4	3	2	2	3	3	3
More maize, less grassland	4	3	4	3	4	3	3	2	4	4	3
More legumes	3	4	2	2	3	2	2	2	2	2	2

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Housing design, manure management and energy

A summary of the impacts of housing, manure management and energy management is provided in Tables 3a and b. Low emission flooring is very effective for ammonia emissions reduction because of the decreased contact between faeces and urine. This separation also slightly affects CO_2 emissions. It's an expensive solution. The efficiency in the field is "better" because we can manage two different kinds of manure (liquid and solid) with higher nutrient content. Its effects on biodiversity are neutral (although reduced ammonia losses may be beneficial). It can improve animal welfare (with respect to cubicles).

Cow toilets are also very effective for ammonia emissions reduction. It's an expensive solution and needs training of the cows to adapt to the new system. It can be used only if you supply concentrated feed (so not suitable for unifeed system). The farmer income can be considered "worse"- The efficiency in the field is "better" because we can manage two different kinds of manure (liquid and solid) with higher nutrient content. Neutral about biodiversity. It doesn't improve animal welfare.

Use of a urease inhibitor is very effective for ammonia emissions reduction. It's not a very expensive solution ("neutral"), but it needs more storage tanks due to the large use of water. About CO_2 all the energy to move the slurry has to be considered. The net farm income can be "worse" due to the big amount of slurry produced, that needs labour to manage (spreading in the field). The efficiency in the field is neutral because slurry is more diluted but urease inhibitor decrease N losses. It can improve animal welfare (respect to cubicles). The biodiversity can be "worse" due to the large amount of diluted slurry spread on the fields. Animal welfare can improve thanks to the cleaning of flooring.

Covering the manure storage can reduce ammonia and CO_2 emissions. But the cost of the covering is to be considered (it can become mandatory in meany regions). Neutral about net income. Good quality manure can allows the efficiency in the field and improve the biodiversity of the soil. Neutral from welfare point of view. Covering the manure storage with straw can have an effect on ammonia and CO_2 emissions. The solutions is not very expensive, but requires labour to manage the straw. It is neutral with regards to net income. The quality of manure can improve, so the efficiency in the field is "better". The biodiversity of the soil can improve. It is neutral from welfare point of view.

Mechanical manure separation can reduce NH_3 emissions, mainly from urine. When quickly removed this means lower NH_3 emitted. When removed from the barn it means lower field emissions. CO_2 is estimated to be neutral, but emissions could increase. Cost for investment; Potentially higher incomes (Chemical N saved) more important than cost for investment. Same total N-inputs, but manure brings a diversity of "fertilizers". Could help to avoid foot disease.

Low pH - low NH_3 emissions. Not sure that manure stays acid when spread. CO_2 on farm based on CCCFarming experimentation. Cost for investment is an equilibrium between costs and N-savings. The same total N-input are used, but manure brings a diversity of nutrients. Acidification could have long term effect on soil microbial composition and could disturb soil biodiversity. Low pH could help to avoid foot disease.

Manure acidification reduces the pH and lowers NH_3 emissions in the field. More fossil fuel used to carry acid tanks on tractors. There are also costs for investment. Supposed equilibrium between costs and N-savings. Same total N-inputs, but manure brings a diversity of "fertilizers". Acidification could have long term effect on soil composition. Neutral - But acidification could disturb soil biodiversity.

Low emission spreading techniques vary, but in general they provide good results to lower NH_3 from the barn. CO_2 on farm there can be increased emissions due to more fuel. Low emission spreading may provide higher incomes (Chemical N saved) than the cost for investment. The approach uses the same total N-inputs, but manure brings a diversity of nutrients. For soil the impact is likely to be neutral, but burying manure would mainly need to use tractors twice, which would be bad for soil compaction. The effects on biodiversity are not known.

Anaerobic digesting depends on size farm, use of heat, price of energy, export of green gas or making electricity and on farm level or on central level (cooperation of farmers).

