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A new approach to explain farmers' adoption of climate change mitigation measures

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Abstract
The determinants of farmers' decisions to reduce greenhouse gas (GHG) emissions are currently not well understood. This study takes several new angles in investigating farmers' climate change mitigation behaviour. Based on two identical surveys among representative samples of Dutch farmers, this study examines the underlying determinants and motivating factors for three different types of climate change mitigation measures on farms: energy saving, the production of renewable energy and reduction of emissions of methane and nitrous oxide (non-CO_2 emissions). Furthermore, the study explores whether farmers' awareness and behaviour has been influenced by a communication campaign carried out by the government of the Netherlands between 2012 and 2015. Four major conclusions emerge. Firstly, the analyses demonstrate that accounting for the cost-effectiveness and technology readiness level (TRL) of different types of climate change mitigation measures provides for a better understanding of the factors that motivate farmers to adopt these measures. Secondly, neither the willingness to take GHG reduction measures nor knowledge on GHG emissions are consistent motivating factors for energy-related measures. Thirdly, it seems that external factors, such as economic hardship, dominate the overall environmental awareness of farmers. Fourthly, the farmer's propensity to innovate proved to be the strongest and most consistent predictor of both the willingness and the actual adoption of climate change mitigation technologies. Therefore, focusing on making farmers more open to change and general innovation in campaigns in the agricultural sector might be more effective than campaigns focusing specifically on climate change mitigation.

Keywords Climate change mitigation · Agriculture · Communication campaign · Energy use · Farmer behaviour

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1 Introduction

The Paris Agreement aims to promote and coordinate the international response to climate change, without putting global food production at risk (United Nations 2015). Although food production and food security are to be safeguarded, the agricultural sector also has to take responsibility to reduce its greenhouse gas (GHG) emissions. It is estimated that agriculture accounts for about 14% of global GHG emissions, land-use changes excluded (Smith et al. 2014). While global anthropogenic GHG emissions are dominated by carbon dioxide (CO_2) from the combustion of fossil fuels, emissions from agriculture mainly take the form of methane (CH_4) and nitrous oxide (N_2O), which are emissions from biogenic processes related to livestock farming and soils.

The Paris Agreement endorses the importance of developing and promoting successful climate change mitigation strategies in the agricultural sector. Literature on the reduction of GHG emissions in agriculture is extensively addressed by Working Group III of the Intergovernmental Panel on Climate Change (IPCC, Smith et al. 2014). For the purpose of this paper, a distinction is made in the realisation of energy savings, the production of renewable energy on the farm and reduction of non-CO_2 GHG emissions (Fellmann et al. 2018; de Boer et al. 2011). Distinguishing between these measures is essential when investigating the determinants of farmers' willingness to adopt these climate change mitigation options, because they differ significantly in terms of their technology readiness level (TRL), upfront investment costs, changes in farming practices and farm sustainability.

There is a growing attention on assessing farmers' motivating factors for climate change mitigation behaviour in the literature. A number of studies examine the actual adoption of measures (Jørgensen and Termansen 2016; Burbi et al. 2016; Jones et al. 2013) while other studies refer to the underlying willingness and intentions of farmers to adopt mitigation measures (Arbuckle et al. 2013, 2014; Haden et al. 2012). Furthermore, Niles et al. (2016) examine the relation between the intended and actual behaviour on climate change mitigation, without finding clear links between both issues, thereby showing that farmers might be perfectly willing to change their behaviour, but still do not act accordingly for different reasons. This 'intention-behaviour gap' is frequently observed in psychological research on pro-environmental behaviour (Kollmuss and Agyeman 2002; Sheeran 2002). The decision to adopt an innovation, including the different stages of that mental process, is described in Sect. 2.2.4 (Rogers 2010), which was also tested by Niles et al. (2016).

In the Netherlands, the 'Covenant Clean and Efficient Agro Sectors' (Rijksoverheid 2008) came into force in 2008, being a formal voluntary agreement between the Dutch government and stakeholders in agriculture and the agro-food sector, with specific targets related to energy and climate. In the context of this covenant, the Dutch government decided to set up an intensive communication campaign to raise farmers' awareness and to stimulate farmers to reduce GHG emissions. Before the start of the campaign in 2012 and at the end of the campaign in 2015, farmers' willingness as well as their actual adoption of GHG emission reduction measures was captured in two identical surveys.

Given the ambitious targets, the Paris Agreement calls for new approaches in climate change mitigation. The unique dataset we collected on farmers' adoption of climate change mitigation measures facilitates the investigation of two unexplored aspects. Firstly, the applicability of the diffusion of innovations theory (Rogers 2010) is tested by estimating the influence of farmers' readiness to innovate ('innovator type') on the adoption of different types of climate change mitigation measures. Accordingly, the underlying determinants and motivating factors for the different groups of measures are examined, taking into account the differences in cost-effectiveness, TRL and complexity of measures. Secondly, the study examines the effects of the communication campaign in terms of influences on farmers' willingness to reduce GHG emissions and their actual adoption of climate change mitigation measures.

2 Background

2.1 Context in the Netherlands

The Netherlands is one of the world's biggest export countries of agricultural products, exporting approximately €75 billion annually and employing one tenth of the population in agriculture and the food sector. Emissions from agricultural sources amount to 14% of the national emissions, which is in line with the global average share (Smith et al. 2014). Dutch farmers are confronted with high costs for energy and labour, as well as high environmental standards. With a well-established political party for animal rights ('Animal Party') in the Dutch parliament, frequent attention is being drawn to social issues of the agricultural sector, such as animal welfare, odour and health impacts (Polman and Michels 2017). In 1999, the government of the Netherlands started a program to 'reduce non-CO_2 greenhouse gases', with agriculture as one of the target groups (Harmelink et al. 2005). In 2008, this policy was reinforced as a part of the 'Clean and Efficient' program, with specific targets for agriculture in the 'Covenant Clean and Efficient Agro sectors'. The covenant sets a policy framework for energy efficiency, renewable energy and GHG emission reduction in agriculture and runs until 2020. In a recent evaluation, the Organisation for Economic Cooperation and Development (OECD) praises the Dutch government for this policy, aimed at reducing agricultural emissions while stimulating agricultural productivity (Ignaciuk and Boonstra 2017).

