Report on stakeholder workshops and report on stakeholder attitudes to mitigation (D1.6)

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Project: CCC Farming

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Summary of the CCCFarming project

Technological development and eventual adoption of environmentally friendly practices by farmers are key elements of agriculture's transition towards more sustainable food production; contributing to the European Union's target of climate neutrality by 2050 and its environmental targets for air and water. To this extent, CCC Farming, a JPI funded research project, aims to further develop cattle farming practices and innovations which reduce greenhouse gas (GHG) and ammonia (NH_3) emissions. The project investigates mitigation practices in all aspects of cattle farming, including feeding, housing, manure management, breeding, grassland, soil and cropland management by measuring and modelling farm emissions as well as testing innovative approaches. While engaging with farms across eight European countries, the project also explores how much these farmers have engaged with reducing GHG and NH_3 and what changes they have made or planning to make on their farms in these directions.

Introduction

The dairy sector is one of the most important agricultural sectors in Europe. It accounts for 12% of total output from agriculture and is the second-largest agricultural sector in the European Union (Augère-Granier 2018; Bas-Defossez et al. 2019). The milk production from the dairy sector stood at 158.2 million tonnes of raw milk in 2019[1] with approximately 70% produced by Germany, France, Poland, the Netherlands, Italy and Spain[2]. However, the environmental sustainability of the livestock industry, in particular ruminant production is increasingly scrutinised. Evidence suggests that though milk often is shown to have the lowest environmental impact of ruminant products, it is still associated more greenhouse gas (GHG) and ammonia (NH_3) emissions, nitrogen losses to water and adverse environmental impacts per kg of protein than non-ruminant livestock products and plant based food (Leip et al. 2014; Poore & Nemecek 2018). Despite the observed decoupling of GHG emissions from production – higher productivity usually being associated with lower emission intensity (Gerber et al. 2011; Läpple et al. 2022) – further, substantial reductions from the dairy system are needed to meet the net zero GHG target in the EU. NH_3 is posing a difficult challenge too, as agricultural emissions continue to rise despite the policy efforts in the area[3].

Several GHG and NH_3 mitigation strategies have been proposed for livestock production, such as improving the fertility and reducing the mortality in the herd, better feeding management, selective breeding and changes in manure management (Herrero et al. 2016; Webb et al. 2005). Specifically for dairy cattle, the management strategies with potential for reducing non-CO_2 GHG emission intensity include increased productivity, residual feed intake, animal

[1]Eurostat Milk and milk product statistics https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Milk_and_milk_product_statistics
[2] FAOSTAT statistical database. http://www.fao.org/faostat/en/#data/QC
[3] https://www.eea.europa.eu/highlights/ammonia-emissions-from-agriculture-continue

health, reduced animal mortality (Hristov et al. 2013). Mitigation options for NH_3 often overlap with GHG mitigation practices (Kupper et al. 2020).

As advice on more environmental friendly farming becomes more available and requirements to reduce negative impacts are increasingly built into the European subsidy system, understanding about how farmers make decisions on adopting emission mitigation technologies becomes increasingly important. Information on the uptake of certain technologies exists (e.g. manure storage types, anaerobic digesters, the use of high breeding value animals), but an overall picture is still unavailable, with studies scattered between countries, livestock species and technologies (Buckley et al. 2015; Glenk et al. 2014; Konrad et al. 2019). Similarly, very few studies report on farmers' awareness and knowledge about their alternative farm management options (Jantke et al. 2020), potentially limiting the development of more targeted and effective advisory activities and policy schemes. Moreover, the context dependency of adoption could warrant participatory and co-design approaches, which are not yet widely used in Europe (Burbi et al. 2016; Hurley et al. 2022).

The work reported here addresses these gaps, in particular focusing on the following questions: 1) to what extent pollution reduction is embedded in farmers past actions and future plans and 2) what are the GHG and NH_3 mitigation actions they have recently adopted and planning to adopt, 3) what are the drivers and barriers for their adoption of mitigation practices.

Methods

Participatory action research is a process where stakeholders (in this case farmers) work together with researchers with the aim of solving problems related to a specific domain (in this case GHG and NH_3 emissions). The process involves data collection, reflection and action (Baum et al. 2006). By definition, it is highly context dependent (i.e. a case study approach), but as such can highlight details which methods using larger samples might miss.

In the CCC Farming project researchers have recruited farmers to work with them over a 4-year period, focusing on the development of GHG and NH_3 mitigation technologies. The overall workplan with the farmers involved repeated contact with researchers, on average once a year. These contact points included in person farm visits, emission measurements, farm carbon footprinting, and in person and virtual discussions carried out at the beginning and end of the project. This report summarises the findings from the discussions at the beginning of the project.

The sample consists of 57 dairy farmers in eight countries (Table 1). The questionnaires gathered information on the farmers' and farms' background along with recent changes made, information used to support decisions, awareness and actions on GHG and NH_3 mitigation and barriers to these actions.

Table 1 Sample size (N) in each participating country

	N
Germany (DE)	7
France (FR)	8
Italy (IT)	7
Lithuania (LT)	4
Latvia (LV)	8
The Netherlands (NL)	8
Poland (PL)	8
United Kingdom (UK)	7
Full sample	57

Results

Farm characteristics

Farm area ownership (*versus* renting) was highest in Latvia and the UK (82% and 74%, respectively) and lowest in France (14%), on average 50% of the farmers owned more than 2/3 of the land area they cultivate (Table 2). While the majority of farms are operated with up to 10 workers, there were two farms in the sample (one in Italy and one in Poland) which had more than 50 workers (Table 2). All but one of the farms received Common Agricultural Policy (CAP) direct payments, though CAP greening payments were not as uniform (in France, the Netherlands and the UK 71-88% received them, while in Poland only 14%) (Table 3). On average half of the farm got other types of government subsidies; this proportion varied greatly between countries. The majority of the farms had only up to 10% income from agriculture related diversification sources (e.g. farm shop, tourism, creamery, forestry), but off-farm income was slightly more important: for 26% of the farmers more than 20% of the total family income were from non-farming activities (Table 3).