There are two strategies: (1) take fresh manure or (urine and faeces) out of the barn, then transport to closed storage. A company collects methane from storage (passive digesting), (2) On site biodigester with onsite use of methane produced or export. Option 2 involves higher capital investment and is more appropriate for larger farms of farm cooperatives.

Farms are able to install solar or wind generation but this is highly capital intensive. It is important to determine how much energy is produced and the income generated (national tariffs vary significantly). There are many possibilities to recycle energy like using heat from milk to heat water and cool milk, or low energy light or tractor on electricity.

Table 3a. The level of implementation of housing design, manure management and energy in different countries

	Emission		Readiness in each country							
Mitigation category, and related practices	NH3	GHG	Po	Lt	La	It	Fr	Ge	Sc	Nl
Housing										
Increasing the scrapping frequency	X	X	1	4	3	5	1	5	1	4
low emission floor (e.g. separation faeces and urine)	X		1	3	1	2	1	1	1	4
Low emission floors (e.g. prefabricated floors with grooves)	X		1	1	1	3	2	3	1	4
Slight slope in walking areas	X		2	2	2	5		4	1	3
Use of straw where manure stays (with solid manure storage)	X		1	3	4	5	1	1	1	3
Freewalk organic bedding	X	-	5	1	1	3		3	1	3
Innovative floors (separation faeces/urine) and bedding	X		2	1	1	2	1	1	1	3
Manure acidification	X		2	3	1	1	1	1	1	2
Manure additives	X		2	3	2	1	1	2	3	3
Air filtering of ammonia and methane	X	X								2
Storage										
Conversion of manure lagoon to cylindrical storage	X		3	1	3	5		1	2	2
Lower manure level in liquid storages	X	X	1	1	1			1	3	2
Covering manure storage	X	(X)	3	3	3	4	4	5	5	5
Covering liquid manure tanks with passive methane production	X	X	1	1	1		2	4	4	2
Composting the manure	X		3	1	2	3	3	3	1	3
Energy, general										
Anaerobic digester		X	2	2	3	3	3	4	3	3
Biofermentor	X	X	3	1	3		3	4	1	2
Burning methane		X	3	1	1	1	1	4	1	2
Solar / PV panels, plus solar power applications		X	5	3	3	4	4	5	3	4
Less energy demanding machines, tractors, equipment	X	X	5	5	3	5		5	2	3

Key

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Table 3b. The effect of housing, storage, manure management and energy use on farm level outcomes.

	Emission				**Other indicators**						
Strategy	NH3-barn per LU	NH3 field per ha	CO2 off farm/kg FPCM	CO2 on farm/kg FPCM	economics-investment	net farm income	Efficiency - field	Efficiency animals	soil	biodiversity	animal welfare
Housing											
Low emission floor	1	1	2	2	4	3	2	3	3	3	2
Cowtoilet	1	1	2	2	4	4	1	1	3	3	3
Plate, water, urease inhibitor	1	1	2	2	3	4	3	3	4	4	2
Storage											
Covering manure storage	1	2	2	2	4	3	2	3	2	3	3
Straw to cover manure[e]	2	2	2	2	3	3	2	3	2	3	3
Manure Management											
Mechanical manure separation	2	2		3	4	2	2				2
Manure acidification stable	2	3		2	4	3	2		4	3	2
Manure acidification field		2		4	5	3	2		4	3	
Low emission spreading		1		4	5	2	2		3	3	
Energy											
Anaerobic digester	2	3	2,5	1	5	2,5	3?	3	4	3,5	2,5
Cover tank; use passive methane	2	3	3	2	3	2	3	3	3	3	3
Renewable energy	3	3	1	3	5	1,5	3	3	3	3	3
Energy saving equipment	3	3	3	2	3,5	2	3	3	3	3	3

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

The importance of farming systems

Livestock management in different European Regions

Management in dairy farming provides a major opportunity to improve the performance of systems from an economic and environmental perspective. However baseline conditions vary in different regions. We chose to explore four contrasting future system designs; Intensive, Extensive, Organic and Visionair, and asked working groups to describe the characteristics of these systems and their affect on different impact categories on a regional basis. The outcome of this exercise are described in Tables 4-7 and reflect regional differences in approach based on climate and existing management baselines.