In the context of the covenant, it was decided in 2011 to launch a communication campaign called '*AgroEnergiek*', aimed at raising awareness and improving behaviour of farmers with respect to reducing their GHG emissions. In close cooperation with the Dutch farmers' organization (LTO), Wageningen University and agricultural consultants, more than 120 workshops and study tours were organised between the years 2012 and 2015, with direct participation of more than 4000 farmers. Awareness was raised by sharing knowledge through scientists and non-governmental organisations (NGOs), and by emphasising the environmental importance of reducing GHG emissions in focus groups of farmers. This approach is essential, because farmers tend to rely more on peer knowledge and experience, rather than on scientific advisors (Šūmane et al. 2018). The campaign was widely covered in the national media thereby reaching a large number of agricultural stakeholders. The 2015-survey of our study indicated that 29% of the total Dutch farmer population was familiar with the '*AgroEnergiek*' campaign.

As a further policy reinforcement, in May 2019 a Climate Law passed the Dutch Senate, setting targets for GHG reductions of 49% in 2030 and 95% in 2050, as compared to 1990 levels. The government of the Netherlands is aiming for a Climate Agreement at the end of 2019, in which each sector, including agriculture, commits itself to contribute to a certain amount of emission reduction needed to reach the overall national target.

2.2 Theories and models

2.2.1 Types of climate change mitigation measures in agriculture

The various studies on GHG emission reduction in agriculture differ both in the applied theories and in the types of mitigation measures they consider. The IPCC distinguishes several sets of measures for the reduction of GHG emissions in agriculture, such as reducing the carbon intensity (e.g. by energy efficiency or renewable energy), optimising nutrient use (e.g. precise dosage and timing of fertilisers) or methane emission reduction by the digestion of manure (Smith et al. 2014). While energy saving measures are relatively simple and usually cost-effective, many studies have underlined the complexity and uncertain effects of non-CO_2 GHG measures (Fellmann et al. 2018; Burbi et al. 2016; de Boer et al. 2011). However, in farmer-related behavioural studies, only few studies distinguish in the analyses between different types of measures (Haden et al. 2012). For the purpose of this paper, the distinction is made between energy saving, renewable energy and non-CO_2 GHG measures.

2.2.2 The disconnection between beliefs and the willingness to reduce emissions

A number of studies have addressed the willingness of farmers to adopt climate change mitigation measures. Arbuckle et al. (2014) examined farmers' confidence in agricultural interest groups as sources of climate information, beliefs, perceptions and support for climate change mitigation responses, while summing up the different theories and models used in the burgeoning body of research. They could not observe a statistically significant relationship between perceived risks and support for mitigation action among farmers in Iowa. However, farmers who believe that climate change is happening due to human activities are more likely to favour government action for mitigation. These findings are in line with findings of Roesch Mcnally et al. (2018), who investigated the US Corn Belt farmers' decision-making process in the context of climate change through the adoption of key management practices with soil and water benefits. Also, Carlton et al. (2016) found that extreme weather events did not cause significant shifts in climate change beliefs, thereby suggesting that increasing risk perceptions due to extreme weather events do not necessarily lead to an increased willingness to take climate action. Hornsey et al. (2016) conducted a meta-analysis on the determinants of individuals' willingness to act in climate-friendly ways, including a number of farmer-related studies. They concluded that it is difficult to identify coherent messages from earlier studies due to, among others, different definitions of core concepts across various disciplines and the bidirectional correlation of some variables. For this reason, Prokopy et al. (2015) conclude that survey research on farmers and climate change in various locations at least should strive to include common questions, to facilitate comparisons. Hornsey et al. (2016) also concluded that climate change beliefs are only marginally related to people's willingness to act in climate-friendly ways.

2.2.3 Linking perceptions and actual behaviour

Lane et al. (2018) investigated farmer views and decisions related to climate change mitigation in New York and Pennsylvania. They found that farmers articulated serious concerns regarding climate change, but farmers also experienced other business pressures, such as profitability, labour availability and government regulations, as more critical issues affecting their decision-making. Jorgensen and Termansen (2016) found no correlation between perceptions of climate change and mitigation action. Niles et al. (2016) applied a combination of the diffusion of innovations theory (Rogers 2010) and the theory of planned behaviour (Ajzen 1991) and found no relationship between intentions to adopt measures and the actual adoption of measures. They suggest that there are different incentives of intended and actual adoption of climate change practices among farmers. Liu et al. (2013) used Greiner and Gregg's model for 'adoption of best management practices' and found that political ideology strongly influenced farmers' knowledge and perception regarding climate change. Haden et al. (2012) surveyed farmers in California using the 'construal level theory' and concluded that mitigation strategies of farmers were motivated by global concerns, while adaptation strategies were motivated by local concerns. Schewe and Stuart (2017) found that agricultural contracts in highly competitive agricultural sectors also can also impose significant structural barriers to adopt climate change mitigation measures.

2.2.4 Diffusion of innovations theory

Overall, researchers use many different theories and approaches to explain farmers' willingness and actual adoption of climate change mitigation measures. However, no conclusive explanation has been found yet to explain the full picture of farmers' climate-related perception, attitude and behaviour. In fact, the many intrinsic and extrinsic influencing factors imply that developing a theory or model that incorporates all these factors might neither be feasible nor useful (Kollmuss and Agyeman 2002). This paper explores several intrinsic and extrinsic factors, with focus on the 'diffusion of innovations theory' (Rogers 2010). The diffusion of innovations theory explains how innovations are adopted over time, based on the characteristics of the innovation itself, the communication channels through which the innovation is spread and the social context of the innovation. Regarding the stage in which the innovation is taken up, Rogers recognises five successive adopter categories: innovators, early adopters, early majority, late majority and laggards. Rogers also identifies several features that determine the adoption rate of an innovation: the relative advantage, compatibility, complexity, trialability and observability. Moreover, Rogers considers the decision to adopt an innovation as a mental process following five different stages: knowledge, persuasion, decision, implementation and confirmation.

The diffusion of innovations theory has proven its scientific importance and predictive power in explaining the adoption of technological and other innovations. Yet, this theory also faces certain challenges (Rogers 2010). Firstly, although the adopter categories and their characteristics do explain diffusion in many cases, increased complexity of either the innovation, the industry or the environmental circumstances, leads to a fuzzier set of factors influencing the adoption (Diederen et al. 2003). Secondly, external biases may occur that lead to different levels of adoption. For example, technology suppliers tend to provide assistance especially to their innovative, wealthy and information-seeking clients (Stephenson 2003; Rogers 2010). Thirdly, the network perspective, including interactions between the different innovator types, adds another layer of complexity to the diffusion of innovations (Hermans et al. (2013).