Table 2 Ownership and farm worker (incl. farmer and family) numbers (respondent number in brackets if smaller than sample size)

	DE	FR	IT	LT	LV	NL	PL	UK	Full sample
Proportion of area owned	(5)	(7)	(6)						(53)
Up to 33%	60%	86%	33%	0%	0%	50%	38%	14%	34%
34-66%	40%	14%	33%	25%	50%	13%	13%	14%	26%
More than 66%	0%	0%	33%	75%	50%	38%	50%	71%	40%
Number of workers									
Up to 10	100%	14%	86%	75%	75%	100%	63%	43%	79%
Between 11 and 50	0%	86%	0%	25%	25%	0%	25%	57%	18%
More than 50	0%	0%	14%	0%	0%	0%	13%	0%	4%

Table 3 Financial characteristics of the farms (respondent number in brackets if smaller than sample size)

	DE	FR	IT	LT	LV	NL	PL	UK	Full sample
Receives CAP direct payment	100%	100%	100%	100%	100%	88%	(7) 100%	(6) 100%	(55) 98%
Receives CAP greening payment	(6) 100%	(7) 71%	100%	100%	100%	88%	(7) 14%	71%	(54) 80%
Receives any other gov't payment for sustainable practices	100%	71%	(4) 25%	100%	50%	(7) 14%	(6) 66%	(5) 20%	(49) 47%
Agricultural diversification (proportion of income)	(4)					(6)			(52)
Up to 10%	75%	75%	86%	100%	100%	100%	100%	71%	88%
More than 10%	25%	25%	14%	0%	0%	0%	0%	29%	12%
Off-farm family income proportion	(3)		(5)			(7)			(50)
Up to 20%	33%	63%	100%	100%	0%	43%	75%	71%	74%
Between 21% and 80%	33%	38%	0%	0%	25%	14%	25%	29%	20%
More than 80%	33%	0%	0%	0%	75%	43%	0%	0%	6%

The proportion of organic producers were substantially higher in the sample (19%) than the proportion of organic milk production in Europe (2%)[4] (Table 4). On average half of the farms had contractual obligations to improve their sustainability – these included contracts with slaughterhouse, milk buyer (mentioned in 13 cases), crop buyer, but also voluntary farm

[4] Eurostat, [org_aprod] and [apro_mk_pobta]

associations (e.g. organic producers, LEAF farms). Dutch farmers mentioned grazing premium often. The differences between countries were notable: all farms had these arrangements in Germany and the Netherlands, while none in Latvia and Lithuania. Finally, roughly one quarter of the farms were closer than 3 km to a Natura 2000 area and another half of them were between 3-10 km distance from them.

Table 4 Other farm characteristics (respondent number in brackets if smaller than sample size)

	DE	FR	IT	LT	LV	NL	PL	UK	Full sample
(Partial) organic producer	25%	25%	29%	0%	25%	13%	13%	14%	19%
Contractual sustainability assessment (industry)	(6) 83%	63%	57%	0%	0%	100%	63%	43%	(56) 54%
Distance to closest Natura 2000 area		(4)			(5)				(50)
Up to 3 km	29%	75%	14%	25%	40%	13%	38%	29%	28%
Between 3.1 and 10 km	71%	0%	86%	50%	40%	50%	38%	0%	48%
More than 10 km	0%	25%	0%	25%	20%	38%	25%	71%	24%

Farmer characteristics

The average age of the farmers was less than the average in European Union (EU) (Table 5), where only 11% of the farmers is aged under 40[5]. The sample underrepresents women in agriculture, as only 12% were women, while the EU average is 35% and it highly over-represents both farmers educated at tertiary level (59% in the sample *versus* 9% in the EU) and farmers who had agricultural education (88% in the sample and 30% in the EU)[6]. The farmers had a long experience in farming (median: 25 years), most of them were co-op members (81%) and owners or occupiers rather than employed managers (74%).

[5] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20180719-1

[6] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Farmers_in_the_EU_-_statistics

Table 5 Farmers' personal characteristics

	DE	FR	IT	LT	LV	NL	PL	UK	Full sample
Age							(7)		(56)
Up to 45 years old	43%	38%	29%	25%	50%	38%	71%	0%	38%
45-65 years old	57%	63%	57%	75%	50%	63%	29%	100%	61%
Above 65 years old	0%	0%	14%	0%	0%	0%	0%	0%	2%
Gender: male	100%	75%	86%	100%	75%	100%	(6) 100%	(5)[1] 100%	(54) 85%
Years in farming									
Up to 20 years	57%	38%	14%	25%	25%	25%	50%	29%	32%
21-40 years	43%	63%	71%	75%	63%	63%	50%	43%	59%
More than 40 years	0%	0%	14%	0%	13%	13%	0%	29%	11%
Tertiary education	57%	88%	14%	100%	(7) 100%	38%	100%	100%	(56) 59%
Agricultural education	100%	75%	71%	100%	75%	100%	88%	100%	88%
Owner/occupier (not employed manager)	71%	38%	86%	75%	100%	88%	63%	71%	74%
Co-op or farmer union member	86%	50%	100%	100%	50%	88%	88%	100%	81%
Identified successor	66%		29%	75%	63%	25%	25%	43%	42%

[1] In two cases male-female couples were interviewed

Farmers' networking and information sources

The number of meetings farmers had with professional about their farm management ranged between 2 and 120, with a median of 15 (Table 6). These meetings included a range of topics, most prominently nutritional advisors and vets, with financial and science contacts mentioned often too (Figure 1).

Two third of the farmers had been involved in environmental projects or study groups and the majority of them had visited events focusing on environmental issues; half of the farmers went to such meetings three or more times in 2019 (Table 6).

Table 6 Farmers' information environment

	DE	IT	LT	LV	NL	PL	UK	Full sample
Meetings with advisors/ professionals in 2019								
Up to 15	100%	57%	25%	38%	75%	25%	57%	51%
Between 16-50	0%	14%	75%	50%	25%	50%	29%	38%
More than 50	0%	29%	0%	13%	0%	25%	14%	11%
Involvement in environmental projects or study group	100%	29%	100%	38%	100%	50%	86%	67%
Events visited in 2019 on environmental issues								
None	0%	86%	0%	13%	38%	38%	0%	29%
1 or 2	0%	14%	0%	25%	38%	12%	29%	40%
Between 3-10	100%	0%	75%	50%	25%	50%	29%	40%
More than 10	0%	0%	25%	13%	0%	0%	43%	11%

Figure 1 Farmers' meetings with professionals in 2019

Farmers were posed the open-ended question "Usually whose opinion and advice do you consider most in your decision to make a change on your farm?" to which they could list up to five sources of advice. Table 7 shows that their most trusted sources of information was agricultural advisors, specifically vets and nutritional advisors mentioned often. Other farmers and researchers were also frequent sources of trusted advice. In Lithuania farmers listed only five types of different sources, while in Poland twelve categories got mentioned, suggesting a more diverse information environment.