The intensive management system recognises the need for improved livestock nutrition with a greater need for imported feed and higher stocking densities. However, there were regional differences. In Scotland and the Netherlands which already operate at a relatively high level of intensity, some further modest increases in feeding (more maize) and livestock density were proposed However, in regions which currently have lower intensity systems such as France, Italy, Latvia and Lithuania, the approach was to increase home grown proteins, increase forage quality and introduce cover-cropping. The intensive management systems recognise the benefits in terms of improved economics and lower emissions per unit of Fresh Protein Corrected Milk (FPCM) whilst also identifying negative impacts such as increased off farm CO_{2e} emissions and negative impacts on soils and biodiversity.

The extensive systems all identify the need for reducing stoking densities, however differences in system design were apparent between regions. Thus in France and Italy, the importance of local breeds and multispecies swards was identified. In Germany and Poland, traditional breeds and approaches to animal feeding were considered important, while in Latvia and Lithuania landscape management approaches such as wetland management and tillage were considered to provide opportunities. The assessments in all regions recognised the increased emissions intensities coupled with improved environmental outcomes across all regions.

The organic farming systems generally focus on even more extensive farming than the extensive systems without fertiliser inputs and less concentrate feed. This is offset by a higher milk price which is favourable for the economic result. Extensive farming affects ammonia and greenhouse gas emissions per kg of milk and per ha. Due to the low input of artificial fertilisers and concentrate feed, organic scores well in terms of emissions per ha, but less so when expressed per kg of milk. A distinction of organic farming systems is also more focus on local cattle breeds (especially in France, Italy, Latvia and Lithuania), animal-friendly housing, lots of milk from grass, biodiversity and landscape. Some will also adopt new techniques such as virtual fencing, sensors or solar panels. Organic farming adopts regulations laid down by national certification bodies and therefore has less flexibility than other farming systems to introduce alternative management.

Visionary systems vary greatly within and between countries. The Netherlands and Scotland clearly indicate both extensive natural dairy farming and more intensive high-tech development. Variation between farms in terms of scale, animals per ha, degree of grazing, production per cow, use of techniques such as sensors, automation of milking and feeding, manure management and manure digestion will increase. Precision agriculture around nutrition and cultivation will become more important. Use of methane blockers and seaweed in diets will increase to reduce methane emissions. Other crops, less tillage, use of catch crops, less chemical crop protection products will increase to reduce nitrate leaching and improve soil health. Less competition with human nutrition is also mentioned by several countries as becoming important. Think of insects as a source of protein. Germany and Poland also see opportunities for functional foods. And housing will be more focused on both better animal welfare, longer life span and fewer emissions.

Management strategies in France and Italy

Table 4a. Livestock management in different French and Italian systems

Strategy	Intensive	Extensive	Organic	Visionair
Animal-amount	Increase longevity / reduce replacement rate. Increase animal numbers / and density (animals/ha)	reducing numbers / reducing stocking rates	reducing numbers / reducing stocking rates	reducing dairy to increase other animal categories
Animal - breeding	Select for feed efficiency	local breeds / cross breeds	local breeds	select on CH4 index
Animal-feeding	Import more feed	more feed produced on the farm, less inputs	more feed produced on the farm, less inputs	feeding seaweeds
	Reduce the protein level, less concentrates, increase forage quality/digestibility	reducing the protein level, less concentrates, increase forage quality/digestibility	reducing the protein level, less concentrates, increase forage quality/digestibility	feeding insects?
	More feeding robots			
Grazing and grassland	Exercice pasture for dry cows	virtual fencing increase grazing	virtual fencing increase grazing	
		better pasture management	better pasture management	
		multispecies swards including legumes	multispecies swards including legumes	
	Increase grass quality (especially for harversting)	increase grass quality	increase grass quality	
Crops	More hedges	more hedges	more hedges	
	no/minimum depth tillage	no/minimum depth tillage	no/minimum depth tillage	
Soil and water	Drought resisting crops (without irrigation)	drought resisting crops (without irrigation)	drought resisting crops (without irrigation)	
	More efficient irrigation systems		more efficient irrigation systems	
Housing	Use sand as bedding			
	Refreshing mats in cubicle and recovering heat			
	Developping mechanically ventilated barns			
	Promote walking areas/freedom movement/outdoor access	Promote walking areas/freedom movement/outdoor access	Promote walking areas/freedom movement/outdoor access	
	Urine feces separation			
	more sensors and automatisation	More sensors and automatisation?	More sensors and automatisation?	
Storage	Covered pits	Covered pits	Covered pits	
Manure and fertilizing	Increase fertilisation efficiency by best practices for application	increase fertilisation efficiency by best practices for application	increase fertilisation efficiency by best practices for application	
	Reduce chemical fertilizer	Reduce chemical fertilizer	Reduce chemical fertilizer	
Energy, general	biofermenter/biomethane			
	increase solar pannels	increase solar pannels	increase solar pannels	