2.3 Analytical framework

As shown in Fig. 1, an analytical framework is used in this paper as suggested by Meijer et al. (2015), taking into account different intrinsic and extrinsic factors that can potentially influence technology uptake by farmers. The model is adjusted in two ways. Firstly, an attitude is seen as ‘a psychological tendency that is expressed by evaluating a particular entity with some degree of favour or disfavour’ (Eagly and Chaiken 1993, p1). Instead of attitude, we included the ‘willingness to take GHG reducing measures’ in the model (Haden et al. 2012; Spence et al. 2011; Hornsey et al. 2016). Secondly, because we explicitly test the theory of Rogers, the innovator type is incorporated as a personal characteristic of farmers. The framework also contains other aspects of the theory of Rogers, such as characteristics of the technology, knowledge and communication.

Five testable hypotheses are formulated for the empirical analyses and positioned in the conceptual framework (see H1 to H5 in Fig. 1). The first hypothesis refers to the different groups of mitigation measures, predicting that ‘energy saving measures, the production of renewable energy and other GHG emission reduction measures can be explained by different determinants’ (H1). The second hypothesis focuses on the role of willingness to take GHG emission reduction measures, predicting that ‘the willingness to take GHG reducing measures is a robust determinant for the actual behaviour related to GHG mitigation practices’ (H2). The third hypothesis, based on Rogers (2010) classification, predicts that ‘the innovator type is a

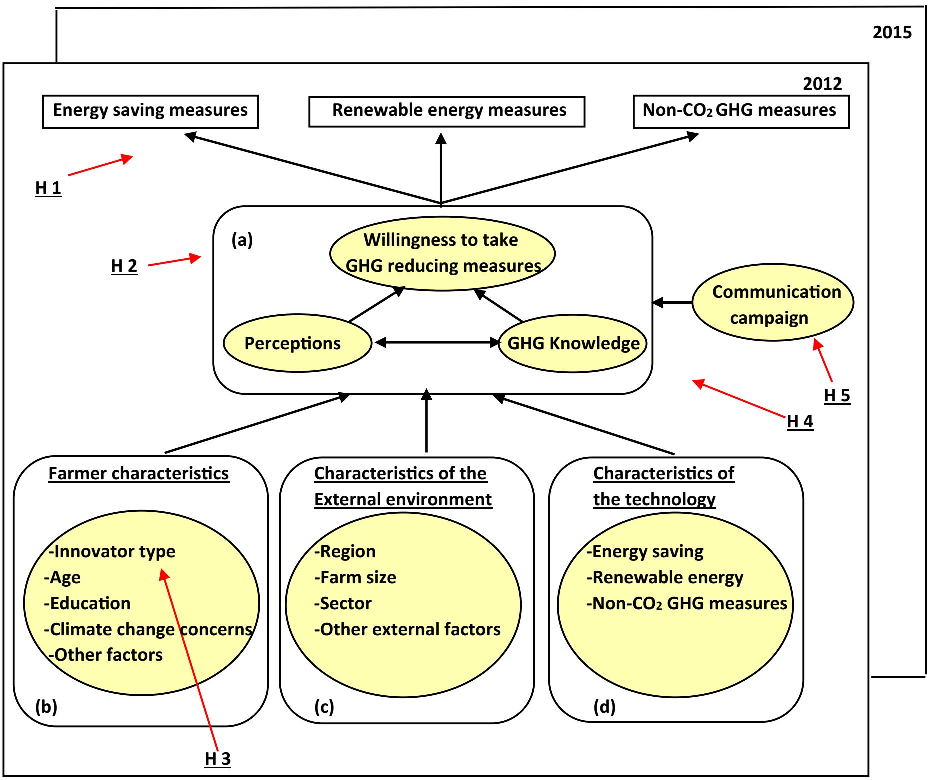

Fig. 1 Conceptual framework of influencing factors on behaviour, including hypotheses (adapted from Meijer et al. 2015)

robust determinant for both the willingness to reduce GHG emissions as well as for the actual behaviour related to climate change mitigation' (H3). In Rogers' theory, knowledge is seen as the first step in the process of adoption. We therefore formulate a fourth hypothesis that 'knowledge on GHG emissions' is an important determinant for both the willingness to reduce GHG emissions as well as the actual behaviour related to climate change mitigation' (H4). The fifth hypothesis evolves around the Dutch communication campaign, suggesting that 'being familiar with the communication campaign in 2015' positively relates to the willingness to take GHG reduction measures, as well as to actual behaviour up to 2015' (H5).

3 Materials and methods

3.1 Data collection

Telephone surveys were used to capture the farmers' levels of awareness and behaviour regarding the adoption of GHG emission reduction measures. The interviews were carried out by experienced interviewers of a professional survey company. The baseline survey was performed in March 2012, shortly before the Dutch government launched the communication campaign '*AgroEnergiek*'. At the end of the campaign, in February 2015, an identical survey was performed to assess the impact of the campaign. In both 2012 and 2015, a stratified random sample was drawn from one of the main farmers' databases in the Netherlands (i.e. Prosu). The survey covered a representative sample with respect to sector and region for four arable sectors and eight livestock sectors, with a minimum of 30 farmers for each sub-sector. Greenhouse horticulture farmers were excluded from the surveys because this group was exposed to a separate communication program. The samples covered 0.74% of the total farmers population. An overview of the sample composition is available as 'supplementary material'.

For the impact assessment in 2015, a new stratified random sample from the same farmers' database was drawn. The main reason for drawing a new sample was that approaching the same farmers as in 2012 would have inevitably led to a much lower response rate (i.e. due to dropouts). In both surveys, 2040 farmers were contacted, resulting in respectively 507 farmers willing to participate in 2012, and 508 in 2015, corresponding to a response rate of 25% for both surveys. This can be considered as a good response rate (Groves et al. 1992), given that farmers are usually strongly involved with activities on their farm and hence difficult to reach. All data were collected and analysed in the statistical software packages SPSS and STATA.

3.2 Description of the surveys

3.2.1 Different types of climate change mitigation measures

As shown in Table 1, this study accounts for the fact that the three main categories of measures differ in technology readiness level (TRL) as well as in their degree of cost-effectiveness (Smith et al. 2014). The cost-effectiveness of a specific measure for an individual firm can vary widely and changes over time. Based on a combination of different technological characteristics and different governance approaches in the Dutch environmental regulation, we created three levels of cost-effectiveness: (status quo 2012/2015):

1. Measures with < 5 years payback time are mandatory by environmental permits (TRL = 9)
2. Measures with 5–10 years payback time are stimulated by the government in fiscal or subsidy schemes (TRL 7–9)
3. Measures with > 10 years payback time all are involved in fundamental research programs (TRL < 8).