Table 7 Most trusted information sources (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Agricultural advisors, agronomists		43	50	88	25	50	86	53
Technicians		43					14	9
Farm associations	33							2
Buyer/processor/retailer		14			13		29	9
Nutritional advisors		29	25	13		63	43	27
Breeding advisors						13		2
Vets		43	50	38	13	13	43	29
Accountants						13	57	11
Business consultants							43	7
Bank specialists						13	29	7
Employees	33	14						4
Friends						13		2
Other farmers	33			63	25	13	43	27
Family members	33	14		13	25	13	14	16
Own experience/research	33	43		38				16
Researchers	67	14	100	38	13	38		31
Media				13	13	13		7
Other	67	29	25		13	13	14	18
Total number of types of impacts mentioned	7	10	5	8	8	12	11	18

For advice specifically on GHG and NH_3 measures farmers mentioned researchers and agricultural advisors most often. Scientific information reached them via other channels too, as many of them mentioned that they do their own research for scientific information or consult with their peers on these matters (Table 8). The distinction between trusted sources for farming information and for GHG and NH_3 information is interesting, as it shows that environmental information is only partially embedded in general farm management, potentially leaving space for conflicting information or gaps.

Table 8 Most trusted information sources regarding GHG and NH_3 mitigation measures (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Agricultural advisors, agronomists		57	100	63		13	43	38

Technicians		29						4
Farm associations		14					29	7
Buyer/processor/retailer		14		13			29	9
Nutritional advisors						13		2
Breeding advisors								
Vets								
Accountants								
Business consultants								
Bank specialists								
Employees								
Friends								
Other farmers	67			63	25		14	22
Family members							14	2
Own experience/research	67	14		13	25		29	18
Researchers	33	29	75	75	38	13	43	42
Media								
Other		14	25	50	13	25	14	22
Total number of types of impacts mentioned	3	7	3	6	4	4	8	10

Farmers' understanding of GHG and NH_3 processes was tested with two questions for each pollutant. Farmers scored better on the NH_3 related questions, giving correct answers in three quarters of the cases. The GHG knowledge scores were lower, with only one-third correct answers (Table 9).

Table 9 Farmers' knowledge score (average percentage of correct answers)

	DE	IT	LT	LV	NL	PL	UK	Full sample
GHG knowledge score	83	14	0	6	50	31	79	36
NH_3 knowledge score	100	79	63	69	63	63	100	74
Overall knowledge score	92	46	31	38	56	47	89	55

Farm management

Farmers were asked – in a closed question – about how they saw the importance of different aspects of farm management for the long-term financial viability of the farm. They perceived animal health and animal feeding the most important topics, scoring a bit lower but categorising still as "absolutely important" grassland management and business management. Drainage, machinery and fuel use and other aspects of crop cultivation were considered as the least important aspects. Responses varied between countries, for example Italian farmers did consider animal feeding as only "moderately important", and drainage and other aspects of crop cultivation were the least important for German farmers. Polish and

Lithuanian farmers were more interested in technology and automation than their peers from other countries. In an open-ended question respondents mentioned further considerations, including climatic conditions, labour topics (staff qualifications, management skills and innovativeness, farmer's health and wellbeing), the policy and economic environment (subsidy system, sustainability regulations, milk price, consumers) and environmental issues (biodiversity, carbon management).

When comparing these results with the responses on how important are different farm management aspects for GHG reduction, we could not observe a big difference in opinion, with the general trend being that many farm actions were considered a bit less important for GHG than for farm finances with the exception of irrigation/drainage (interestingly, though there are GHG benefits from improving drainage, and also some from improving irrigation, these actions are not highlighted in the scientific literature as the most prominent GHG mitigation measures).

Table 10 Importance of farm management aspects in the long-term financial viability and of the farm (F) and in reducing GHG emissions (G) (mode of categories 1-5) (1: Absolutely important, 2: Very important, 3: Moderately important, 4: Of little importance, 5: Not important at all, 6: Not applicable)

	DE		IT		LT		LV		NL		PL		UK		Full sample	
	F	G	F	G	F	G	F	G	F	G	F	G	F	G	F	G
Animal feeding	2	2	3	2	1	3	1	1	1	1,3	1	1	1,2	2	1	2
Animal breeding	2	2	2	2	1,2	2,4	1	3	2	2	1	2	2	2	2	2
Animal health	2	2	1	2	1,2	2,3	1	1	2	2	1	1,3	1	2	1	2
Livestock housing and manure storage	2	1	2	1,2	2	1,2,3	1	1,2	2	1,2	1,2	1	1,2	2	2	1,2
Fertiliser/manure application, soil management	2	2	2	2	2	2	2	1	2	2	1,2	1	2	2	2	2
Irrigation and/or drainage	3,4,5	3	3	2	1,2	2	3	2	2	2	1	2	3	3	3	2
Other aspects of grassland and grazing management	3	3	2,3	2	1	2,3	2	1,3	2	1	1	2	1	2	1	2
Other aspects of crop cultivation	2,3,4	3	2	2	1,2	2,3	2	1,3	2	2	1	3	2	2	2	2
Business management (contracts and labour)	2	3	3	3	1	2,3	2	3	2	3	1	2,3	1	2	1	2
Machinery and fuel use	3	2	2	2	2	2	1,2	2	2,3	3	1	2	3	3	2	2
Technology and automation	3	2	2	2	1	3	2	2	3	3	1	1,2	3	3	2	2

Changes on the farm

Farmers reported on the bigger changes they made in the past five years on their farms and what actions they are planning to make to adapt to changes in external factors impacting them in the coming five years (Table 11). Amongst the past actions changes in livestock buildings were the most frequent by far (67% of farmers), grassland management and feeding infrastructure coming as second (22% for both). Breeding and feed ration changes were both mentioned by 16% of the farmers. Farmers in the Netherlands and Italy mentioned the most diverse set of changes (14 and 13, respectively), in contrast Latvian farmers only listed five different actions.