The impact of farm systems on environmental outcomes in France and Italy

Table 4b. The impact of farm systems on environmental outcomes in France and Italy

Impact	Intensive	Extensive	Organic	Visionair
NH_3 stable per kg LU	2	3	3	3
NH_3 field per ha	4	2	2	
CO_2 off farm per kg FPCM	4	2	2	
CO_2 on farm per kg FPCM	2	3	3	
Economics-investment	4	3	3	
Net farm income	2	3	2	
Efficiency field	2	2	2	
Efficiency animals	2	2	2	
Soil	3	2	2	
Biodiversity	3	2	2	
Animal welfare	2	2	2	

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Management strategies in Latvia and Lithuania

Table 5a. Livestock management in different Latvian and Lithuanian systems

Strategy	Intensive	Extensive	Organic	Visionair
Animal-amount	Increase longevity	Reducing stocking rates	Reducing stocking rates	Increase longevity Reducing stocking rates
Animal -breeding	Genetic selection on feed efficiency, health, low emission	Local breeds	Less intensive breeds (apart Holstein), local breeds	Breeding based on genomic analysis, embrio transplantation, sexed semen (only females)
Animal-feeding	Increase forage quality/ Feed effeciency	Increase of grazing and feeds grown on the farm and forage quality	Grazing and feeds origin from organic farm	Microalges
	More balanced diets and use of feed additives/ probiotics	More balanced diets and use of feed additives	Improve quality of own grown feeds	Feed more maize
	Low protein diets		More balanced diets and use of feed additives	Feeding local protein feeds (also soya)
	Precision feeding tools and techniques		Feeding local protein feeds	Methane blocker as feed additive
				Precision feeding tools and techniques
Grazing and grassland	Increase of grassland quality, plant species biodiversity and dry matter production	Increase grass quality	Increase grass quality	Electrical robot shepherd / Milking robot
	Increase grazing rate by improving of grass production per ha	Increase grazing rate by improving of grass production per ha	Increase grazing rate by improving of grass production per ha	Increase of grassland quality, plant species biodiversity and dry matter production
	More hours grazing	More hours grazing	More hours grazing	
Crops	More maize	More efficient roughage production (output/input)	More efficient roughage production (output/input)	Soya growing, precission agriculture
	Covercrops	Crop rotation	Covercrops	Cover crops, non/minimum tillage technologies
	More own grown legumes	More own grown feedstuffs for concentrates (grain, legume)	More own grown feedstuffs for concentrates (grain, legume)	More own grown legumes
Soil and water	Fertiliser sink reduction	Reduced tillage and restored pastures	Reduced tillage and restored pastures	Application of microorganisms preparats to soil
	Cach crops	Wetland management	Wetland management	Cach crops
	Improving health of soil	Green fallow	Green fallow	Smart drainage system
	Green fallow	Soil analyses	Soil analyses	Reduced tillage and restored pastures
Housing	Increasing the scrapping frequency	Slight slope in walking areas	Increasing the scrapping frequency	Low emission floors
	Low emission floors		Slight slope in walking areas	Automatisation (sensors)
				Sand beddings
				Cow toilet
Storage	Conversion of manure lagoon to cylindrical storage	Use of straw for manured surfaces (with solid manure storage)	Conversion of manure lagoon to cylindrical storage	Covering liquid manure tanks with passive methan
	Covering manure storage	Composting the manure	Composting the manure	Composting the manure
Manure and fertilizing	Manure acidification	More organic and less chemical fertilizer	Bury slurry <6 hrs after application arable land	Manure acidification
	More organic and less chemical fertilizer	Fertilization according to soil analyses	Application of manure according to soil analyses	Precision techniques for manure handling and fertilization