Subsequently, the differences between the three groups of measures emerge. Firstly, energy saving measures are subdivided in a cost-effective sub-group, and a sub-group that is involved in fiscal or subsidy schemes and thus not yet cost-effective. Secondly, renewable energy measures are all involved in subsidy schemes and thus not yet cost-effective. Thirdly, apart from fuel related measures, non-CO_2 GHG measures are all involved in research programs, with TRL levels below eight. Only a few measures of this group, such as precision farming and manure digestion, are seen as possible cost-effective options (de Boer et al. 2011).

Table 1 Overview of measures as examined.

Measure	TRL	Payback time (years)
Energy saving measures		
Cost-effective*, TRL 9		
1. Isolation	9	0–5
2. Climate control	9	0–5
3. Efficient lighting	9	0–5
4. Natural daylight	9	0–5
5. Shallow manure pit	9	0–5
6. Motion detectors	9	0–5
7. Twilight switches	9	0–5
Not cost-effective, TRL < 9		
8. Frequency control	8–9	5–10
9. Heat recovery	8–9	5–10
10. Precooling (milk)	8–9	5–10
11. Energy storage	8	5–10
12. Energy efficient heat	8–9	5–10
13. Heat exchange	8–9	5–10
14. Other measures	5–8	> 10
Renewable energy measures		
Not cost-effective, TRL < 9		
1. Solar panels (PV)	8–9	5–10
2. Solar heat	8–9	5–10
3. Wind energy	7–9	5–10
4. Biogas (digestion)	7–9	> 10
5. Other measures	5–8	> 10
Non-CO_2 GHG measures		
(Not) cost-effective, TRL 7–9		
1. Fuel measures	7–9	0 to > 10
Not cost-effective, TRL < 8		
2. Soil measures	3–7	> 10
3. Feed adaptation	4–6	> 10
4. Animal management	2–7	> 10
5. Other fertilisers	4–7	5–10
6. Manure measures	5–7	5–10
7. Other measures	2–7	> 10

*Cost-effective when payback time < 5 years

3.2.2 Setup of the surveys

To capture the awareness and behaviour related to the reduction of GHG emissions, a questionnaire was developed consisting of 43 open- and closed-ended questions. Binary scores (yes/no), as well as Likert-type scale questions were used. Table 2 summarises the key variables used in the analysis, including the survey questions. For the explanatory variables we included as many levels as needed to capture the influencing factors, which were sometimes combined into fewer categories in the analysis, to keep the regression model parsimonious. For example, the farm size was captured on a five-point scale, but analysis proved that a three-point scale yielded the same results: large farms and medium farms, with small farms as a base category. Table 2 also summarises the results and differences between the 2012 and 2015 surveys.

3.2.3 Innovator type

In this paper the 'innovator type' according to Rogers (2010) was captured by asking what is most applicable to the respondents when there are new developments in the sector:

1. 'I prefer to experiment myself'. We compare these respondents with the innovators from Rogers. These are people who want to be the first to try the innovation, which on average applied to 12.3% of the respondents in the surveys.
2. 'I take action when I saw it at another farm'. These are the early adopters, the opinion leaders who enjoy leadership roles, and embrace change opportunities, which on average applied to 21.5% of the respondents in the surveys.
3. 'I wait until the concept has proven itself at many other companies'. For reasons of brevity the categories 'early majority' and 'late majority' were being combined in our survey in the category 'majority'. The early majority are rarely leaders, but they do adopt new ideas before the average person. The late majority are sceptical of change, and will only adopt an innovation after it has been tried by the majority. On average the category 'majority' applied to 54.9% of the respondents in the surveys.
4. 'I don't take action so quickly, I don't like to change'. These people are the laggards, bound by tradition and very conservative, which on average applied to 11.3 % of the respondents in the surveys.

This way of categorization avoided the group of non-adopters. For example, Diederen et al. (2003) examined the innovator type among Dutch farmers by asking them if they had implemented important innovations during the last three years and how they would place themselves on the diffusion curve according to Rogers, leading to a majority (63 %) of non-adopters.

3.2.4 Survey questions

The survey consisted of six parts. Firstly, questions focused on *farm- and farmer characteristics* such as farm size, region, age and education. Secondly, the *perceived importance* of GHG reduction measures was captured for energy saving measures, renewable energy generation and non-CO_2 GHG measures separately, followed by the perceived importance of the three types of measures, including the reasons for importance. Thirdly, the *innovator type* of

Table 2 Overview of key variables in the surveys

Variable	Survey question	Variables used in the analyses	Average values in 2012 and 2015
Age	What is your age?	Age < 41 = base category Age 41–50 = dummy Age 51–60 = dummy Age > 60 = dummy	A shift in average age was observed from 3.43 in 2012 to 3.65 in 2015 (corresponding to app. 49.8 years old in 2012 and 51.9 in 2015)
Education	What is your highest level of education?	1/2. Basic (Professional) = base category 3/4. (High) Professional = dummy	Shifted from 2.84 in 2012 to 2.58 in 2015
Sector	What is the biggest sector in your company?	Arable = dummy Livestock = base category	A proportional sector-sample was taken for both years
Farm size	How many animals (livestock) or hectares do you have?	1/2. Small farms = base category 3. Medium farms = dummy 4/5. Large farms = dummy	The average farm size was 2.7 in 2012 as well as in 2015.
Region	What is your postal code?	Other regions = base category North West = dummy North East = dummy	A proportional sample was taken for all regions in both years
Innovator type (preferred style for behavioural change)	At new sector developments, which answer is most applicable to you? 1. I like to experiment myself (= innovator) 2. When seen with a colleague (= early adopter) 3. When seen with many colleagues (= majority) 4. I don't like to change (= laggards)	1. Innovator = dummy 2. Early adopter = dummy 3. (Early + late) majority = dummy 4. Laggards = base category	The average innovator type shifted from 2.58 in 2012 to 2.73 in 2015.
Reasons for behavioural change	When do you usually change your business? (e.g. when I can save money, earn money, work faster, when it gives more societal commitment, or when it is mandatory by the government)	Other categories = base category Save money = dummy Earn money = dummy	Most mentioned: save money (42.0% in 2012 to 60.4% in 2015). Earn money (15.4% in 2012 to 9.7% in 2015). Work faster (7.9% in 2012 to 10.2% in 2015).
Knowledge—general	Do you think your farm generates GHG emissions?	No = base category Yes = dummy	From 80.1% 'yes' in 2012 to 63.6% in 2015
Knowledge—sources	What are important sources of GHG emissions on your farm? (possible answers: Fuels, animals, manure, soil, energy, other)	No sources = base category Categorical variable which counts the number of possible sources the farmer knows.	Most mentioned: animals (37.5% in 2012 to 34.5% in 2015). Fuels (35.3% in 2012 to 24.8% in 2015). Manure (28.6% in 2012 to 26.2% in 2015).
Farmers in 2015: familiar with campaign	Are you familiar with the communication campaign '*AgroEnergiek*'?	Farmers in 2012 = base category	29.1 % of farmers were familiar with campaign in 2015