There are some marked differences between past and future changes. Future plans involved livestock buildings only in 9% of the cases (such infrastructural investments have a long payback period, so such a difference is expected). Feeding infrastructure was not mentioned by the farmers at all as a future plan (even though only one fifth have done such changes in the past five years), but grassland management was mentioned at a similar rate as a future plan than it was as a past action. Future actions were slightly more diverse (29 in total as opposed to 24 past actions) and more evenly distributed.

Table 11 Past (P) and future (F) changes on the farms (percentage mentioned; empty cell means 0%)

	DE		IT		LT		LV		NL		PL		UK		Full sample	
	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
Fieldwork timing		33										13				4
No-till / min till			14				13	13			13				7	2
More legumes								13		13						4
Crop species/variety		33	14					13			13	13		14	4	9
Rotation									13	13				14	2	4
Irrigation			14	14								13			2	4
Fertilisaton (e.g. PF, timing)						25			13				43	29	9	7
Slurry/manure storage or treatment	33	33	14	14	25		13		13	13			14	14	13	9
Slurry/manure spreading	33	33		14						25					2	9
Grassland management					25	25	50	50	13	25			57	57	22	24
Home grown feeds									13	13			29	29	7	7
Breeding or mating	33		14						13				57	29	16	4
Digital livestock monitoring and management	33		14								25			14	9	2
Feeding infrastructure	67				75		25		25		13				22	
Feed ration		33					38		13	13			43		16	4
Livestock buildings	67	33	86	14	50	25	75	13	75		50		57		67	9
Ventilation	33		43	14					13						11	2
Tree planting	33												14	14	4	2
Renewable energy			14						13	13	13	38	29	14	11	11

	DE		IT		LT		LV		NL		PL		UK		Full sample	
	P	F	P	F	P	F	P	F	P	F	P	F	P	F	P	F
Energy saving			29	14							25	25			9	7
General efficiency improvements				14				13						14		7
Milking robots			29		25		25	13							11	2
Production structure (e.g. livestock types, organic)				29			13	25	25				14	14	9	11
Farm size			14				13						29		9	
Consumer dialogue		33														2
New permits, certificates										38						7
Diversification									13	13					2	2
Labour (amount, structure)											25	25			4	4
Financial risk management				14								13				4
Retirement								13								2
Other	33		43					13	25	38	38		29	14	24	11
Total number of areas of change mentioned	9	7	13	9	5	3	9	10	14	11	9	7	12	13	24	29

The reasons farmers listed for the above-mentioned past changes were mainly related to animal welfare and health (38%), reducing environmental impact (24%), financial aspects (cost decrease and farm economics, 29% and 18%, respectively) and the wide topic of productivity/efficiency (productivity, efficiency, labour efficiency 29%, 22% and 18%, respectively each) (Table 12).

On the other hand, the expected drivers for changes on their farms featured mainly policy, climate change and macroeconomic changes, 13% (57% in The UK) also mentioning societal pressure (Table 13). When talking specifically about external factors which might make the farmers to adopt GHG mitigation measures, they mostly expected increased regulation and better availability of subsidies (Table 14).

Table 12 Reasons for past changes (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Compliance with regulations	33				13	13		7
Sustainability scheme (buyer, processor)					13			2
Reduce environmental impact		29		38	38		43	24
Improve soil quality or reduce erosion	33				38			9
Improve animal welfare/health	33	71	25	50	25	38	14	38
Gain more information about the herd			25					2
Reduce climate change effects on farm		14				25		7
Reduce damage from wildlife					13			2
Reduce debt ratio				13				2
Increase competitiveness		14			13			4
Improve farm economics	33	14					86	18
Reduce (fixed) costs		57	25		13	38	57	29
Increase income		14			13			4
Increase productivity	33	57	25	63	13		14	29
Increase efficiency	33	57			13	13	43	22
Increase product quality (including products used on farm)		14			25			7
Increase self-sufficiency				13	25			7
Change old infrastructure/machinery		29	25	13		13		11
Decrease labour requirement		43		13				9
Increase labour efficiency	33	29	50			25	14	18
Improve work safety		29				13		7
Improve working conditions		14		13				4
Have more specialised workforce					13	13		4

	DE	IT	LT	LV	NL	PL	UK	Full sample
Fits other technologies	33	14						4
Scientific interest	33							2
Farmer became less profit oriented (happiness, idealism)					25			4
Not specified					13			2
Total number of types of reasons mentioned	9	16	6	8	16	9	7	27

Table 13 External changes expected to impact on the farm in the next five years (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Policy	33	29	75	88	75	25	100	62
Environmental protection						13		2
Climate change effects on farm	33	43	25	38		50	29	31
Societal pressure				13		13	57	13
Consumer demand	33	14			13		14	9
Financing from banks					13		14	4
Supply chain pressure							14	2
Macroeconomics	33	43	25	25		50	29	29
Labour supply				38			14	9
New technologies		29				13	14	9
Not specified	33				25			7
Total number of types of impacts mentioned	5	5	3	5	4	6	8	11

Table 14 External changes related to GHG emissions which farmers expect would make them adjust the farm in the next five years (mode of categories 1-3) (1: Very likely, 2: Fairly likely, 3: Not likely at all, 4: Does not know)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Increased expectations from the general public on reducing GHG emissions from my farm	2	1	2	1,2	1,3	2	2	2
Increased requirements from my buyers or milk processing company to reduce GHG emissions from my farm	2	1	2	2,3	1	2	1	2
Increased availability of subsidies to reduce GHG emissions from my farm	1,2,3	1,2	1,2	1,2	1	1	2	1
Increased pressure from local community on reducing GHG emissions from farm	2	2	2	3	3	2,3	3	3

Increased regulatory requirements to reduce GHG emissions from my farm	2	1	2	1	1	2	2	1
Increasing educational programs on sustainable farming practices	2	2	2	1,2	2,3	2	2	2

Opinion on environmental issues

Most farmers agreed that they had to protect the environment, even if that reduces their revenues. They also agreed~~s~~ that their individual actions matter for GHG reduction and that sustainable farming practices offered opportunities for their farming business (Table 15). However, they felt that the environmental impact of farming is overestimated by the public and half of them stated that farming only contributes to GHG and NH_3 emissions a little bit (Table 16).