	Precision techniques for manure handling and fertilization			More organic and less chemical fertilizer
	Mechanical manure separation Bury slurry <6 hrs after application arable land			Precise fertilization according to soil quality map
Energy, general	Anaerobic digester	Solar / PV panels, plus solar power applications	Solar / PV panels, plus solar power applications	Anaerobic digester
	Solar / PV panels, plus solar power applications	Lesss energy demanding machines, tractors, equip	Lesss energy demanding machines, tractors, equip	Lesss energy demanding machines, tractors, equipments
	Lesss energy demanding machines, tractors, equip			Biofermentor/biomethane

The impact of farm systems on environmental outcomes in Latvia and Lithuania

Table 5b. The impact of farm systems on environmental outcomes in Latvia and Lithuania

Impact	Intensive	Extensive	Organic	Visionair
NH_3 stable per kg LU	2	4	4	2
NH_3 field per ha	2	4	4	1
CO_2 off farm per kg FPCM	4	3	2	3
CO_2 on farm per kg FPCM	2	4	3	2
Economics-investment	2	4	4	1
Net farm income	2	4	3	2
Efficiency field	2	4	4	2
Efficiency animals	2	4	4	2
Soil	4	3	2	3
Biodiversity	5	3	1	3
Animal welfare	3	2	2	3

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Management strategies in Germany and Poland

Table 6a Management strategies in Germany and Poland

Strategy	***Intensive***	***Extensive***	***Organic***	***Visionair***
Animal-amount	more animals/m2	about 20 cows, closed barn, tie stall barn	less animal/m2	less animals, more efficiency, sustainable production
	Less animals per m2/increase longevity/ health	f. farms will collapse	f. more importance	
Animal - breeding	selection not only for the milk production	based on local breeds; less genetic improvement	better longevity and health	"super cows" high efficiency, high milk solids content, low emission
	inseminations/ better genetic improvement			functional foods
Animal-feeding	More concentrate, better starch	Traditional feeding	higher protein degradation in the rumen	no competition with human nutrition (feed/food), insects as a source of protein, more essential amino acids
	More supplements, lysine and methionine		better source of protein (improved legumes)	
	Similar nutrition as in monogastrics (enzymes)			
Grazing and grassland	does not work, less grass silage	possible/summer and winter season, in Germany if grazing only in summer season	dedicated to the system, yield limitation	better plant species, well balance nutrient content, resistant to climate change
Crops	More energy for maize production (more fertilizers)	less production from crops/less production from cows	reduce yield, less fertilizers	precision farming, better management
Soil and water	Limiting biodiversity, higher water consumption	traditional farming/crop rotation	higher biodiversity, less water consumption	precision farming, better management
Housing	cubical, well ventilated,	closed barn, worse ventylation	freewalk system	milking robot following a cows, zero emission barn, intelligent buildings
	more robotised . better bedding			
Storage	less solid fraction		more soild fraction	ongoing slurry utilization, no storages are needed
Manure and fertilizing	higher production, negative impact of increased use	manure/slurry separately large amounts of straw used	better management	high quality, no extern/chemical fertilizier needed
Energy, general	higher consumption, more devices to power	average consumption, less robotised	less consumption, robotised possible	produce all energy with own renewable energy systems

The impact of farm systems on environmental outcomes in Germany and Poland

Table 6 b The impact of farm systems on environmental outcomes in Germany and Poland