Table 2 (continued)

Variable	Survey question	Variables used in the analyses	Average values in 2012 and 2015
		'Yes' in 2015 = dummy 'No' in 2015 is dummy	
Perceived importance	How important is it to: - *save energy* - *produce renewable energy* - *reduce GHG emissions?*	Separate for energy saving, renewable energy and GHG emission reduction: - Not important (at all) = base category - (Very) important = dummy	Perception (very) important in 2012 and 2015: energy: from 90.1 to 82.7%. Renewable energy: from 74.4 to 64.4%. GHG emission reduction: from 64.9 to 51.6%.
Reasons for perceived importance	Why is it important to: - *save energy* - *produce renewable energy* - *reduce GHG emissions* (Possible answers a.o: save costs, climate change concerns, necessary for financial support, society asks, government asks)	For energy saving, renewable energy and GHG emission reduction: Other reasons = base category Save costs = dummy Climate change concerns = dummy	Energy saving: save costs from 59.2% in 2012 to 68.1 in 2015. Renewable energy: save costs from 40.6 to 52.2%. GHG emission reduction: Climate change concerns from 44.6 % in 2012 to 43.7 % in 2015.
Willingness to take GHG measures	Are you generally willing to reduce your greenhouse gas emissions?	No = base category (Conditionally) Yes = dummy	A significant decrease in willingness was observed. From 78.3% 'Yes/Yes (but only if….)' in 2012 to 41.5 % in 2015.
Actual behaviour	Did you already take measures to: -Save energy? (13 measures) -Produce renewable energy? (5 measures) -Reduce your greenhouse gas emissions? (7 different categories) If yes, which measures? (see Table 1)	All measures are split up in three different categories of cost-effectiveness: - Payback time 0–5 years - Payback time 5–10 years - Payback time > 10 years	A significant increase in behaviour was observed. The implementation of all measures increased in 2015, compared to 2012, most of them significantly. (only non-CO_2 GHG reducing measures decreased)

the participating farmers was captured as described above. Fourthly, the questionnaire examined the farmers' GHG-related *knowledge* by asking whether and through what sources their farm generates GHG emissions. Fifthly, the *willingness to take GHG reducing measures*' is elicited (Haden et al. 2012; Spence et al. 2011; Hornsey et al. 2016). Finally, the actual behaviour was captured separately for the measures as mentioned in Table 1. The full questionnaire is available as 'supplementary material' to this paper in the English translation.

By definition, the impact of the communication campaign is investigated for the 2015 sample only. For this purpose, the 2015 sample was split up into a group 'being familiar with the communication campaign' and a group 'unfamiliar with the campaign' which were compared to the 2012 sample of farmers. Due to the limited number of farmers in some sectors, all analyses are done on the full datasets and no further analysis is made at the subsector level. Only the differences between livestock and non-livestock sectors (i.e. *arable*) were examined by including a binary explanatory variable that takes the value '1' if a farm is an arable farm. A shortcoming of the questionnaire is that we did not gather information on personal values and ideologies of farmers, while this appears to be a powerful predictor of behaviour (Hornsey et al. 2016; Liu et al. 2013).

3.3 Data analysis

To investigate the most important determinants of farmers' adoption behaviour, a series of logistic regression analyses was conducted (Greene 2012; Long 1997). Given that the two surveys were carried out among different groups of farmers in 2012 and 2015, we have two cross-sectional datasets, which we pooled for analysis. The level for testing the statistical significance was set at 0.05, unless mentioned otherwise.

4 Results

4.1 Descriptive statistics of sampled farmers

To verify the representativeness of the 2012 and 2015 samples, the sectoral distribution and the main characteristics of farms and farmers were compared to the overall population of farmers in the Netherlands. The statistical data of the sectoral distribution, average age, farm size and education of farmers in the Netherlands show that these findings can be considered to represent the general trend in Dutch agriculture well (CBS / Statline 2015).

Table 2 shows the average values for 2012 and 2015 of the variables. Farmers in 2012 proved to have a higher age category, corresponding from 49.8 in 2012 to 51.9 years old in 2015, and a lower education level (from 2.84 to 2.58). Younger farmers proved to be more highly educated than older farmers. We also observed significant changes in innovator type, i.e. the degree to which the farmers are open to innovations on their farm: on a four-point scale the average innovator type shifted from 2.58 in 2012 to 2.73 in 2015 (1 = innovator, 4 = laggard). The reasons for innovations also changed significantly. A statistically significant increase in economic motivations was observed for innovations: the mentioning of the motivation 'when I can save money' increased from 42.0% in 2012 to 60.4% in 2015. In 2012, more than 80% of farmers were aware of GHG emissions on their farm, and all of them knew one or more emission sources on their farm. Unexpectedly, this level decreased to 64% in the 2015 survey, while also the knowledge of all different sources decreased.

In 2012, energy saving was perceived (very) important by 90 % of farmers, the generation of renewable energy by 74 %, while 65 % of farmers perceived GHG reduction as (very) important. Also, as an unexpected result, significant decreases in the levels of perceived importance were observed between 2012 and 2015 for all three types of measures. In 2012, more than 78% of farmers were, conditionally or unconditionally, willing to take measures for GHG reduction. Remarkably, the willingness to take measures in 2015, after three years of intensive communication, decreased to 42%. Despite this decline in willingness to take measures in 2015, farmers demonstrated a more actual climate and energy behaviour, with increased energy savings (+ 5%) and more use of renewable energy (+ 10%). For non-CO_2 GHG measures, the degree of implementation remained approximately at the same level (34% in 2012 and 33% in 2015). The complete overview of descriptive statistics is available as 'supplementary material' to this paper.

4.2 Results of the logistic regressions

4.2.1 The willingness to reduce GHG emissions and the actual adoption of different types of measures

The main results of the regression analyses of the pooled dataset are summarised in Table 3. The results in Table 3 show that the adoption of the three different types of GHG emission reduction measures are driven by different combinations of influencing factors. Even the splitting up of different energy saving measures, based upon TRL and cost-effectiveness, results in different combinations of influencing factors. The willingness to reduce GHG emissions is strongly related to non-CO_2 GHG measures, which is in line with several previous studies (Niles et al. 2016; Arbuckle et al. 2013; Barnes and Toma 2012). The willingness to reduce GHG emissions is also strongly related to renewable energy, but only weakly positively related to energy saving measures with TRL < 9, and even negatively to energy saving measures with TRL = 9.