Table 15 Agreement to statements on environmental issues (mode) (1: strongly agree, 2: agree, 3: unsure, 4: disagree, 5: strongly disagree)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Farmers have the obligation to contribute to environmental protection as much as possible	2	2	2	3	2	1	2	2
I am willing to take environmental protection measures on my farm even if it is at the expense of revenues	2	2	3	3	2	1,2	2,3	2
The negative environmental effects of farming are often overestimated by the public	2	2	1,2	1	1	1	2	1
An individual farmer cannot do anything to reduce greenhouse gas emissions	5	4	3	4	4,5	4	5	4,5
Climate change impacts are already noticeable	2	1	1	1,2	2	1	2	1
Sustainable farming practices can create business opportunities	2	2	2	2	2	1	1,2	2

Table 16 Opinion on farming's contribution to GHG and NH_3 emissions

	DE	IT	LT	LV	NL	PL	UK	Full sample
Do you think that agriculture contributes to GHG emissions?								
Yes, a lot	100%	29%	25%	63%	13%	29%	86%	45%
Yes, a little bit	0%	71%	75%	38%	75%	71%	14%	52%
No	0%	0%	0%	0%	13%	0%	0%	2%
Do you think that agriculture contributes to NH_3 emissions?								
Yes, a lot	100%	40%	0%	57%	63%	43%	57%	51%
Yes, a little bit	0%	60%	100%	43%	38%	57%	43%	49%
No	0%	0%	0%	0%	0%	0%	0%	0%

Uptake of GHG and NH_3 mitigation practices

Almost all farmers have heard about greenhouse gases or carbon footprinting, except one in Poland and almost all farmers have heard about ammonia emissions, except one each in Poland, Italy and Latvia. 41% of the farms have done carbon audits; high proportions in the Netherlands, in The UK and Germany, and no carbon audits in Poland and Lithuania (Table 17). A variety of carbon calculators had been used to do the audits, notably the Cool Farm Tool, Agrecalc, Farm Carbon Toolkit, ANCA tool, Alltech E-CO_2, Latvia University of Life Sciences GHG and ammonia calculator.

Table 17 Farms which have had carbon audits

	DE	IT	LT	LV	NL	PL	UK	Full sample
Carbon audit	66%	14%	0%	38%	88%	0%	71%	41%

Farmers were asked about their use of 16 GHG and NH_3 mitigation measures. Six measures were commonly adopted (by more than 60% of the farmers): increasing milk production per cow, increasing longevity, using grass-clover mix, increasing fertilisation efficiency, increasing roughage production per area and increasing soil organic matter. These data also correspond with the large proportion of farmers reporting past action to reduce their emissions (Table 19).

We need to note that these are self-reported adoption data, and the way the certain practices were operationalised on the farms were not checked by the researchers (e.g. a farmer might say that they use clover in their swards, but the clover content might not be large enough to substantially reduce nitrogen fertiliser application, which is the key GHG and NH_3 benefit of clover use).

On the other hand, two mitigation options were widely unknown: manure store cooling and methane capture and burn. Manure acidification, manure dilution and reducing the protein content of the feed were not known by one-third to one-fourth of the farmers.

Between 4-10% of the farmers mentioned that they were planning to use the practices in the next five years – suggesting a very slow diffusion process, as adoption intention does not necessarily lead to adoption and our sample are from those farmers who are on the front of the adoption curve. On the other hand, on average one in four farmers stated that they are not planning to adopt the practices in the next five years. This is in contrast to the responses obtained about farmers' intention to adopt practices (in general) reduce their emissions: 75% and 76% of them said that in the next five years they were planning to adoption GHG and NH_3 mitigation actions, respectively (Table 19). The discrepancy might arise from farmers plans to adopt mitigation practices which were not in the list of 16 action, but it also might be a result of bias in responses, depending on how a question is phrased: wider agreement might be obtained to more general questions.

Table 18 Familiarity and use of GHG and NH_3 mitigation practices (full sample, percentage of respondents, empty cell means 0%)

	I haven't heard about this practice	I am using this practice	I am planning to use this practice in the next five years	I have used this practice in the past and would not like to use it again	I have not used this practice before and not planning to use it in the next five years
Increase milk production per cow		78	9	13	
Increase longevity of stock	2	87	9	2	
Use grass clover mix in pastures	2	62	9		27
Increase fertilisation efficiency		78	20		2
Separate faeces from urine	13	36	20	4	24
Increase roughage production per ha	2	73	13	4	7
Provide lower crude protein content feed	24	36	7	2	29
Provide higher fat content feed	18	36	11	4	27
Add feed additives to ration	13	42	20	7	16
Cool the manure store	53		4		42
Acidify the manure	33	4	18	2	42
Dilute the manure	29	27	7	9	24
Compost the manure	11	38	18	2	31
Increase soil organic matter		73	18	2	2

	I haven't heard about this practice	I am using this practi ce	I am planning to use this practice in the next five years	I have used this practice in the past and would not like to use it again	I have not used this practice before and not planning to use it in the next five years
Anaerobic digestion of manure	13	9	16		62
Capture the methane from the manure store and burn or purify it (without anaerobic digestion)	42	4	9		44
Across measures	16	43	13	3	24

Table 19 Changes to reduce emissions

	DE	IT	LT	LV	NL	PL	UK	Full sample
Changes made to reduce GHG emissions (past 5 years)	100%	57%	75%	75%	100%	86%	86%	82%
Changes made to reduce NH_3 emissions (ever)	100%	66%	100%	71%	100%	71%	86%	81%
Considered changes to reduce GHG but abandoned the idea	33%	43%	25%	25%	88%	50%	86%	49%
Considering changes to reduce GHG in the next five years	100%	71%	50%	50%	100%	71%	86%	75%
Considering changes to reduce NH_3 in the next five years	100%	83%	75%	57%	100%	57%	86%	76%