Impact	***Intensive***	***Extensive***	***Organic***	***Visionair***
NH_3 stable per kg LU	*2*	*4*	*4*	*1*
NH_3 field per ha	*4*	*2*	*1*	*3*
CO_2 off farm per kg FPCM	*4*	*2*	*1*	*1*
CO_2 on farm per kg FPCM	*2*	*4*	*1*	*1*
Economics-investment	*5*	*2*	*4*	*1*
Net farm income	*2*	*5*	*1*	*1*
Efficiency field	*1*	*4*	*4*	*1*
Efficiency animals	*1*	*4*	*3*	*1*
Soil	*4*	*2*	*2*	*1*
Biodiversity	*4*	*2*	*1*	*1*
Animal welfare	*3*	*4*	*1*	*1*

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Management strategies in the Netherlands and Scotland

Table 7a. Management strategies in the Netherlands and Scotland

Strategy	Intensive	Extensive	Organic	Mixed with arable	Visionair	
				regionale or farm level	nature based	high tech
Animal-amount	more cows	Less cows			extensive	intensive
	>3 cows per ha	<1,5 cows per ha	<1,5 cows per ha			
Animal - breeding					10000 kg per cow	14000 kg per cow
Animal-feeding	3900 kg/cow	760/cow	800/cow	own concentrates	grass	grass, luzerne, maize
	11000 kg/cow	7000 / cow	7000 / cow	TMR	byproducts	concentrates
Grazing and grassland	no grazing	1790 hours	1790 hours	720 hours grazing	Mixed species grass Clover	limited grazing
					3000 hours grazing	
Crops	20% maize		more clover	alfalfa, maize, grain	no maize	high yielding crops
	12500 dm maize/ha	12500 dm maize/ha	9800 dm maize/ha		feed centre?	
Soil and water	Enhanced fertiliser	Nutrient budgeting		Increased circularity	Sensor technology	Precision fertiliser
Housing	low emission floor			separate feces and urine	freewalk, organic, multiple use	Low emission barn
					Sensor technology	separate feces and urine
Storage					milking robots? Concentrates	
Manure and fertilizing		lower fertilizer	no fertilizer	feces, urine, fertilizer		precision
Energy, general				electric tractors	mono biodigester ?	digester

The impact of farm systems on environmental outcomes in the Netherlands and Scotland

Table 7b. The impact of farm systems on environmental outcomes in the Netherlands and Scotland

Impact	*Intensive*	*Extensive*	*Organic*	*Visionair Nature based*	*High tech*
NH_3 stable per kg LU	*4*	*1*	*4*	*1*	*1*
NH_3 field per ha	*2*	*4*	*1*	*4*	*3*
CO_2 off farm per kg FPCM	*5*	*2*	*1*	*1*	*3*
CO_2 on farm per kg FPCM	*2*	*5*	*4*	*1*	*3*
Economics-investment	*2*	*4*	*4*	*2*	*5*
Net farm income	*2*	*5*	*1*	*3*	*3*
Efficiency field	*1*	*4*	*4*	*3*	*2*
Efficiency animals	*1*	*4*	*3*	*1*	*2*
Soil	*4*	*2*	*2*	*1*	*3*
Biodiversity	*4*	*2*	*1*	*1*	*3*
Animal welfare	*3*	*4*	*1*	*2*	*2*

Score 1 to 5: 1 = Much better, 2 = Better, 3 = Neutral, 4 = Worse, 5 = Much worse

Overall environmental performance of European dairy systems

The dairy industry is recognised as having a high carbon and environmental footprint (Feil et al 2020). However, European systems compare favourably with international benchmarks. A global analysis reported average emissions from milk of 3.1 kg CO_{2e} kg PCFM (Poore and Nemecek, 2019) which is significantly higher than the 1.0 kg CO_{2e} kg PCFM reported from participating European farms in this study.

This study has demonstrated a wide range of environmental performance across dairy farming within Europe. An analysis of modelled C footprint data from 60 farms across the participating European countries demonstrated emission intensities on whole farms of between 0.39-2.11 kg CO_{2e} kg PCFM (Fig. 1). This analysis shows differences between countries with Italy having the highest average emissions of 1.23 and Poland the lowest at 0.80 kg CO_{2e} kg PCFM. However, these national differences were not statistically significant with a wide range of emission intensities reported within each country. The absence of any strong national difference indicates that climatic and environmental controls over emissions may be less important in controlling GHG emissions than management interventions such as those discussed in this report.