The extent to which farmers perceive renewable energy as 'important' is positively associated with their actual adoption of renewable energy technologies, but this association is not observed for energy saving measures or other GHG emission reduction measures. The perceived importance of energy saving is even negatively related to the actual behaviour for TRL = 9 measures, which seems counterintuitive. As expected, the reason 'save costs', mentioned by a number of farmers as a reason for their perceived importance of energy saving, relates positively to the actual behaviour on energy saving. 'Knowledge on GHGs' is a strong determinant for non-CO_2 GHG measures, but not for the measures in the energy domain.

A common determinant for all types of measures is the variable 'innovators', i.e. the general openness of the farmers to innovation. Innovators and early adopters relate positively to measures for renewable energy and energy saving measures. As expected, the innovator type 'majority' relates positively only to the most common applied energy saving measures with TRL = 9. Arable farmers seem less likely to take energy saving measures compared to livestock farmers, while there is no significant difference between the farm types in adoption behaviour of renewable energy or non-CO_2 GHG measures. Medium and large sized farms are only significantly positively related to the more complex and less cost-effective measures with TRL < 9, while they are negatively (not significantly) related to the more commonly applied energy saving measures with TRL = 9. Also, we found a positive association between farm size and non-CO_2 GHG measures. Age is hardly found to be a significant driver for the implementation of climate change mitigation measures. Only younger people (41–50 years old) relate positively to the implementation of renewable energy. High levels of education are negatively related to the most common applied energy saving measures with TRL = 9, which appears counterintuitive.

The perceived importance of GHG emission reduction is positively related to the willingness to take those measures, yet only weakly significantly. Innovators, early adopters as well as the majority, relate positively to the willingness to take measures. Knowledge is also strongly related in a positive sense. Obviously there are no economic reasons for GHG reduction, because economic reasons such as saving or earning money are negatively influencing the willingness to take GHG reduction measures. The results in Table 3 show that elderly people (> 51) are strongly negatively related to the willingness to take measures to reduce GHG emissions, while a high education is strongly positively related to willingness to take measures.

Table 3 Overview of statistically significant influencing factors from multiple regression analyses

Variable	Willingness to take mitigation measures	Actual adoption of measures			
		Energy saving (see Table 1)		Renewable energy	Non-CO_2 GHG measures
		Measures TRL = 9	Measures TRL < 9		
Age 41–50	− 0.3236 (0.252)	0.0460 (0.237)	− 0.1001 (0.276)	*0.5423 (0.306)**	− 0.1637 (0.221)
Age 51–60	*− 0.6968 (0.249)****	0.0093 (0.240)	0.1174 (0.280)	0.4627 (0.311)	− 0.1649 (0.225)
Age > 60	*− 1.0809 (0.308)****	0.0154 (0.285)	− 0.1670 (0.323)	0.1696 (0.394)	− 0.1731 (0.273)
Education (high)	*0.5493 (0.158)****	*− 0.2654 (0.158)**	− 0.0593 (0.181)	0.0097 (0.192)	0.0847 (0.154)
Arable farms	− 0.0491 (0.248)	*− 1.7197 (0.268)****	*− 2.4651 (0.399)****	− 0.4552 (0.302)	0.1238 (0.253)
Medium farms	− 0.1323 (0.260)	− 0.4081 (0.273)	*1.2724 (0.275)****	− 0.3954 (0.326)	0.3068 (0.262)
Large farms	− 0.2062 (0.266)	− 0.1304 (0.279)	*1.7690 (0.281)****	0.2441 (0.303)	*0.5896 (0.266)***
North− West area	− 0.0703 (0.195)	− 0.1053 (0.197)	0.0825 (0.249)	0.1043 (0.249)	− 0.2821 (0.193)
North− East area	0.1371 (0.178)	0.0575 (0.174)	0.1032 (0.191)	0.2124 (0.213)	− 0.0579 (0.164)
Innovator	*1.1149 (0.327)****	*0.8431 (0.324)****	*1.0024 (0.391)****	*0.9250 (0.450)***	*0.9515 (0.332)****
Early adopter	*1.5197 (0.304)****	*0.7872 (0.288)****	*0.7340 (0.321)***	*1.0485 (0.416)***	0.4866 (0.308)
Majority	*0.7388 (0.264)****	*0.5127 (0.245)***	0.3110 (0.274)	0.3168 (0.390)	0.3274 (0.282)
Knowledge on GHG	*0.4247 (0.082)****	*0.2347 (0.083)****	0.1125 (0.088)	− 0.1294 (0.101)	*0.3604 (0.075)****
Importance energy saving	–	*− 0.3549 (0.198)**	− 0.0049 (0.237)	–	–
Importance renewable energy	–	–	–	*0.6997 (0.269)****	–
Importance GHG reduction	*0.2802 (0.156)**	–	–	–	0.1826 (0.147)
Save costs (as a reason for 'importance')	–	*0.3889 (0.157)***	*0.3793 (0.178)***	− 0.0433 (0.193)	–
Save money (as a reason for innovation)	*− 0.4005 (0.169)***	–	–	–	–
Earn money (as a reason for innovation)	*− 0.5686 (0.248)***	–	–	–	–
Willingness to take GHG measures	–	− 0.1734 (0.180)	*0.3873 (0.206)**	*0.6007 (0.217)****	*0.6278 (0.167)****
Group of farmers in 2015 familiar with campaign (n = 148)	*− 1.0224 (0.217)****	*1.9499 (0.252) ****	*1.7193 (0.277)****	*1.1577 (0.268)****	*0.4246 (0.212)***
Group of farmers in 2015 unfamiliar with campaign (n = 360)	*− 1.5593 (0.168)****	*1.6645 (0.185) ****	*0.9142 (0.208)****	*1.2208 (0.220)****	0.2768 (0.171)
Log pseudo-likelihood	− 534.9	− 543.8	− 415.3	− 393.8	− 594.9
Pseudo R^2 (McFadden)	0.22	0.21	0.33	0.08	0.08

Parameter estimates (robust standard errors in parentheses) are italicized. More details are available as 'supplementary material'

$^*p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

4.2.2 Familiar with campaign in 2015

The regression models reported in Table 3 include a variable for awareness of the governmental campaign and a second variable for non-awareness of the campaign, which are both interacted with the dummy for 'farmers surveyed in 2015' (see definition of this dummy in Table 2). The base category for these two dummies is 'farmers surveyed in 2012'. The results reported in Table 3 show, inter alia, that farmers surveyed in 2015 have a lower willingness to take GHG reduction measures compared to the farmers surveyed in 2012, irrespective of whether they were familiar with the governmental campaign or not. The same holds for the adoption of energy saving measures and renewable energy. Only the group 'being familiar with the campaign in 2015' is associated positively to the actual behaviour on non-CO_2 GHG measures. The fact that the overall willingness to take GHG reduction measures is significantly lower in 2015 than in 2012 could be the result of comparing two different samples. However, Sect. 3.1 describes that the trends in both the datasets of 2012 and 2015 seem to represent the general trend in the Dutch farmer population well. Therefore, the differences in the datasets as described above must be rooted in other external circumstances in 2015, such as economic, political or social developments. Remarkably, despite the decrease in both knowledge, perceived importance and willingness in 2015, a significant increase was found in actual behaviour in terms of number of measures in the three domains. Furthermore, Table 3 shows that both the variables familiar and unfamiliar with campaign in 2015 relate negatively to the willingness, but positively to the actual behaviour.