Open-ended questions were asked the farmers to reveal the various actions they have done in the past five years to reduce their GHG and NH_3 emissions, respectively (Figure 2 and Figure 3). The responses were very varied, particularly for GHG. The most commonly mentioned GHG action was solar panel installation, followed by manure storage improvement, anaerobic digestion, reduced energy use, new machinery, reduced fertiliser use, reduced tillage and genetic improvement. The practices mentioned could be – loosely – grouped into three separate categories. 1) practices which are mainly considered by scientists as specific GHG reduction actions, 2) practices which improve efficiency and therefore have the potential to reduce emissions (if production is kept constant) and 3) practices of which beneficial effects on GHG emissions are questionable. In the first group belongs e.g. solar panel installation, anaerobic digestion, and also some less frequently mentioned actions, like slurry acidification, agroforestry and clover-grass mixture. Many actions mentioned belong to the second group, like reductions in input use, improved efficiency, genetic improvement, sexed semen use, more balanced feed. The third group has a large number of actions: new machinery, reduced concentrates/more grass in the diet, Freewalk housing, liquid fertiliser, slurry additives, more home-grown crops, stopping feeding soya, livestock housing improvement. The actions implemented by farmers to reduce NH_3 emissions were less varied, with manure management changes dominating the list. While most of them are indeed considered as NH_3 reduction technologies, there are a few which often increase NH_3 emissions (manure separation, compost bedding).

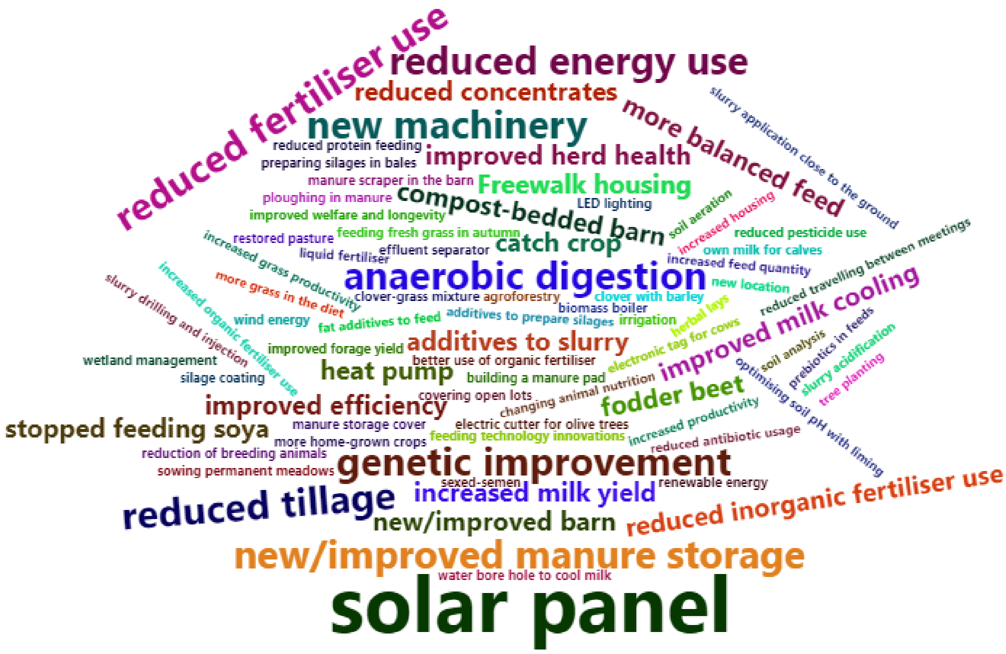

Figure 2 Changes implemented to reduce GHG emissions

Figure 3 Changes implemented to reduce NH_3 emissions

Interestingly, responding to an open-ended question about the reasons for adoption of GHG mitigation measures, over one third of the farmers mentioned farm economic considerations and over one fifth mentioned improving efficiency (Table 20). These were the main drivers, followed by improving other (non-GHG) environmental outcomes (18%), soil quality and animal welfare (11% each). Only one farmer mentioned that they adopted a GHG practice to reduce GHG emissions and 11% more referred to increasing soil carbon sequestration.

Reasons for NH_3 mitigation adoption were similar, efficiency improvement – often specifically nitrogen use efficiency – (44%) being the major reason, while farm economics was mentioned by 11% of farmers. 18% of farmers wanted to improve other environmental outcomes (18%) (most often odour reduction was mentioned). 13% of farmers mentioned regulatory reasons for NH_3 mitigation adoption (this was 7% for GHG).

Table 20 Reasons for adopting GHG reduction measures (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Compliance with regulations			25	13	13			7
Sustainability scheme (buyer, processor)					13		14	4

Reduce GHG emissions					13			2
Reduce NH_3 emissions								
Increase carbon sequestration					50		14	11
Improve other environmental outcomes (incl. odour)	67	14		25	13	13	14	18
Match manure storage capacity with demand								
Improve soil quality or reduce erosion	33		25		38		14	13
Improve animal welfare/health		29	25	13	25			13
Reduce climate change effects on farm						13		2
Improve farm economics	33	57	25	25	13	38	71	38
Increase productivity		14			13	13	14	9
Increase efficiency		14		13	50		57	22
Increase product quality	33	14		13			29	11
Increase self-sufficiency		14			38		14	11
Improve work safety		29				13		7
Recommendation from others						13		2
Research participation			25					2
Number of reasons mentioned	4	8	5	6	11	6	9	16

Table 21 Reasons for adopting NH_3 reduction measures (percentage mentioned; empty cell means 0%)

	DE	IT	LT	LV	NL	PL	UK	Full sample
Compliance with regulations	33			13	13	25	14	13
Sustainability scheme (buyer, processor)								
Reduce GHG emissions			25					2
Increase C sequestration								
Reduce NH_3 emissions			25		25		14	9
Improve other environmental outcomes (incl. odour)		29	50		13		43	18
Improve soil quality or reduce erosion		14			13			4
Match manure storage capacity with demand								
Improve animal welfare/health		29		25				9
Reduce climate change effects on farm								
Improve farm economics		14		13		13	29	11
Increase productivity				13		13	14	7
Increase efficiency	33	29		25	100	25	71	44

Increase product quality								
Increase self-sufficiency								
Improve work safety								
Recommendation from others								
Research participation	33		75					9
Total number of types of reasons mentioned	3	5	4	5	5	4	6	10

Regarding changes farmers might implement in the next five years, for GHG mitigation renewables, manure management options (specifically manure separation and anaerobic digestion) and feed management options (general change and home-grown feed) were often mentioned (Figure 4). As with the implemented actions, these measures also contained some which might not reduce, or can even increase GHG emissions (e.g. home-grown feed, manure separation, slurry aeration). The planned NH_3 mitigation measures were fewer, and proportionally contained fewer actions which might be contrary to the stated environmental goal (NH_3 reduction) (Figure 5). This suggests that farmers have a better understanding of which actions can reduce NH_3 emissions than they have about GHG emissions.