The variability in the C intensity of milk production was found to be focussed on smaller farming enterprises (Fig. 2), with a convergence of emission intensities to a value of around 1 CO_{2e} kg PCFM. This is likely to reflect the widespread adoption of mitigation approaches used in larger more commercial dairy enterprises that deliver improved economic and environmental performance. However, there is also a constraint in such operations in terms of the application of higher cost mitigations that could further lower the carbon footprint.

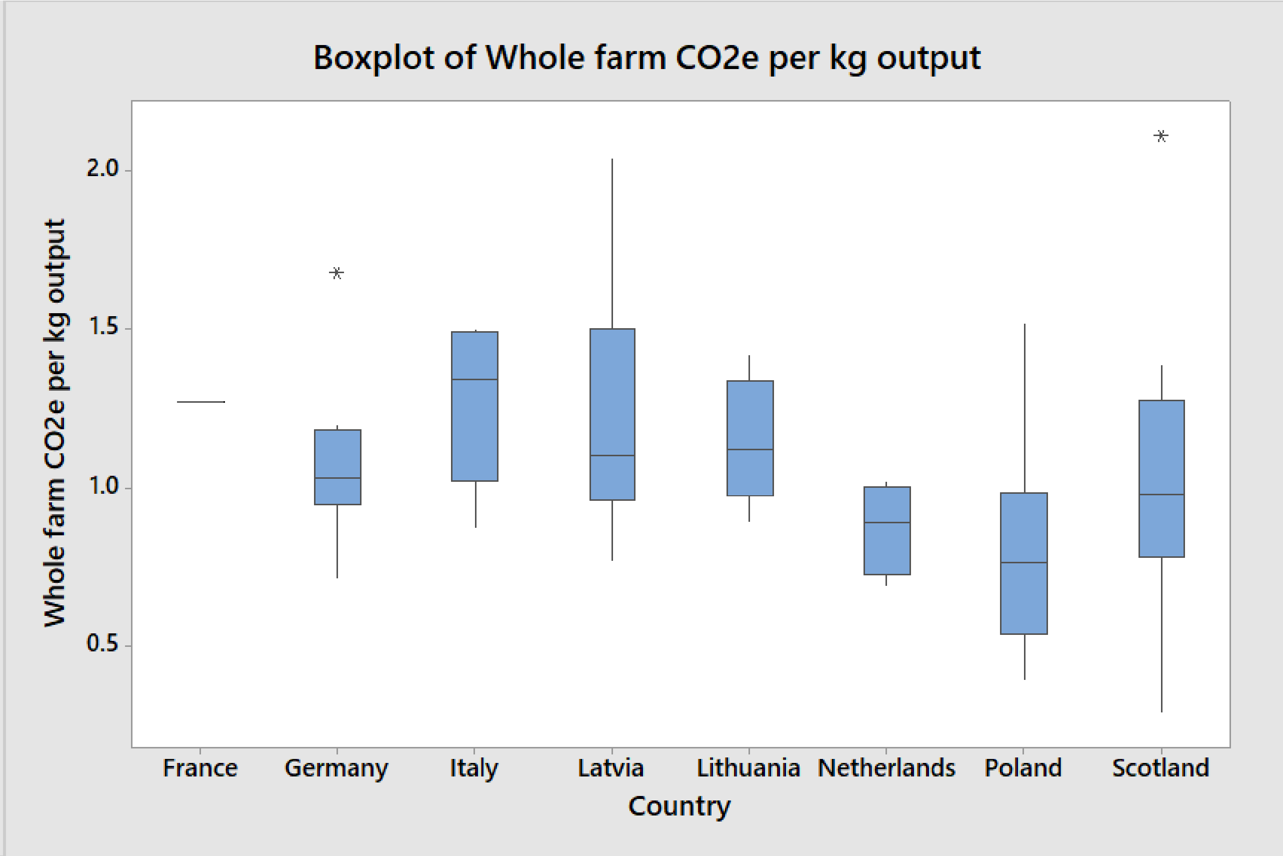

Figure 1. The carbon footprint of dairy farming across Europe.