The determinants for the different types of mitigation measures can be derived from Table 3 and are visualised in Fig. 2.

5 Discussion

5.1 Actual adoption of different types of measures (H1)

Table 3 and Fig. 2 clearly show that the different types of measures have different determinants. Given that there are no studies available comparing the three types of measures as conducted in this study, a comparison to previous findings is hampered. Haden et al. (2012), examining farmers' willingness to take measures in the domains of energy saving and renewable energy, found differences in the level of influence of perceived weather changes and the local and global climate concerns. They also observed that farmers were more likely to save energy or use less nitrogen fertilisers, which allows them to save money. In addition, they found that farmers were less inclined to take measures with high upfront costs. However, Haden et al. (2012) did not explore these differences further. Niles et al. (2016) also emphasised the importance of the financial attractiveness of measures. They recognised that all eight measures they considered have different levels of costs, benefits and possible trade-offs, which might have influenced their adoption. Burbi et al. (2016) found similar results. This is corroborated by findings in our research, showing that there is a positive relationship between the implementation of energy saving measures and 'cost saving' as a motivation for taking action.

Although the predictive power of socio-economic factors is not very high (Hornsey et al. 2016); Prokopy et al. (2008),, it appears that a more precise definition of the character of the climate change mitigation measure will improve the quality of the relationships with those

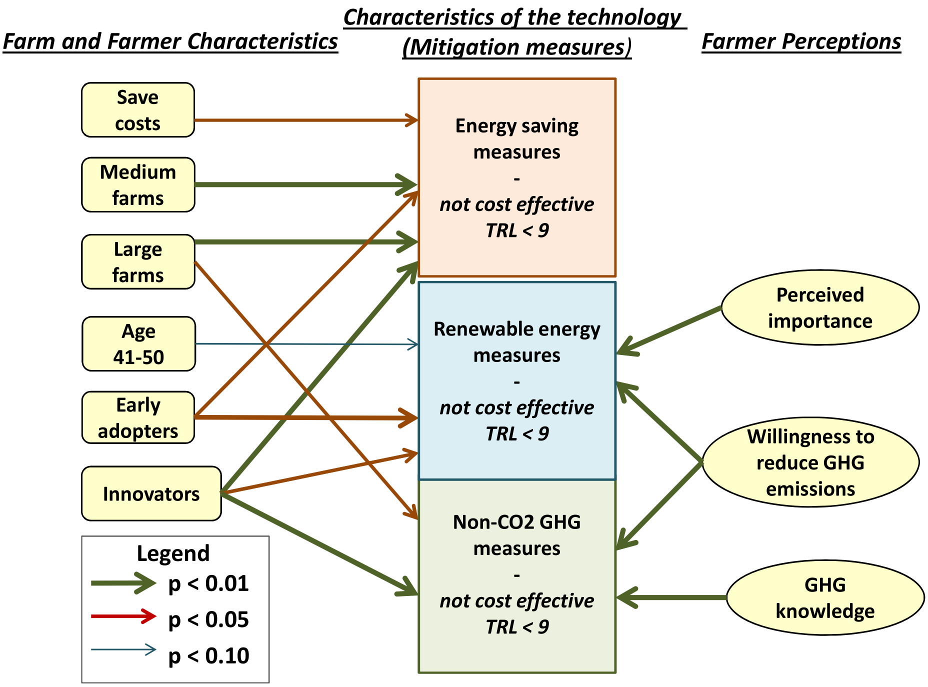

Fig. 2 Determinants for measures for energy saving, renewable energy and non-CO_2 emission reduction (not cost-effective, TRL < 9)

factors. For instance, Table 3 shows no significant relation between age and behaviour, except for younger people (41–50) taking significantly more measures for renewable energy. Niles et al. (2013) found that age is a negative predictor for the likelihood of adaptation measures and a positive one for mitigation measures. Jørgensen and Termansen (2016), on the other hand, found that younger farmers were more likely to take mitigation action than older farmers. No clear relationship was found between education and climate change mitigation behaviour, even a negative relation with energy saving measures with TRL = 9 was observed, which is consistent with literature. Although a higher level of education is associated with a higher awareness of climate change, no relation with actual behaviour is found (Jørgensen and Termansen 2016; Liu et al. 2013). The exception is Niles et al. (2016) who find that education is a positive predictor for the likelihood of mitigation measures, but not for adaptation. Medium and large farms are strongly positively related to complex energy saving measures (TRL < 9), while large farms are also positively related to complex non-CO_2 GHG measures. However, Jorgensen and Termansen (2016), examining the sustaining or raising of soil carbon levels, found a negative relation between farm size and the probability to act.

The series of results above imply that there is support for hypothesis 1 (H1), which states that energy saving, the production of renewable energy and non-CO_2 GHG measures can each be explained by a unique pattern of determinants. Even better insights are obtained by splitting up different groups of measures into terms of cost-effectiveness and TRL, which is suggested by some authors (Niles et al. 2016; Burbi et al. 2016; Jones et al. 2013), but which so far has not been tested.

5.2 Influence of willingness to reduce GHG emissions on actual behaviour (H2)

The willingness to reduce GHG emissions proved to be a robust determinant for the actual adoption of non-CO_2 measures. The relationship with the measures in the energy domains is less obvious. The willingness even correlates negatively, though not significantly, with the most commonly applied energy measures with a TRL of 9. This is intuitive as even farmers who are not willing to take GHG measures, are likely to implement a number of commonly applied cost-effective energy measures with TRL = 9. The variable 'save money', which reflects a financial motivation for on-farm innovations, has a negative sign which implies that farmers who consider saving money as their priority when adopting GHG emission reduction measures are less willing to take GHG measures. This is in line with other studies, examining barriers for the implementation of GHG reducing measures (Roesch Mcnally et al. 2018; Stuart et al. 2014).