Probably not surprisingly, almost half of the farmers have considered implementing certain GHG changes but decided against them finally. Examples of such practices are solar panel and anaerobic digestion installation, low emission slurry spreading, covering slurry tank, but also some which are innovative, like plasma-powered manure nitrogen enhancement and air extraction from manure storage.

Figure 4 Planned future changes to reduce GHG emissions

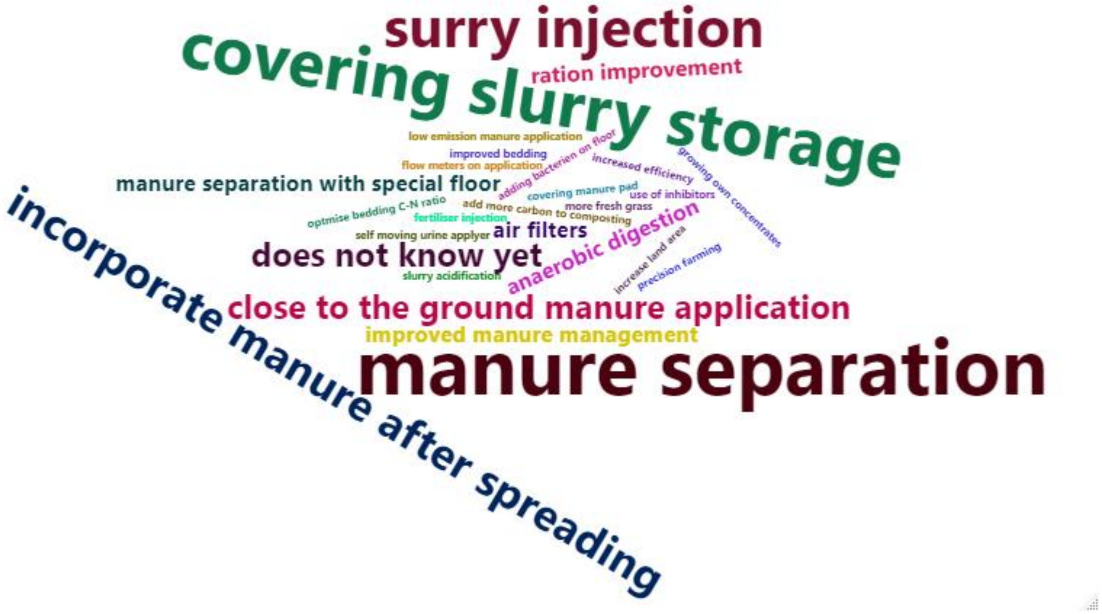

Figure 5 Planned future changes to reduce NH_3 emissions

Discussion and conclusions

The sample consists of farmers who are ready to work with researchers (often have worked with them in the past), tend to be younger than the average farmer population and much better educated. From these characteristics we can assume that they are the farmers who can be described as early adopters or even innovators (Rogers 1962). This would suggest that they have a higher awareness of technologies which can reduce the environmental damage from farming, higher actual adoption rates and stronger intentions. Indeed, almost all respondents had heard about greenhouse gases, carbon footprinting and ammonia emissions and over 40% of them has done carbon audits. Thus, our results are likely to reflect the most advanced views in the respective countries' dairy farming communities with regards to GHG and NH_3 mitigation.

As general changes and improvements in their farms, most farmers have been investing in improving their livestock buildings in the past five years, and a bit less than one quarter have also worked on improving grassland management, feeding infrastructure, breeding and feed ration. Their main reasons for these changes were related to animal welfare and health, environmental impact and financial and efficiency aspects. Interestingly, though they are the innovators, working with environmental researchers, reasons for changes as animal welfare/health, cost reduction and productivity increase came all before the environment.

Most of the farmers expected important changes in policy, climate and the macroeconomic environment in the future, and their planned actions to adopt to these circumstances were very diverse, with only grassland management featuring highly, followed by one-tenth of the farmers mentioning renewable energy and production structure (e.g. changing the type of livestock, adopting organic methods). This higher diversity in planned actions is an expected part of a decision process (where options are narrowed down as businesses get closer to making changes) and reflects on the variety of avenues farmers are constantly considering.

The farmers on average adopted six mitigation measures out of the 16 they were asked about. These were: increasing milk production per cow, increasing longevity, using grass-clover mix, increasing fertilisation efficiency, increasing roughage production per area and increasing soil organic matter. Such responses need a word of caution, though, as the actual implementation of a measure might be not according to best practice regarding emission reduction (e.g. a farmer might say that they use clover in their swards, but the clover content might not be large enough to substantially reduce nitrogen fertiliser application). A few mitigation options were not well-known amongst the farmers: manure store cooling, methane capture and burn, manure acidification, manure dilution and reducing the protein content of the feed. These options tend to be the ones which do not provide high efficiency gains but are more focused on pollution reduction.

When describing the GHG and NH_3 mitigation actions they had implemented, in their own words, a very wide range of practices emerged, particularly for GHG. The most commonly mentioned GHG action was solar panel installation, followed by manure storage improvement, anaerobic digestion, reduced energy use, new machinery, reduced fertiliser use, reduced tillage and genetic improvement. The actions implemented by farmers to reduce NH_3 emissions were less varied, with manure management changes dominating the list. Particularly amongst GHG actions, but also in NH_3 mitigation, farmers mentioned practices of which beneficial effects on GHG or NH_3 emissions are questionable, like new machinery, reduced concentrates/more grass in the diet, Freewalk housing, liquid fertiliser, slurry additives, more home-grown crops, stopping feeding soya, livestock housing improvement for GHG and manure separation and compost bedding for NH_3. The prevalence of these actions raises the question on how well farmers are informed about the likely environmental effects of their management choices and highlights the need for a substantial improvement in communication between farmers, farm advisors and researchers. The larger number of questionable practices for GHG than NH_3 corresponds with the knowledge scores farmers obtained, which was lower for GHG than for NH_3. A possible explanation for these observations can be that the level of awareness of GHG and NH_3 problem in the farming community are different, which might be related to how long advice and regulations related to these environmental problems have been around.