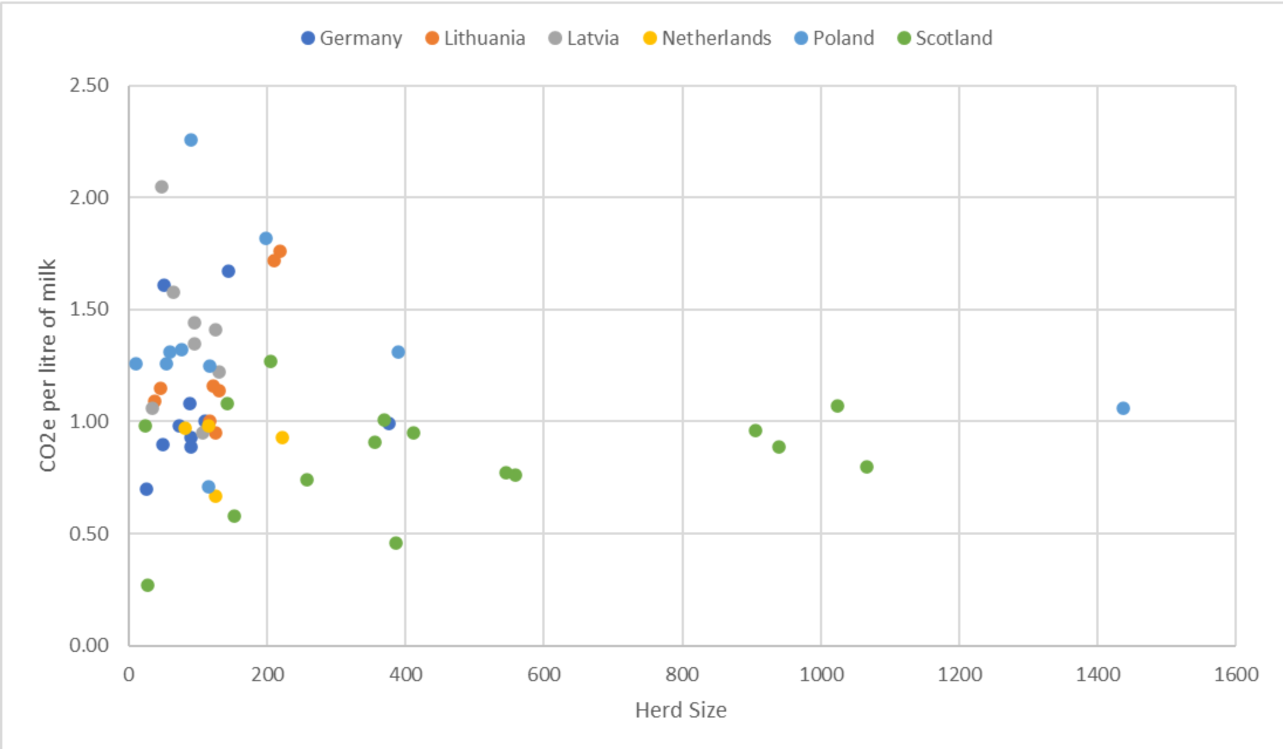

Figure 2. The relationship between carbon intensity and herd size across European dairy farms.

Conclusions

This study has highlighted the important role that management interventions have in delivering efficient, productive and low emission dairy production across Europe. Milk produced in European dairy systems already achieve high levels of efficiency when compared with global baseline, however, it is also recognised that more needs to be done to reduce current levels of emissions in order to meet ambitious climate change and ammonia mitigation targets. No single intervention will achieve this, but our study has shown that changes to livestock management, pasture management, housing, energy use and manure management can have beneficial and additive effects on productivity and environmental outcomes. The carbon footprints of real dairy farms across Europe indicate that the variability within countries is often larger than that between countries highlighting the opportunity for management interventions to influence environmental outcomes.

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