The results above provide sufficient support for hypothesis 2 (H2), predicting that 'the willingness to take GHG reducing measures' is a robust determinant for the actual behaviour related to GHG mitigation practices. However, this does not necessarily account for measures in the energy domain.

5.3 Influence of innovator type according to Rogers' theory (H3)

The resulting pattern for farmers' propensity to innovate ('innovator type') in Table 3 clearly suggests that the increasing complexity of measures from energy saving to renewable energy and non-CO_2 measures, impacts on the probability of adoption by farmers. Energy saving measures with a TRL of 9 are likely to be adopted by the majority of farmers. The adoption of the more complex renewable energy measures are more likely adopted by innovators and early adopters, while the complex non-CO_2 measures with lower TLR's are more likely adopted only by 'innovator' type of farmers. These findings are in line with the diffusion of innovations theory (Rogers 2010) and findings of Diederen et al. (2003). Barnes and Toma (2012) also introduced a farmer typology of 'innovators' and concluded that this group was more responsive to information channels and more open to technology adoption. However, Niles et al. (2016) found that New Zealand farmers who already adopted mitigation measures (called 'innovators') were less likely to indicate that they would adopt other climate change mitigation measures in the future.

The results in Table 3 suggest that a farmer's overall mindset or approach to innovation is the strongest and most consistent predictor of taking up climate change mitigation technologies. Even farmers who know little about climate change, or who are unaware of campaigns to make farmers change their behaviour, but who are innovation-minded persons, are more likely to take up a climate-friendly approach. We therefore found strong evidence for the third hypothesis, predicting that (H3): the 'innovator type' is a robust determinant for both the willingness to reduce GHG emissions as well as for the actual behaviour related to climate change mitigation.

5.4 Knowledge (H4)

Table 3 shows that knowledge of GHGs is a strong and robust determinant for both the willingness to reduce GHG emissions and the actual reduction of non-CO_2 GHG emissions. This is in line with the theory of Rogers (2010), in which knowledge is seen as an important first step in the adoption process. However, knowledge on GHG's is not a determinant for energy saving measures with TRL lower than 9, and it even negatively relates to renewable energy, though not significantly. These results corroborate the conclusion of previous research. Kellstedt et al. (2008) found that climate change knowledge does not consistently influence behaviour and can even make people less concerned and less likely to act. Others suggest that only specific knowledge can be a predictor of specific types of behaviour (Ajzen et al. 2011; St John et al. 2010). Accordingly, the adoption processes for measures on energy saving with TRL lower than 9 and renewable energy might only be influenced by knowledge specifically related to these measures. Our findings underline once more that, when comprehending the influence of climate-related knowledge, it is important to distinguish between different categories of climate change mitigation measures.

The results of the regression analyses show evidence for the fourth hypothesis (H4), stating that knowledge on GHG's is an important determinant for the willingness to reduce GHG emissions as well as actual behaviour related to GHG emission reduction. However, this does not necessarily account for energy saving measures.

5.5 Effects of the communication campaign (H5)

Despite an overall decrease in 2015 of factors such as knowledge, perceived importance and willingness to reduce GHG emissions, a significant increase in the number of adopted measures was observed in 2015. This accounts for both the group being 'familiar with campaign' and the group being 'unfamiliar with campaign' in 2015. 'Saving money' as a reason for behavioural change increased from 42.0% in 2012 to 60.4% in 2015 (Table 2). Although this study was not aimed at examining the role of other external factors, this suggests that economic factors played an important role in the farmers' decision-making process. In the same period, other external factors, such as social or policy changes may also have played a role, given the political context in the Netherlands between 2012 and 2015 (Polman and Michels 2017). The phenomenon of fluctuating awareness often is discussed in the literature, showing that levels of awareness will vary over time under the influence of external variables. For example, the Al Gore's movie 'An Inconvenient truth' (2006) and the IPCC Nobel Peace Prize had positive effects on public awareness on climate change. However, the IPCC-errors and emails of the Climate Research Unit (CRU) widely featured in the media have negatively influenced public acceptance and increased public scepticism on climate change (Leiserowitz et al. 2012). The findings concerning 'innovator type' may also lead to the conclusion that campaigns in the agricultural sector should mainly focus on making farmers more amenable to change and innovation in general, without focusing specifically on climate change mitigation.

Table 3 suggests a small effect of the communication campaign for the non-CO_2 measures. The group being familiar with the campaign relates positively to this category, while the group being non-familiar with the campaign does not relate to this behaviour. We hardly found any evidence for the fifth hypothesis, predicting that (H5): 'being familiar with the communication campaign in 2015' positively relates to the willingness to take GHG reduction measures, as well as to the actual adoption of measures up to 2015.

6 Conclusion

This study presents a new approach in examining farmers' GHG mitigation behaviour. Using data from a large survey among a total of 1015 Dutch farmers in 2012 and 2015, we investigated the differences in determinants for, respectively, energy saving measures, the production of renewable energy on the farm, and the implementation of non-CO_2 GHG measures. Moreover, we examined the influence of an extensive national communication campaign on Dutch farmers' awareness and behaviour in the area of climate change mitigation.

Our analysis shows that there are different combinations of motivating factors for different types of GHG emission reduction measures. The results suggest that accounting for the cost-effectiveness and TRL of measures to reduce emissions in agriculture provides a better understanding of the factors that motivate farmers to adopt mitigation measures. The more complex non-CO_2 GHG measures are more likely to be adopted by the innovative farmers, and the further diffusion of these complex measures would require more efforts in the form of research and demonstration farms, exploring the possible trade-offs with farming issues such as animal welfare, animal health and soil fertility, and to further improve the cost-effectiveness of these measures.

The farmer's propensity to innovate proved to be the strongest and most consistent predictor of their willingness to adopt GHG reducing measures, including the actual adoption of climate change mitigation technologies. Neither the willingness to reduce GHG emissions nor knowledge of GHG emissions are consistent motivating factors for energy saving measures. The communication campaign on farmers' adoption of GHG measures proved to have a minor impact. Only a positive influence was found on the actual reduction of non-CO_2 GHG emissions. Despite the intensive campaign, the overall awareness of farmers strongly decreased between the surveys in 2012 and 2015, most likely due to external factors that were not covered in the survey. These findings might lead to the conclusion that increasing farmers' openness to innovations in general should be in the focus of future governmental campaigns, rather than specific motives related to climate change. Continuing research in this field is important, as many questions still remain unanswered and further verification of our findings in other contexts would be desirable.

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