Regarding farmers' future plans the responses were suggesting a slow adoption process in the future: only ¾ of them stated that they were planning to adopt GHG mitigation practices in the next five years, and an equal amount said the same about NH_3 practices. These answers related to any practice (not only specific ones), suggesting that at least a quarter of these advanced farmers are not going to (further) reduce their GHG and NH_3 emissions in the close future. When asked about particular practices, only 4-10% of the farmers mentioned that they were planning to use the practices in the next five years. This is despite many of them expecting stronger regulations on both GHG and NH_3 emissions and higher pressure from the supply chain and society to reduce emissions.

The most frequently mentioned future changes for GHG mitigation were renewables, manure separation and home-grown feed, for NH_3 manure separation and slurry store cover were the most frequent options. As with the implemented actions, these measures also contained some which might not reduce, or can even increase emissions.

Probably not surprisingly, almost half of the farmers have considered implementing certain GHG changes in the past but decided against them. Examples of such practices are solar panel, anaerobic digestion installation, low emission slurry spreading, covering slurry tank, but also some which are innovative, like plasma-powered manure nitrogen enhancement and air extraction from manure storage.

Overall, the study revealed that amongst the most environmentally aware dairy farmers in seven European countries, there are still big gaps in the knowledge about the effects of farming practices on GHG and NH_3 emissions. This emphasises the need for much stronger knowledge exchange activities in the industry, preferably also involving those agents whom farmers are consulting about farm matters most frequently (feed advisors, vets), not only environmental advisors. The other important message arising form the work is that the adoption of further measures is likely to be very slow. Farmers even emphasised their need for achievable goals and not too fast changes, along with higher level of societal recognition of their effort. As the most important incentives – unsurprisingly – they mentioned financial compensation (both in the form of subsidies and higher product price for more environmentally friendly products) and their need for improved education, guidance and advisory service.

References

Augère-Granier, M.-L. (2018) The EU dairy sector: Main features, challenges and prospects. European Parliamentary Research Service, 1-12.

Bas-Defossez, F., Allen, B., Lorant, A. & Kollenda, E. (2019) A vfor the future of the European dairy industry. IEEP: Brussels, London, 1-38.

Baum, F., MacDougall, C. & Smith, D. (2006) Participatory action research. *Journal of Epidemiology & Community Health*, 60, 854-857.

Buckley, C., Howley, P. & Jordan, P. (2015) The role of differing farming motivations on the adoption of nutrient management practices. 152-162.

Burbi, S., Baines, R.N. & Conway, J.S. (2016) Achieving successful farmer engagement on greenhouse gas emission mitigation. *International Journal of Agricultural Sustainability*, 14, 466-483.

Gerber, P., Vellinga, T., Opio, C. & Steinfeld, H. (2011) Productivity gains and greenhouse gas emissions intensity in dairy systems. *Livestock Science*, 139, 100-108.

Glenk, K., Eory, V., Colombo, S. & Barnes, A. (2014) Adoption of greenhouse gas mitigation in agriculture: An analysis of dairy farmers' perceptions and adoption behaviour. *Ecological Economics*, 108, 49-58.

Herrero, M., Henderson, B., Havlík, P., Thornton, P.K., Conant, R.T., Smith, P., Wirsenius, S., Hristov, A.N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T. & Stehfest, E. (2016) Greenhouse gas mitigation potentials in the livestock sector. *Nature Climate Change*, 6, 452-461.

Hristov, A., Oh, J., Lee, C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, A., Dell, C., Adesogan, A., Yang, W.Z., Tricarico, J., Kebreab, E., Waghorn, G.C., Dijkstra, J. & Oosting, S. (2013) Mitigation of greenhouse gas emissions in livestock production - A review of technical options for non-CO_2 emissions. *In:* Gerber, P., Henderson, B. & Makkar, H. FAO: Rome, Italy, 1-231.

Hurley, P., Lyon, J., Hall, J., Little, R., Tsouvalis, J., White, V. & Rose, D.C. (2022) Co-designing the environmental land management scheme in England: The why, who and how of engaging 'harder to reach' stakeholders. *People and Nature*, n/a.

Jantke, K., Hartmann, M.J., Rasche, L., Blanz, B. & Schneider, U.A. (2020) Agricultural greenhouse gas emissions: Knowledge and positions of German farmers. *Land*, 9, 130.

Konrad, M.T., Nielsen, H.O., Pedersen, A.B. & Elofsson, K. (2019) Drivers of farmers' investments in nutrient abatement technologies in five Baltic Sea countries. *Ecological Economics*, 159, 91-100.

Kupper, T., Häni, C., Neftel, A., Kincaid, C., Bühler, M., Amon, B. & VanderZaag, A. (2020) Ammonia and greenhouse gas emissions from slurry storage - A review. *Agriculture, Ecosystems & Environment*, 300, 106963.

Läpple, D., Carter, C.A. & Buckley, C. (2022) EU milk quota abolition, dairy expansion, and greenhouse gas emissions. *Agricultural Economics*, 53, 125-142.

Leinonen, I., Eory, V., MacLeod, M., Sykes, A.J., Glenk, K. & Rees, R. (2019) Comparative analysis of farm-based carbon audits. ClimateXChange, 1-53.

Leip, A., WEISS, F., Lesschen, J.P. & WESTHOEK, H. (2014) The nitrogen footprint of food products in the European Union. *The Journal of Agricultural Science*, 152, 20-33.

Poore, J. & Nemecek, T. (2018) Reducing food's environmental impacts through producers and consumers. *Science*, 360, 987.

Rogers, E.M. (1962) *Diffusion of innovations*. Free Press of Glencoe: New York.

Webb, J., Menzi, H., Pain, B.F., Misselbrook, T.H., Dammgen, U., Hendriks, H. & Dohler, H. (2005) Managing ammonia emissions from livestock production in Europe. *Environmental Pollution*, 135, 399-406.